# Strength training for physical performance and injury prevention in sports

## Individualised and supervised training for female athletes

Sofia Ryman Augustsson

**UNIVERSITY OF GOTHENBURG**

**Institute of Neuroscience and Physiology/Physiotherapy**
**Department of Orthopaedics, Institute of Clinical Sciences**
**Sahlgrenska Academy at the University of Gothenburg**
**Göteborg, Sweden**
**2009**
**ISBN 978-91-628-7808-5**
**http://hdl.handle.net/2077/20448**

*Dolor temporalis, gloria aeterna*

Pain is temporary, glory is forever

# Contents

**Strength training for physical performance and injury prevention in sports – individualised and supervised training for female athletes**

**Sofia Ryman Augustsson**

**Abstract.** The overall purpose of this thesis was to obtain knowledge about individualised, supervised strength and conditioning programmes for physical performance and injury prevention in female athletes. Data are presented both on the influence of individualisation and supervision during resistance training for physical performance and injury prevention and on the athletes' experience of resistance training and the role of the physical coach. Data are also presented on physical performance testing and injury prevalence and preventive action in female volleyball.

**Study I:** The purpose of this study was to examine the prevalence of injury and the extent of preventive action in elite Swedish volleyball players. Injuries to players in the elite male and female Swedish division, during the 2002-2003 season, were registered using a questionnaire. Of the 158 volleyball players, a total of 82 players (52%) reported 121 injuries, during a total exposure time of 24,632 h. The majority of the injuries were located in the ankle, knee and back. Most injuries were classified as being of minor severity. Although most players took part in some kind of preventive action, one in every two players incurred an injury during the season, which indicates that the risk of suffering an injury in elite volleyball is relatively high.

**Study II:** The purpose of Study II was to evaluate the test-retest reliability of sit-ups and push-ups and to investigate performance differences in muscular endurance (maximum number of repetitions) and power (timed; maximum number of repetitions in 30 s) in young women and men. Thirty-eight women and 25 men (age18-35) participated in the study. Thirteen female participants performed two test sessions of each test using a test-retest design. A high level of reliability was noted for both the sit-up and the push-up tests. There were no significant differences between the men and the women in the sit-up test, whereas the men performed significantly more push-ups than the women.

**Study III:** The purpose of Study III was to evaluate the effects of a 26-week individualised and supervised strength and injury-prevention programme on performance enhancement. Young female volleyball players completed resistance training with either a supervised, individualised training programme (experimental group; n=10) or an unsupervised, non-individualised training programme (control group; n=17). Exposure and injury data were collected during the 2006-2007 season (baseline) and the 26-week programme with physical performance testing was carried out during the 2007-2008 season. After the intervention, the experimental group had improved significantly more ($p<0.05$) than the control group in the squat, barbell bench press, push-ups and sit-ups. Individualisation and supervision of resistance training seem to improve greater training adherence and strength gains compared with non-individualised and unsupervised training.

**Study IV:** The purpose of Study IV was to explore and describe volleyball players' experience of an individualised, supervised strength-training programme aiming at physical performance and injury prevention. The purpose was also to use the players' observations to obtain an understanding of the role of a physical coach. The study comprised nine participants (mean age 19 years) who had been involved as the experimental group in Study III. Data were collected using semi-structured interviews and were analysed using qualitative conventional content analysis. Three overarching themes describing the content of the text emerged: *1)* being in an enjoyable, relaxed situation, *2)* interaction between coach and athlete and *3)* mental and physical achievements.

**Conclusions:** Individualisation and supervision appear to be of importance for compliance, strength gains and athletic performance, during strength training. From the female team athletes' perspective, the willingness to perform strength training is dependent on team spirit, individual goal-setting and bonding with the coach. Strength training, on the one hand, could be used to improve self-esteem among young females. On the other hand, when designing strength-training intervention studies, it is important to be aware of the fear and feeling of uncertainty that may exist among the participants when it comes to strength training.

**Key words:** Strength training, physical performance, functional tests, strength assessment, injury prevention, physical coach, young female athletes, volleyball

## List of papers

The present thesis is based on the following papers, which will be referred to in the text by their Roman numerals.

I. Injuries and preventive actions in elite Swedish volleyball. Augustsson SR, Augustsson J, Thomeé R, Svantesson U. Scand J Med Sci Sports 2006: 16: 433-440.

II. Gender differences and reliability of selected physical performance tests in young women and men. Augustsson SR, Bersås E, Magnusson Thomas E, Sahlberg M, Augustsson J, Svantesson U. Advances in Physiotherapy 2009: 11: 64-70.

III. Performance enhancement following a strength and injury prevention programme: a 26-week individualized and supervised intervention in adolescent female volleyball players. Augustsson SR, Augustsson J, Thomeé R, Karlsson J, Eriksson B, Svantesson U. Submitted.

IV. Athletes' experience of individualised and supervised strength training for physical performance and injury prevention. Augustsson SR, Willén C. Submitted.

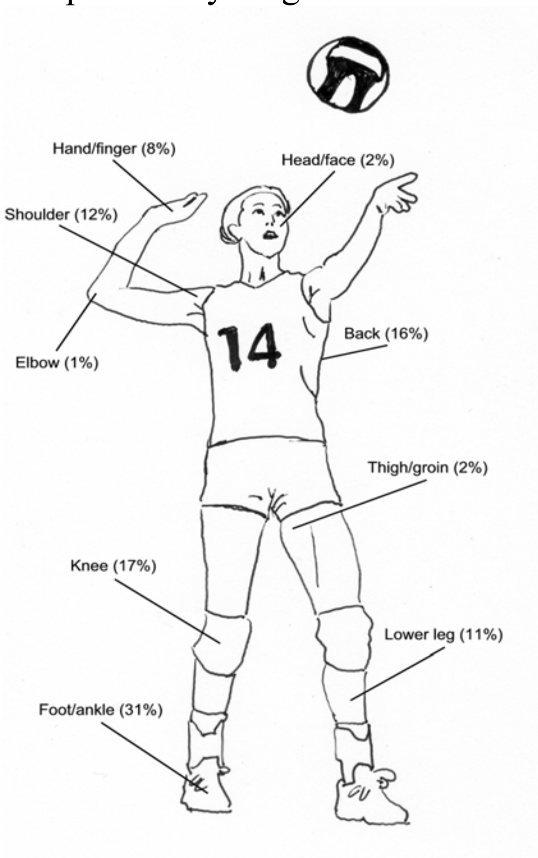
## Thesis at a glance

**Study I – What is the injury prevalence and to what extent is preventive action undertaken in elite Swedish volleyball players?**

**Subjects:** 158 elite Swedish volleyball players (83 females and 75 males); the mean age of the players was 25±4 years.

**Methods:** Retrospective injury registration.

**Conclusion:** Although most players (96%) took part in some kind of preventive action, one in every two players incurred an injury during the season, which indicates that the risk of suffering an injury in elite volleyball is relatively high.



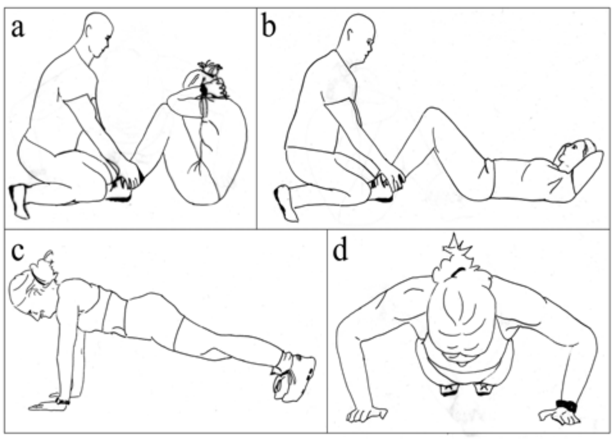

**Study II – What is the test-retest reliability of sit-ups and push-ups and what are the performance differences in muscular endurance and power in young women and men?**

**Subjects:** Sixty-three university students (38 females and 25 males) aged between 18 and 35. Thirteen female participants performed two test sessions of each test to evaluate test-retest reliability.

**Methods:** Laboratory study with a test-retest design.

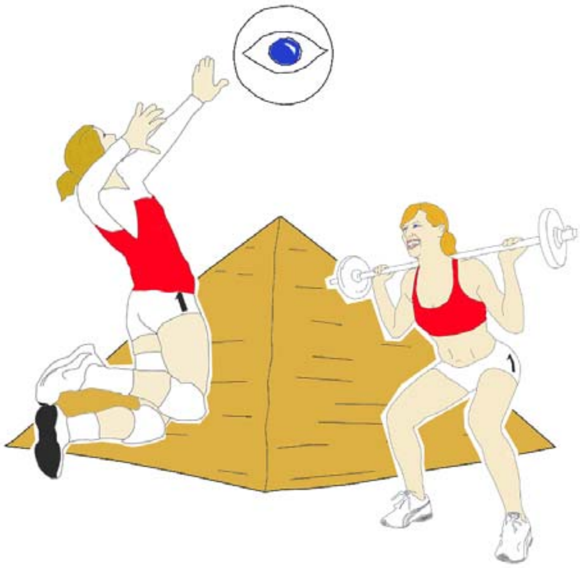
**Conclusion:** Sit-ups and push-ups have high reliability, are easy to perform and may therefore be recommended for clinical use to evaluate muscular endurance and power in young men and women.

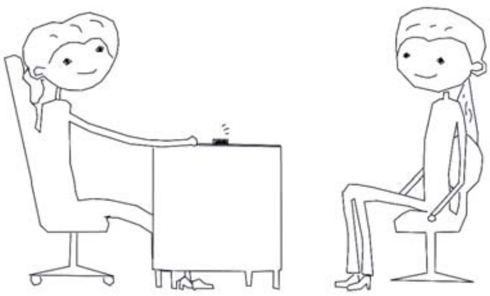
Moreover, women do not appear to differ from men in terms of the local endurance or power of the abdominal muscles, whereas men are twice as strong as women when it comes to push-ups.



**Study III – What are the effects of a 26-week individualised and supervised strength and injury-prevention programme on performance enhancement in adolescent female volleyball players?**

**Subjects:** Twenty-seven female volleyball players (10 in the experimental group, mean age 18 (±2), and 17 in the control group, mean age 16 (±2).
**Methods:** A two-season prospective intervention study.
**Conclusion:** Both the individualisation and supervision of resistance training appear to improve training adherence and strength gains more effectively when compared with non-individualised, unsupervised training.





**Study IV – What are the volleyball players' experiences of an individualised, supervised strength-training programme aiming at physical performance and injury prevention? What are the players' observations and understanding of the role of a physical coach?**

**Subjects:** Nine female volleyball players, mean age 19 (17-21) years.
**Methods:** A qualitative conventional content analysis.
**Conclusion:** From the female team athletes' perspective, the willingness to perform strength training is dependent on team spirit, individual goal-setting and bonding with the coach.
Strength training, on the one hand, could be used to improve self-esteem among young females. On the other hand, when designing strength-training intervention studies, it is important to be aware of the fear and feeling of uncertainty that may exist among the participants.

## Abbreviations and definitions

In the present thesis, the following abbreviations and definitions were used.

**ACSM.** The American College of Sports Medicine.

**Concentric muscle action.** When the muscle shortens while producing force.

**Conditioning programme.** A programme designed to enhance the athletes' fitness and aerobic and anaerobic performance. Among other things, a conditioning programme encompasses resistance training, aerobic endurance, plyometrics, flexibility and skill-based exercises.

**Content analysis.** A research technique used in both quantitative and qualitative research. Qualitative content analysis is also used as "a research method that uses a set of procedures to make valid inferences from text" (Weber, 1990).

**CPAFLA**. The Canadian Physical Activity, Fitness & Lifestyle Approach Protocol.

**CSEP.** The Canadian Society for Exercise Physiology.

**Dynamic muscle action.** Involves either an increase or decrease in joint angles.

**Eccentric muscle action.** When a muscle lengthens while producing force.

**Eurofit test battery.** A test battery introduced by the Committee for the Development of Sport of the Council of Europe. The test battery includes nine motor fitness tests and five anthropometric measurements. It is designed for the evaluation of physical fitness in children and youth.

**FIVB.** Federation Internationale de Volleyball.

**ICC.** Intraclass correlation coefficient.

**Injury frequency.** Injury frequency is used interchangeably with injury rate and is the total number of injuries occurring during a season, for example the number of hamstring strains from one season is compared with the number of strains during the next season. Injury frequency does not take the number of players or exposure time into account.

**Injury incidence.** Injury incidence is the risk of suffering an injury in a specific sport and takes the exposure factor into consideration. The injury incidence, calculating the time during which the participant is at risk, can be expressed as the number of injuries, usually per 1,000 hours of participation.

**Injury prevalence.** Injury prevalence is the risk of suffering an injury and takes the number of players but not the exposure time into account. Injury risk is usually used in the same manner as injury prevalence. In team sports, injury prevalence is usually described as injuries per player and season.

**Power.** Power is the rate of performing work; the product of force and velocity. Power during one repetition can be increased by lifting the same weight the same vertical distance at a faster velocity. Power can also be increased by performing as many repetitions as possible during a specific time (e.g. sit-ups for 30 sec) more quickly.

**Repetition maximum (RM).** This is the maximum number of repetitions per set that can be performed until failure at a given resistance using an appropriate exercise technique. A set at a certain RM therefore means that the set is performed to momentary voluntary fatigue. 1 RM is the heaviest resistance that can be lifted for one complete repetition of an exercise. 8 RM, for example, is a lighter resistance that allows the completion of eight, but not nine, repetitions using an appropriate exercise technique.

**Repetition.** A repetition is one (complete) movement of an exercise. It normally consists of two phases: the concentric muscle action, in which the muscle shortens, and the eccentric muscle action, in which the muscle lengthens.

**SD.** Standard deviation.

**Set.** A group of repetitions normally performed continuously without stopping. While a set can be made up of any number of repetitions, sets during weight training typically range from one to 20 repetitions.

**Strength.** Strength or muscular strength is the maximum amount of force a muscle or muscle group can generate in a specified movement pattern at a specified velocity (including an isometric muscle action) of movement.

**Strength training.** Strength training is the use of resistance to muscular contraction to build the strength, anaerobic endurance and size of the skeletal muscles. The terms “resistance”, “weight” and “strength training” have all been used to describe a type of exercise that requires the body’s musculature to move (or attempt to move) against an opposing force. The term “strength training” encompasses a wide range of training modalities, including body weight exercises, plyometrics (drop jumps, for example) and hill running. Weight training is typically used to refer to strength training but only to training using free weights, such as barbells and dumbbells, or weight machines. Resistance training is generally used to refer to strength training using some kind of external load and equipment.

**Training frequency.** Training frequency is used to describe how frequently training is performed, e.g. 2 days/week.

**Training intensity.** Training intensity is the amount of weight or load used in a specific exercise. The intensity of an exercise is usually estimated as a percentage of 1 RM (e.g. 80% of 1 RM), or any RM resistance for the exercise (8 RM).

**Training volume.** The product of sets x repetitions performed during strength training.

# Introduction

## Strength and conditioning programmes and injury prevention in sports

*Brief history of strength training*

As much as 5,000 years ago, achievements of muscular strength were noted and admired in ancient Egypt (Fry & Newton, 2002). The art of strength training probably has it roots in the ancient Greek culture. As early as 400 BC, Hippocrates, often described as the founder of the art of healing, spoke of the importance of training when he wrote “that which is used develops, and that which is not used wastes away”. Progressive resistance training dates back as far as the sixth century BC, when the legendary wrestler Milo of Croton trained by carrying a newborn calf on his back every day until the calf was fully grown (Fry & Newton, 2002). Another Greek, the physician Galen, described resistance-training exercises using an early form of dumbbell in the 2nd century (AD 129-200). The ancient Greeks also used strength-building exercises for military purposes and one of the earliest bodybuilding contests has been found in records from the Greek city of Sparta (Fry & Newton, 2002). Since the ancient Greeks, the role of strength training has received a large boost in popularity and knowledge.

Strength training has previously been limited to sports like bodybuilding, wrestling, powerlifting and Olympic weightlifting (Fry & Newton, 2002). As recently as 50 years ago, strength training was considered ineffective for sports conditioning and also potentially harmful to the athlete’s performance (Fry & Newton, 2002). However, the mythology associated with strength training has slowly given way to a greater scientific understanding and, today, strength training has become one of the most popular forms of training regimens. In Sweden, it is one of the most frequently performed workouts in the general population (Riksidrottsförbundet/SCB, 2009). Strength training has also been confirmed to be efficacious in improving athletic performance and is currently a frequent component of most conditioning programmes for athletes of all kinds (Hetu et al., 1998; Kraemer et al., 2000; Gorostiaga et al., 2006; Santos & Janeira, 2008; Gabbett, 2008; Marques et al., 2008).

*Strength training in team sports*

Athletes participating in team sports do not usually have an extraordinary capacity in any particular characteristic of physical performance. Most of the time spent on team sports is largely based on the technical aspects of the game itself (Thomson et al., 2008; Stanganelli et al., 2008). Football, for example, requires many different qualities, such as kicking, passing and trapping the ball, throwing in, goalkeeping, tackling, falling behaviour, jumping, running, sprinting, starting, stopping and changing direction (Lees & Nolan, 1998).

Today, however, a variety of training methods are used to increase strength and power in sports in order to enhance physical performance and thereby specific team sport performance, such as sprinting and jumping (Gabbett, 2008; Marques et al., 2008; Santos & Janeira, 2008). Studies have shown that maximum strength could determine sprint performance and jumping height in athletes (Wisløff et al., 2004; Nuzzo et al., 2008) and that throwing (ball) velocity correlates with strength performance in the upper extremities (Forthomme et al., 2005; Gorostiaga et al., 2005; Marques et al., 2007; Prokopy et al., 2008). It has also been implied that strength training could improve aerobic endurance performance, in the form of improved running economy, due to improvements in neuromuscular characteristics, including motor unit recruitment and reduced ground contact time (Hoff et al., 1999; Hoff et al., 2002; Jung, 2003).

The key factor to successful resistance training at any level of fitness is appropriate programme design. There are many issues that need to be taken into account when designing resistance-training programmes for team sport athletes, individual sports athletes and recreational athletes. For example, the athlete's strengths/weaknesses, the demands of the sport, player position, physical fitness (strength, flexibility, endurance) and injury profile all require attention when designing resistance-training programmes (Kraemer & Ratamess, 2004).

In overall terms, strength training is frequently used by athletes in order to enhance specific team sport performance and many issues require attention when designing an optimal programme prescription. The main background variables for strength training and most important for this thesis are discussed below. Appendix 1 lists the recent resistance-training studies conducted on team sports.

*Training variables*

Improvements in physical performance as a result of strength training and the associated physiological adaptations are correlated to the intensity and number of repetitions that are performed (Campos et al., 2002). It appears that training aimed at optimal strength, power, hypertrophy, or muscular endurance gains respectively requires the different training variables (e.g. intensity, volume, frequency) to be carried out in "zones" with different ranges for optimal results. The intensity zone when training for maximum strength gains, for example, appears to be fairly narrow, somewhere between 85-100% of 1 RM (American College of Sports Medicine, 2009b; Fry 2004) compared with the intensity zone for hypertrophy, which appears to have a much wider range, from approximately 50 to 100% of 1 RM (Wernbom et al., 2007). When it comes to power-training intensity ranges, the use of relatively light loads (0-60% of 1 RM for lower body exercises; 30-60% of 1 RM for upper body exercises) performed at a rapid contraction velocity with three to five minutes of rest between sets has been proposed (American College of Sports Medicine, 2009b). As mentioned above, it has been recommended that training with loads corresponding to 85-100% of 1 RM or more is appropriate for increasing maximum strength (American College of Sports Medicine, 2009b; Fry 2004). Although strength also increases using loads corresponding to 70-80% of 1 RM, it is believed that this range may not be as effective in increasing maximum strength in advanced strength-trained athletes compared with heavier loading (e.g. 85% of 1 RM). The intensity required to increase maximum strength in untrained individuals appears to be fairly low (60%) (Peterson et al., 2005). It has been suggested that intensity corresponding to 45-50% of 1 RM (or less) could increase muscular strength in previously untrained individuals (American College of Sports Medicine, 2009b). For this reason, a simple low-load (50-60% of 1 RM) programme design is recommended when resistance training is introduced and, the more advanced the athletes become in performing the exercises, the more variation may be necessary to avoid performance plateaus (Kraemer & Ratamess, 2004).

Taken as a whole, the optimal zones for different strength-training variables vary considerably when it comes to optimal hypertrophy and maximum strength or power gains and may also differ with regard to the athletes' experience.

*Periodisation*

The periodisation of strength training includes the variation of volume, intensity, frequency and exercise selection over time to enable the training stimulus to remain challenging and effective during a training programme (American College of Sports Medicine, 2009b). Recent studies have indicated that periodised strength training may improve sports-specific performance (Kraemer et al., 2000; Hoffman et al., 2009) and, further, is thought to be beneficial when it comes to injury prevention (Haff, 2004). Strength and conditioning programmes in sports usually vary during the in-season and off-season periods, due to the change of the game and practice schedule. It is often recommended that in-season training programmes should aim to maintain the muscular strength and power developed during the off-season period (Bompa & Carrera, 2003). However, improvements in strength and power have also been demonstrated using a well-designed periodised strength-training regimen during in-season training (Marques et al., 2008).

*Individualisation*

As mentioned above, in order to obtain strength gains, the resistance must be sufficiently challenging, as low intensity does not appear to produce improvements in strength of any significance (Kraemer et al., 2000). For this reason, it might be important to individualise factors such as the type of exercise, training volume and intensity.

It has been suggested that individualisation is an important factor in order to maintain and maximise progression (American College of Sports Medicine, 2009b; Kraemer & Ratamess, 2004; Mazzetti et al., 2000). Additionally, in team sports, it has been recommended that the training might benefit from an individually constructed programme that takes the individual player’s body type, (e.g. body composition, % body fat, % muscle mass), muscular strength and flexibility into account (Duncan et al., 2006). Taken as a whole, even though there appears to be evidence suggesting that strength-training programmes should be individualised (Kraemer et al., 2000; Kaminski et al., 2003), it has been our observation that many programmes are still non-individualised in team sports science intervention studies.

*Strength training for rehabilitation and injury prevention*

Although the primary reason for resistance training in sports is strength and power improvements and athletic performance enhancement, it has also been widely used for rehabilitation and injury-prevention purposes (Askling et al., 2003; Bahr et al., 2006; Árnason et al., 2008). In addition, muscle strength seems to have an important role for the outcome and the ability to return to sport after anterior cruciate ligament (ACL) surgery (Wells et al., 2009). It has recently been shown that preoperative quadriceps strength is a significant predictor of knee function after ACL reconstruction. It was noted that individuals with more that 20% preoperative quadriceps strength deficits also had persistent significantly larger strength deficits two years after surgery (Eitzen et al., 2009). Recent studies have also suggested that strength training alone (Askling et al., 2003; Árnason et al., 2008;) and together with neuromuscular training (Olsen et al., 2005; Myer et al., 2005; Myer et al., 2008) could both enhance athletic performance and reduce the rate of injuries. Eccentric strength training has, for example, been shown to reduce the risk of hamstring strains (Askling et al., 2003; Árnason et al., 2008). Eccentric strength training has also been used in the rehabilitation and prevention of “jumper’s knee” (Young et al., 2005; Bahr et al., 2006; Frohm et al., 2007; Fredberg et al., 2008). Strength training has also been recommended for reducing pain in patients with impingement syndrome (Lombardi et al., 2008) and decreasing the risk of shoulder injuries in overhead activity athletes (Niederbracht et al., 2008; Stickley et al., 2008). For tennis players, it has been suggested that eccentric resistance training designed to maintain and enhance co-ordinated scapular/rotator cuff function and strength is of importance to avoid shoulder injuries (Niederbracht et al., 2008).

*Concerns in relation to injury prevention*

There are many different issues when designing injury-prevention programmes. It is believed that it is important first to recognise the injury pattern characteristics of the sport before it is possible to design effective prevention programmes (Parkkari et al., 2001). However, even if the injury panorama of the sport is known, it might also be necessary to know the specific demands for the individual player, such as the player's position and the demands (including injury profile) of that specific position, the player's physical weaknesses and strengths and muscular fitness. Poor compliance with the programme is another issue that clearly constitutes a problem when designing injury-prevention study in team sports. Previous studies have reported insufficient compliance with injury-prevention programmes (Steffen et al., 2008a; Engebretsen et al., 2008), which indicates that compliance is difficult to achieve. A real effort therefore needs to be made by physiotherapists and coaches in order to motivate participants to complete the programme. One study with a large sample size, comprising 2,020 football players, was not able to detect any effect using an injury-prevention programme, for example (Steffen et al., 2008a). The lack of effect was thought to be a result of poor compliance with the prevention programme among the players. As prevention programmes apparently have the simultaneous potential to enhance athletic performance, as mentioned above (Askling et al., 2003; Hewett et al., 2005; Myer et al., 2005), it might be interesting to combine an injury-prevention programme with a strength and conditioning programme to facilitate compliance with preventive action among athletes.

Taken as a whole, although studies have indicated that it is quite possible to prevent injuries with strength training, poor compliance with the programme constitutes a difficulty when it comes to the successful realisation of this goal in team sports. Other questions relating to the prevention of sports injuries also remain to be answered such as individual differences in injury panorama.

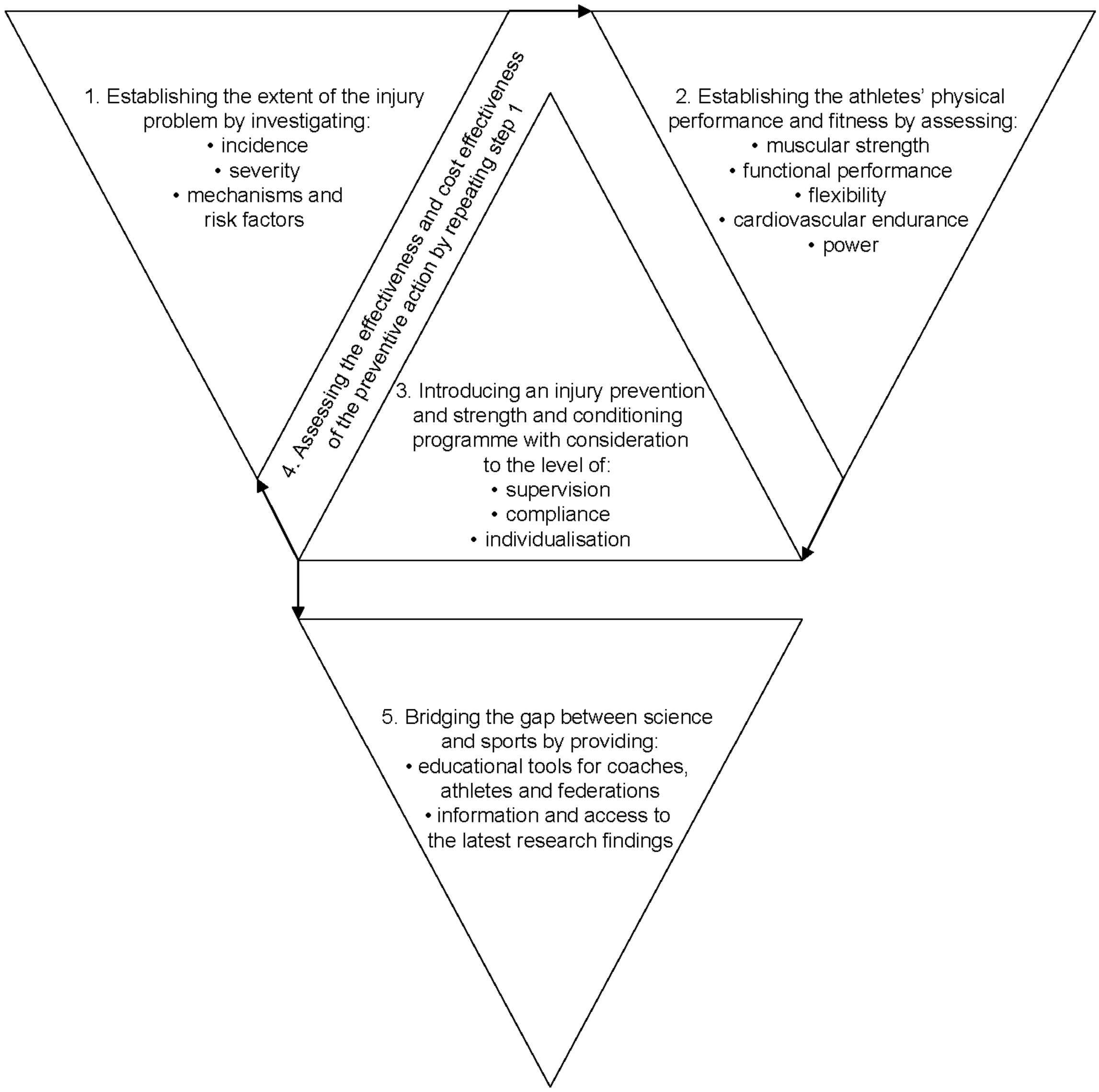



**Figure 1**. The sequence of prevention of sports injuries. Modified from Van Mechelen (1992) by implementing a fifth step.

## Injury panorama and the sport of volleyball

Prior to initiating a strength-training programme for physical performance and injury prevention, the extent of the problem must first be defined. We believe that the injury panorama needs to be continually investigated as the sport continues to develop. We also believe that the injury incidence can differ between countries due to different training strategies. A study comparing the injury incidence and exposure in Danish and Swedish male top football has previously been carried out (Hägglund et al., 2005). It revealed greater training exposure and a longer pre-season period in Sweden, but a higher training injury incidence and more severe injuries in Denmark. However, the distribution of injuries according to type and location was similar in both countries. The study by Hägglund et al. (2005) demonstrates that the injury incidence and severity of the injuries can differ between countries, in the same sport. Since volleyball is a modest sport in Sweden, with resources probably far smaller than those in some other countries, it is not possible to conclude that Swedish volleyball players have the same injury panorama as those involved in international volleyball.

### *Brief history of volleyball*

With approximately 500 million players, volleyball is one of the largest and most popular team sports in the world. The FIVB, which was founded in Paris in 1947, currently comprises 218 member countries. The sport was invented in 1895 by William G. Morgan in Massachusetts, USA, and was intended to be a less strenuous sport for local businessmen compared with basketball (Reeser, 2003). The first World Championships were held in 1949 and, in 1964, volleyball joined the pantheon of Olympic sports. Since the introduction of beach volleyball by the FIVB in 1986, the popularity of the sport has skyrocketed. The basic skills of beach volleyball are the same as those of volleyball, but the number of players differs (6 vs 2 players).

### *Characteristics of the game*

Today, volleyball is regarded as the only non-contact ball game played in teams. The players' position is either at the net (front row), as one of the three front players, or at the back (back row), also with three players. The front players' task is to attack and "spike" the ball, or "block" a ball, to prevent the ball crossing the net. The back row players, also known as "setters", have to "set" the ball for an attacking team-mate in the front row, or pass or "dig up" balls that have penetrated the block. The ball is not allowed to touch the playing surface on the defending team's side of the net and the way to score is to force the opposing team to fail in keeping this rule. Because of the different positional roles in volleyball, a difference in physiological characteristics has also been observed between the players (Duncan et al., 2006). Consequently, it has been recommended that sports scientists, coaches and strength and conditioning professionals need to be aware of the specific positional requirements in volleyball when designing conditioning programmes (e.g. middle blockers tend to suffer from "jumper's knee" more than players in other positions and a prevention programme for "jumper's knee" is therefore recommended for middle blockers) (Duncan et al., 2006; Reeser et al., 2006).

**Figure 2.** A player from Sollentuna volleyball, Sweden in an attacking action. Photo: Martin Karlsson

The literature indicates that volleyball requires a high level of muscular fitness for optimal performance and to prevent injuries (Schafle, 1993, Kugler et al., 1996; Forthomme et al., 2005; Sheppard et al., 2008; Stickley et al., 2008). Serving, passing and setting the ball are accompanied by spiking or attacking actions. To achieve success in volleyball, a strong offensive is needed and the most important form of attack is the smash, or spike (Coleman et al., 1993). Volleyball also requires repeated maximum or near maximum vertical jumps, frequent changes of directional sprints, diving or digging to make a save and repeated overhead upper extremity movement such as spiking and blocking. The normal volleyball play lasts about six seconds, followed by a rest of 14 seconds. It has therefore been suggested that conditioning programmes for volleyball might be more beneficial when performed in intervals (Smith et al., 2008). It has also been suggested that age, experience, lean body mass, lower-body muscular power shoulder and thigh muscle strength and balance are key physical performance characteristics of volleyball players (Barnes et al., 2007; Gabbett & Georgieff, 2007; Melrose et al., 2007). To evaluate a player's development, it appears to be important to identify physical performance data specific to age groups and gender (Melrose et al., 2007; Iwamoto et al., 2008). A conditioning programme might therefore benefit from being designed to address both the demands of the sport and the individual player's fitness. The challenge for both coaches and players is to act on new developments in existing training practice and scientific literature.

*Injury incidence in volleyball*

Although the overall injury incidence in volleyball appears to be relatively low compared with other team sports, the injury incidence has increased as the sport of volleyball has become more physically demanding with time (Aagaard & Jørgensen, 1996; Agel et al., 2007). More training hours, a higher intensity of play and more risks being taken during matches have been suggested as factors contributing to a higher distribution of injuries (Aagaard & Jørgensen, 1996). The injury incidence was noted as 1.7 in 1993 and 2.4 in 2002 for women and 1.7 in 1993 and 3.0 in 2002 for men (Bahr & Bahr, 1997; Verhagen et al., 2004). The prevalence of the injuries ranges from 0.22-1.1 injuries/player/season for women and 0.28-1.5 injuries/player/season for men (Aagaard & Jørgensen, 1996; Augustsson et al., 2006; Verhagen et al., 2004). Most injuries appear to be related to the three front players (attackers and blockers) and spiking and blocking are the skills most often associated with injury (Aagaard & Jørgensen, 1996; Aagaard et al., 1997; Bahr & Bahr, 1997; Augustsson et al., 2006). The injury pattern appears to be similar for men and women (Aagaard & Jørgensen, 1996) and it also appears that the injury incidence does not differ between higher or lower divisions (Bahr & Bahr, 1997; Agel et al., 2007). Taken together, there is every reason to emphasise the prevention of injuries in volleyball and to implement prevention programmes for young players as early in their career as possible.

*Injury panorama*

Epidemiological research has revealed that volleyball athletes generally run the greatest risk of acute ankle sprains and overuse injuries to the knee, back and shoulder region (Aagaard & Jørgensen, 1996; Bahr & Bahr, 1997; Briner & Kacmar, 1997; Verhagen et al., 2004).

Ankle sprains are the most common injuries in volleyball, accounting for about half of all injuries (Bahr & Bahr, 1997). It has also been reported that ankle injuries are the most serious injury in volleyball in terms of absence from participation (Solgård et al., 1995; Bahr & Bahr, 1997). The primary risk factor for ankle injury is a history of a prior ankle sprain (Bahr & Bahr, 1997). The majority of the ankle injuries in volleyball result from technical errors during take-off and landing after blocking and attacking (Bahr & Bahr, 1997). Research has constantly revealed that most sprains occur when a blocker lands on the foot of an opposing attacker who has legally entered the centre line (Bahr et al., 1994; Verhagen et al., 2004). Consequently, middle blockers and outside attackers run the greatest risk of ankle sprains, while setters and defensive specialists run a comparatively low risk.

Patellar tendinopathy, also known as “jumper’s knee”, is described as one of the most common overuse injury in volleyball (Briner & Kacmar, 1997; Verhagen et al., 2004; Reeser et al., 2006). The injury is thought to result from repetitive overloading of the knee joint extensor mechanism. Middle blockers appear to experience more symptoms of “jumper’s knee” than players in other positions (Reeser et al., 2006). Furthermore, “jumper’s knee” appears to be more common in volleyball players who train more (> four times a week) (Ferretti et al., 1984). Another study has reported that volleyball players with “jumper’s knee” are stronger and jump higher compared with athletes without “jumper’s knee” (Lian et al., 2003). From these reports, it is possible to assume that the amount of time spent on volleyball, as well as other sports activities apart from ordinary training, could increase the number of overuse injuries (because of the increased frequency of training and the reduction in recovery time). However, it is not well understood why some athletes become symptomatic and others do not, despite equivalent training loads. One explanation of this might be that those athletes who jump well might be better able eccentrically to activate their knee extensor muscle, thereby placing an increasing load on the patellar tendon-bone junction. Another explanation could be that these well-trained players are matched harder by their coach (i.e. these players participate in more match play and therefore expose themselves more to injuries).

The third most injured region in volleyball is the back (Augustsson et al., 2006). There are high forces acting on the lower back in volleyball because of spinal twisting, lateral bending and asymmetrical movements (Schafle, 1993). Although most back injuries in volleyball are due to overloading, which results in chronic overuse, the players also risk sustaining acute back injuries

(Verhagen et al., 2004). It appears to be essential for athletes, in sports in general, to maintain trunk stability and strength, together with flexibility in the lower back and hips, in order to avoid back problems (Alricsson & Werner, 2004; Smith et al., 2008).

It has been noted that about 15-20% of volleyball players have experienced shoulder pain syndrome (Aagaard & Jørgensen, 1996; Verhagen et al., 2004; Augustsson et al., 2006). Imbalance in the rotator cuff muscles and insufficient eccentric strength appear to be related to shoulder injuries (Stickley et al., 2008). It has also been suggested that elite female athletes have a greater risk of shoulder injuries than male athletes (Sallis et al., 2001). It might therefore be appropriate, especially for female volleyball players, to perform strength training for the shoulder area, thereby minimising the risk of rotator cuff and other shoulder injuries.

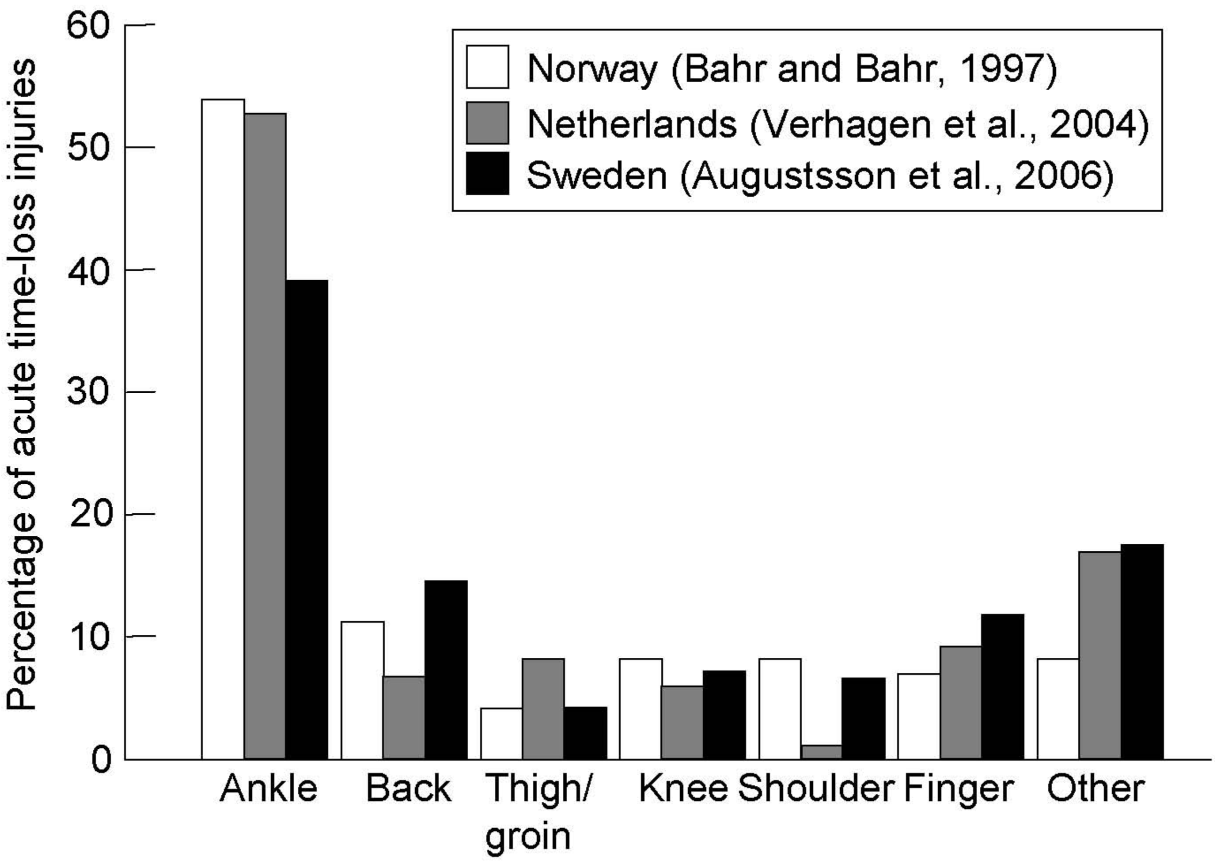



**Figure 3.** A comparison of the acute injury patterns observed in three different epidemiological studies. The data presented from each study represent the number of acute injuries sustained by both male and female volleyball players during both training and competition (combined) while participating in a European national adult competitive amateur league.

## Functional performance testing

After the injury panorama has been investigated, the second step when designing a strength-training and injury-prevention programme is some kind of physical performance testing (see Figure 1). To ensure safe progression throughout a resistance-training, rehabilitation or injury-prevention programme, the use of performance testing appears to be essential (Tagesson, 2008; Cates & Cavanaugh, 2009). Performance testing allows the physical coach to monitor the progress and functional level more accurately when it comes to resistance training, for example. Functional performance testing is widely used in the clinical setting and it is also recommended in sports medicine literature (Augustsson, 2003; Tagesson, 2008; Cates & Cavanaugh, 2009). Functional performance tests are used to measure the ability of injured extremities and to provide information about the loading capacity in sports-specific situations and the physical nature of athletic performance (Pfeifer & Banzer, 1999; Cates & Cavanaugh, 2009). Testing procedures after injury follow a progression, which begins with basic measures and progresses to functional tests of increasing difficulty that include sports-specific testing before returning to sporting activity (Gustavsson et al., 2006). A reliable testing procedure allows the clinician to give qualitative feed back to the athlete during a specific activity.

*Push-ups and sit-ups*

Push-ups and sit-ups are among the most frequently used body-weight exercises to increase strength and fitness. In sports, they are used to evaluate the effect of training, the possible risk of injury and to predict and specify talent (Quarrie et al., 2001; Malliou et al., 2004; Bellardini et al., 2009). They are thought to be convenient and easily learned, require no equipment and can be adapted to different fitness levels. Moreover, sit-ups and push-ups are used clinically as tests and exercises in rehabilitation to increase trunk and upper-body strength and evaluate the effect of treatment (Jones et al., 2007; Malliou et al., 2004; Lear & Gross, 1998). Additionally, sit-ups and push-ups are used to evaluate muscular endurance as in maximum number and power in timed tests, for example (Stanish et al., 1999; Bell et al., 2000). Several physical fitness test batteries that include either push-up or the sit-up tests, e.g. the Eurofit test battery, ACSM guidelines for exercising and CPAFLA, have been developed and used globally over the years. When it comes to the Eurofit test battery, research has been limited to children and the reliability of the Eurofit tests when applied to other sample populations is limited. One study has been performed on university students to examine the test-retest reliability of the Eurofit test battery (Tsigilis et al., 2002). However, no test-retest for push-ups and for the maximum number of sit-ups was performed. Furthermore, the protocols for the sit-up and push-up tests in the above-mentioned physical fitness test batteries differ from each other, making comparisons difficult. In the Eurofit test battery, for example, the sit-ups are measured in 30 s, whereas sit-ups are performed for 1 min in the ACSM protocol. The push-up and sit-up tests in the protocol for the CPAFLA, on the other hand, are performed with no time limits. Moreover, as opposed to the CPAFLA protocol, in the ACSM push-up test, women do not perform push-ups on their hands and feet. Instead, women perform a modified push-up on their hands and knees. So, using the ACSM push-up test, it is not possible to compare men and women in terms of physical fitness. Furthermore, according to CSEP, the reliability is assured, but only if the person administering the tests adheres to the measurement procedures and tolerances specified in the CPAFLA and has been trained by the CSEP (CSEP, 2009). Consequently, the tests might not be reliable if they are supervised by someone other than a CSEP instructor.

Taken together, functional tests such as push-ups and sit-ups are common practice in the evaluation of different aspects of physical performance. However, few test-retest reliability studies exist in the literature.

*Consideration of gender differences*

It is commonly accepted that there are physiological variations between men and women. When the general population is investigated, men appear to have an advantage over women in terms of muscular endurance and strength (Fleck & Kraemer, 2004). It has previously been observed that women's abdominal muscle strength is 75-80% of men's (Andersson et al., 1988) and that women's upper-body strength is 50-55% of men's (Stanish et al., 1999;). It has been suggested that these differences in muscle physiology contribute to the differences seen in the gender distribution of sports injuries (Toth & Cordasco, 2001; Barber-Westin, 2006). It might therefore be important to investigate strength and muscular endurance in women and men in order to optimise conditioning and injury-prevention programmes. Furthermore, on the one hand, reduced physical activity levels and reduced physical performance in young adults and adolescents have been reported in recent years (Leyk et al., 2006; Tomkinson & Olds, 2007), which supports the continued need for monitoring physical performance in this population. On the other hand, in recent years, physical fitness systems and activities have emerged, making people more physically active (e.g. Les Mills$^{TM}$). Programmes such as Body Pump$^{TM}$ (barbell class workout) have become popular among women in particular (Les Mills$^{TM}$ Group Fitness System, 2009; Wictor, 2008). It is possible that these recent forms of resistance training that specifically target women could contribute to a change in gender differences when it comes to strength and fitness. Taken together, because physical activity patterns among young women and men keep changing, it is important to continually examine gender differences when it comes to strength and muscular endurance.

There is no clear consensus in sports literature when it comes to injury distribution in terms of gender. Several studies have reported that there are no differences between men and women in terms of injury incidence (Lanese et al., 1990; Bahr & Bahr, 1997; Dane et al., 2004; Verhagen et al., 2004; Harringe et al., 2007). However, some studies have reported a higher injury incidence in female athletes (Mountcastle et al., 2007; Iwamoto et al., 2008) and, conversely, a higher injury incidence in male athletes (Lian et al., 2005; Hägglund et al., 2008). For example, one previous study reported a higher injury incidence for male players during both training and match play compared with female players in football (Hägglund et al., 2008). On the other hand, no difference was found in the incidence of severe injury (absence >4 weeks). The distribution of some injuries have, however, been reported to differ between genders in several sports, such as volleyball, handball, floorball and football (Solgård et al., 1995; Myklebust et al., 1998; Gwinn et al., 2000; Snellman et al., 2001; Lian et al., 2005; Hägglund et al., 2008). For instance, several studies have reported a much higher incidence (2-fold to 5-fold) of ACL injuries among women compared with men in basketball, football and handball (Arendt & Dick, 1995; Myklebust et al., 1998).
Taken together, there is no clear evidence of gender differences when it comes to total injury incidence. The injury incidence is probably more closely associated with the sport rather than gender. However, there appear to be gender-specific differences in the types and location of injuries sustained in several sports.

**The coach matters for strength and conditioning programmes and injury-prevention actions**

In sports, many people argue that the ability to perform well physically is dependent on many factors, both personal and situational. When attempting to prevent sports injuries, it is important to be aware that participation in sports is a form of behaviour (Parkkari et al., 2001). Typically, the introduction of preventive methods involves a change in or modification of the athlete's attitudes. This modification may very well conflict with the athlete's sports behaviour. Determinants that are considered to describe an athlete's preventive behaviour are knowledge, attitude, social influence, barriers and self-efficacy (Parkkari et al., 2001).

The presence of a physical coach during strength training has been discussed as a contributor to the athletes' performance (Kraemer et al., 2004). It has been reported that direct supervision promotes the magnitude and rate of progression during a period of strength training (Mazzetti et al., 2000; Coutts et al., 2004). A supervised strength and conditioning programme has been reported to enhance physical performance and improve compliance with the programme compared with a non-supervised programme (Coutts et al., 2004).

In addition, supervision may be of importance when it comes to keeping the programmes safe (Kraemer et al., 2002). However, even if training is being supervised, it can still be inappropriate and harmful if the physical trainer is inexperienced in managing sports-specific injuries and/or in designing individual training programmes (Kraemer et al., 2002). Ideally, the trainer should have knowledge of designing individualised training programmes in order to achieve the desired results and prevent injuries (Kraemer & Häkkinen, 2002; Kraemer et al., 2002). Strength and conditioning coaches therefore play an essential part in athlete preparation. In particular, it is believed that the strength and conditioning coach may provide support to the athlete in the form of technique analysis and modification, motivation and goal setting during training. However, while it appears to be generally accepted that a strength and conditioning coach plays an important role in improving athletic performance, few studies have examined the influence of coaching or supervision on physical performance and injury prevention. Further, to our knowledge, no previous studies have investigated the athletes' experience of an individualised, supervised resistance-training programme and the presence of a physical coach. By obtaining a greater understanding of her/his role, we might better be able to design strength and conditioning and injury-prevention programmes.

## Summary of problem areas

In the introduction, the aim was to discuss the often complex matter of designing strength-training and injury-prevention programmes in sports with reference to the injury panorama and physical performance testing. The purpose was also to highlight the problem areas when it comes to individualisation, supervision and compliance with these programmes.

● Although there appears to be evidence suggesting that a training programme designed for physical performance as well as injury prevention should be individualised and supervised, many programmes are still non-individualised and non-supervised in practice and in sports-scientific intervention studies. To our knowledge, no previously published study has examined the influence of supervision and individualisation during one season of a resistance-training programme in young female athletes. This topic is addressed in Study III.

● Prior to initiating a strength-training programme for physical performance and injury prevention, the extent of the problem must first be defined. Since volleyball is a modest sport in Sweden, with resources far smaller than those in some other countries, we are unable to conclude that Swedish volleyball players have the same injury panorama. Secondly, the extent to which injury-prevention programmes in volleyball are being used is not clear. To our knowledge, there are no studies that have registered injuries and preventive action in Swedish volleyball players. This topic is addressed in Study I.

● Furthermore, to ensure safe and effective progression throughout a conditioning and injury-prevention programme, the use of performance testing appears to be essential. Even though push-ups and sit-ups are among the most commonly used body-weight exercises to improve and assess strength and fitness, there is a lack of reproducible test protocols in the scientific literature. This topic is addressed in Study II.

● Finally, while it appears to be generally accepted that a strength and conditioning coach plays an important role in improving athletic performance, there are, to our knowledge, no previous publications studying the athletes' experience of an individualised, supervised resistance-training programme and the presence of a physical coach. This topic is addressed in Study IV.

Taken together, compliance with prevention programmes in sports is not well established and the current scientific literature lacks descriptions of the influence of supervision and individualisation on conditioning and injury prevention in young female athletes.

## Aims of the investigation

### Study I
To examine the prevalence of injury and the extent of preventive action in elite Swedish volleyball players

### Study II
To evaluate the test-retest reliability of sit-ups and push-ups and to investigate performance differences in muscular endurance (maximum number of repetitions) and power (timed, maximum number of repetitions in 30 s) in young women and men

### Study III
To evaluate the effects of a 26-week individualised, supervised strength and injury-prevention programme on performance enhancement in adolescent female volleyball players. The injury panorama was also documented.

### Study IV
To explore and describe volleyball players' experience of an individualised, supervised strength-training programme and the importance of strength training for physical performance and injury prevention. The purpose was also to use the players' observation to obtain an understanding of the quality and characteristics of the physical coach that could influence the training.

## Subjects

### Study I

The sample population in this survey comprised 225 volleyball players, who played in the elite Swedish division during the 2002-2003 seasons. All the teams, 10 men's teams and nine women's teams, agreed to participate and verbal information was given to each team coach. The teams were introduced to the survey at the end of the season, through their team coach, and the data were collected retrospectively. Written information was given to each player and informed consent was obtained. The inclusion criteria were elite male and female volleyball players included in the regular team line-up (including substitutes). Seventy per cent of the players returned the questionnaire (47% men, 53% women). The mean (± SD) age of the players was 25 ± 4 years for the men and 24 ± 4 for the women. The mean weight was 86 ± 8 kg for the men and 68 ± 7 kg for the women. The mean height was 192 ± 6 cm for the men and 175 ± 6 cm for the women.

### Study II

University students, from both practical (28/63) and theoretical programmes (35/63), were asked to participate in the study. Twenty-five men and 38 women between 18 and 35 years of age participated in the study. Thirteen women (13/38) performed the tests on two separate occasions within one week to evaluate the reliability of the push-up and sit-up tests.

Subjects with illness or injury to the musculoskeletal system during the past two months, which were thought possibly to affect the test results, were excluded. Elite athletes (individuals training/competing at a high level) were also excluded. The participants' age, height, weight and physical activity level were documented.

### Study III

Female volleyball players from four (of six) teams in the third division, Göteborg volleyball federation, Sweden, were invited to participate in the study. All four teams agreed to participate in the study and were randomised to an experimental group (two teams and 20 players) or a control group (two teams and 20 players). No differences were found between the groups in terms of age and playing level. Written information was given to each player and written informed consent was obtained. After the baseline season, one of the teams ceased to exist and was consequently excluded from the study. As a result, one team participated as an experimental group (n=13) and two teams as a control group (n=20). The mean (± SD) age of the players in the experimental group was 18 ± 2 years and 16 ± 2 for the control group The players and coaches were informed about the experimental procedures and the possible risks and benefits of the project. Players with an injury at the start of the study were included in the study, but the specific injury was excluded from the injury statistics.

**Study IV**

Ten young female volleyball players were asked to participate. All the participants had been involved in a large intervention study examining the influence of individualisation and supervision on physical performance and injury prevention during resistance training in young female volleyball players. Since the intervention group as a whole consisted of ten players, and since each player was considered to have a different role in the team, they were all included as subjects for purposeful sampling. One participant declined participation. The study therefore included nine participants with a median age of 19 (17-21) years and all the players gave their informed consent before participation.

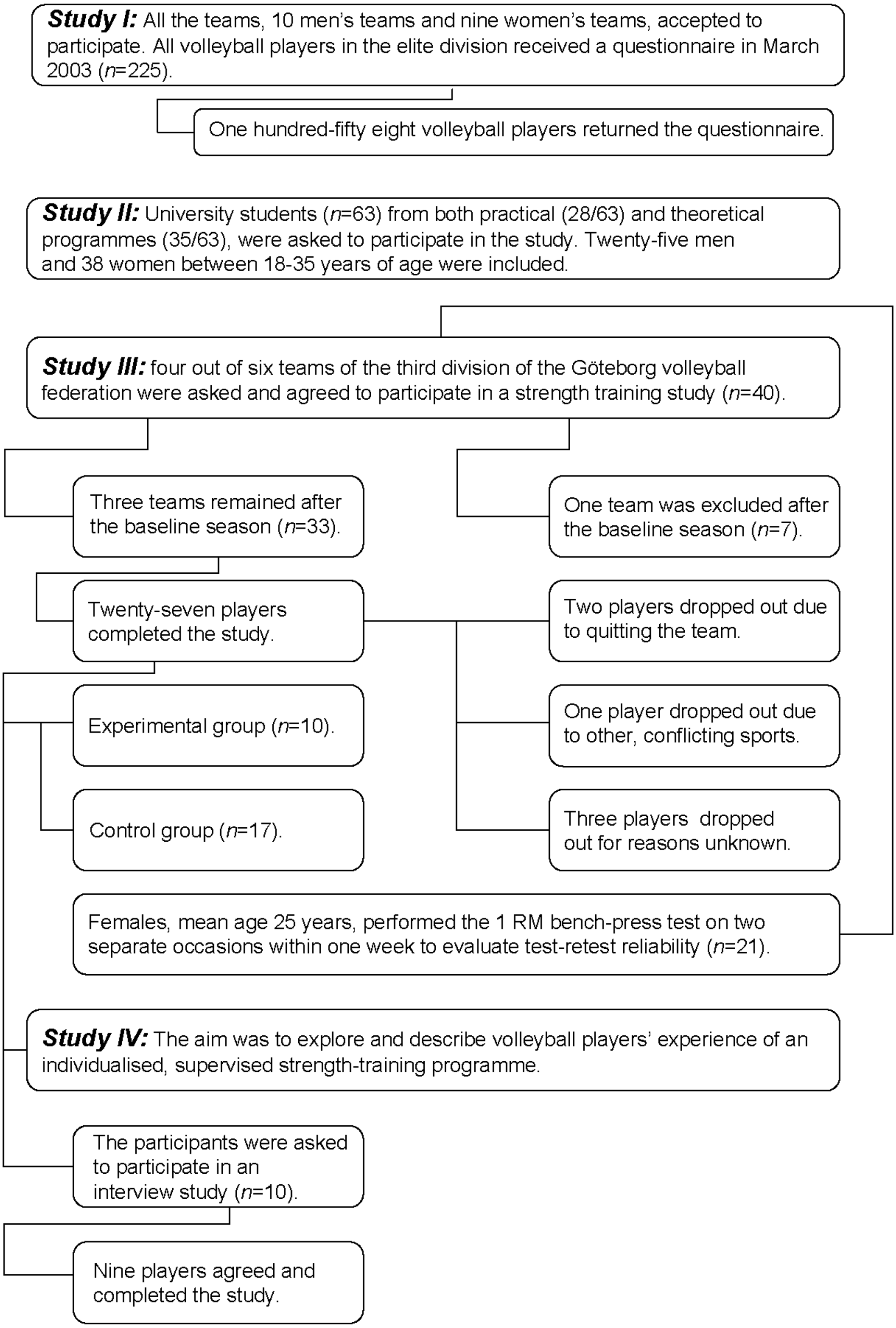



**Figure 4.** Distribution of subjects participating in this thesis.

## Ethics

All the studies were approved by the Human Ethics Committee at the University of Gothenburg.

# Methods

## Injury and exposure registration

In Study I, we used a retrospective questionnaire for injury data collection. The coach or a volunteer from each team was responsible for the distribution and subsequent collection of the questionnaires and for ensuring that the questionnaires were returned by post or e-mail to the author. The questionnaire comprised 15 questions, divided into two parts (Figure 5). Part one included data relating to team affiliation and the players' gender, age, weight and height. Each player was also asked to report the number of years of volleyball training, the number of training hours per week and her/his training routines. Part two included six identical injury profile subsections, in which the players were asked to report each of their previous injuries. The data that were collected included whether the injury occurred during training or a match, the skill performed, the injured player's court position and the anatomical localisation of the injury. Questions concerning the ability of the player to complete the particular match or training session and whether the injury resulted in any absence from training and/or matches were also recorded. The questionnaire was designed by the first author (S.R.A.) and preliminarily tested on a team that was not included in the study to obtain views about the design and to achieve face validity. A final version of the questionnaire was then constructed and used in the present study. The skill terminology was thought to be familiar to the players and, as a result, it was not defined in the questionnaire answered by the players.

Participant nr: _______

**Team affiliation** __________________ **Male ❒ Female ❒**

**Date** ____________________________

**Date of birth** _____________________

**Height (cm)** ______________________

**Weight (kg)** ______________________

---

**Part 1**

1. For how long have you been playing volleyball (senior level)? _______ year(s)
2. How many times per week do you train volleyball (during this season)? _______ times/week
3. How many hours per week do you train volleyball (during this season)? ________ hours/week
4. Are you engaged in other sports activities besides volleyball ❒ no ❒ yes
   If yes, what kind of sports activities? _____________________
5. Do you perform some kind of prevention programme, such as strength training, plyometrics or technique drills? (you can choose more than one option)
   During *preseason* ❒ yes ❒ no
   If yes: ❒ strength training ❒ plyometrics ❒ technique drills
   During *season* ❒ yes ❒ no
   If yes: ❒ strength training ❒ plyometrics ❒ technique drills
6. If you perform a prevention programme: is it performed with or without supervision (coach or physical trainer)? ❒ supervised ❒ unsupervised

---

**Part 2**

7. At which point did you get injured?
   ❒ during training ❒ during warm-up before match
   ❒ 1st or 2nd set ❒ 3rd set ❒ 4th or 5th set
   ❒ the injury occurred gradually
8. In what kind of situation did you get injured? ❒ blocking ❒ spiking ❒ serving ❒ setting ❒ do not know
   other _____________________
9. Were you in contact with another player when you got injured? ❒ yes ❒ no
10. What player position did you have when you got injured? ❒ setter ❒ left/right front-row ❒ center ❒ back line
    other_____________________
11. What part of your body was injured?
    ❒ head ❒ face ❒ finger(s) ❒ hand ❒ elbow
    ❒ shoulder ❒ chest ❒ back ❒ hip ❒ groin
    ❒ thigh ❒ knee ❒ lower leg ❒ ankle ❒ foot
    other body region ______________________
12. Injury location? ❒ right side ❒ left side ❒ bilateral
13. Could you complete the training session/match play? ❒ yes ❒ no
14. What was the amount of absence from subsequent training session(s) following the injury?
    ❒ absence more than 4 weeks
    ❒ absence 2-4 weeks
    ❒ absence less than 1 week
    ❒ no absence
15. What was the amount of absence from subsequent match play following the injury?
    ❒ absence more than 4 weeks
    ❒ absence 2-4 weeks
    ❒ absence no more than 1 week
    ❒ no absence

---

**Figure 5**. Data concerning injuries and preventive actions were collected using a questionnaire.

In Study III, the volleyball training exposure was documented by coaches on a standard attendance record form. The coaches registered the total duration of each training session and game in minutes for each player during the baseline and intervention seasons. For the intervention season, the resistance-training sessions were also recorded for all teams. Completed exposure forms were returned on a monthly basis. Incomplete forms were immediately followed up by the first author (S.R.A). All injuries were recorded on a standard injury form which was a modified protocol of that used in Study II with the same skill terminology. The injury form has previously been used when developing methods for injury registration in attempts to reach consensus on injury definitions and data collection procedures (Hägglund et al., 2005; Fuller et al., 2006).

**Injury definition and severity**

The injury definition used in Studies I and III was an injury that occurred as a result of participating in volleyball, forcing the player to leave the court for the rest of the game/training session and/or leading to an absence from or reduction in play lasting one day or more. The severity of the injuries was classified according to Ekstrand et al. (1983); minor injury, an injury causing absence from practice or games of less than one week; moderate injury, an injury causing absence from practice and games for more than one week and less than one month; major injury, an injury causing absence from practice and games for more than one month. In Study I, acute injuries were not distinguished from overuse injuries. In Study III, the diagnosis determined whether the injuries were classified as either traumatic or overuse injuries, e.g. a sprain was an acute traumatic injury and tendinopathy was an overuse injury. The data in Study III also included whether the injury occurred during training or a game, the skill performed, the injured player's court position and the anatomical localisation of the injury. The team coaches were responsible for the injury registration, but all injuries were followed up by the first author (S.R.A). Subsequently, all injuries leading to absence in Study III were documented.

**Functional performance testing and strength assessments**

In Studies II and III, sit-ups and push-ups were used to assess the participants' physical performance. The sit-up test was a modification of the Eurofit test battery manual (Eurofit, 1988) and the push-up test was a modification of the ACSM's guidelines for exercising, tests and prescription (American College of Sports Medicine, 2009a).

*Sit-ups*

Starting position. The participant sat on a rubber mat, with the knees in 90° of flexion and the feet placed 10 cm apart on the floor. The hands were clasped behind the neck and the elbows placed against the knees. The test examiner knelt in front of the participant, pushing the participant's feet lightly against the mat. The participants wore shoes during the test (Figure 6a).

Procedure: The participant lowered his/her upper body until the scapula came in contact with the mat. The participant's head was not permitted to touch the mat (Figure 6b). The participant then reversed the motion by curling back up to the starting position. For muscular endurance, the participant performed as many repetitions as possible using maximum speed throughout the test. The test was stopped if two consecutive repetitions were unsuccessful or if the participant was unable to continue. An unsuccessful repetition was regarded as one that deviated from the standard procedure. The maximum number of sit-ups was documented to evaluate muscular endurance. To investigate power, 30-second timed sit-ups were also documented.

*Push-ups*

Starting position. The participant was in a prone position on his/her toes and hands. The hands were placed shoulder width apart with the fingers pointing forward. The elbows were held in full extension and the feet were placed 10 cm apart. The push-ups were performed on a rubber mat and the participants wore shoes during the test (Figure 6c).

Procedure: In a continuous motion, the torso was lowered by bending the elbow joints to 90° of flexion (Figure 6d). Keeping the midsection tight and the head held in a neutral position, the participant then pressed him/herself back up to full elbow extension. For muscular endurance, the participant performed as many repetitions as possible using maximum speed throughout the test. The test was stopped if two consecutive repetitions were unsuccessful or if the participant was unable to continue. An unsuccessful repetition was regarded as one that deviated from the standard procedure. The maximum number of push-ups was documented to evaluate muscular endurance. To investigate power, 30-second timed push-ups were also documented.

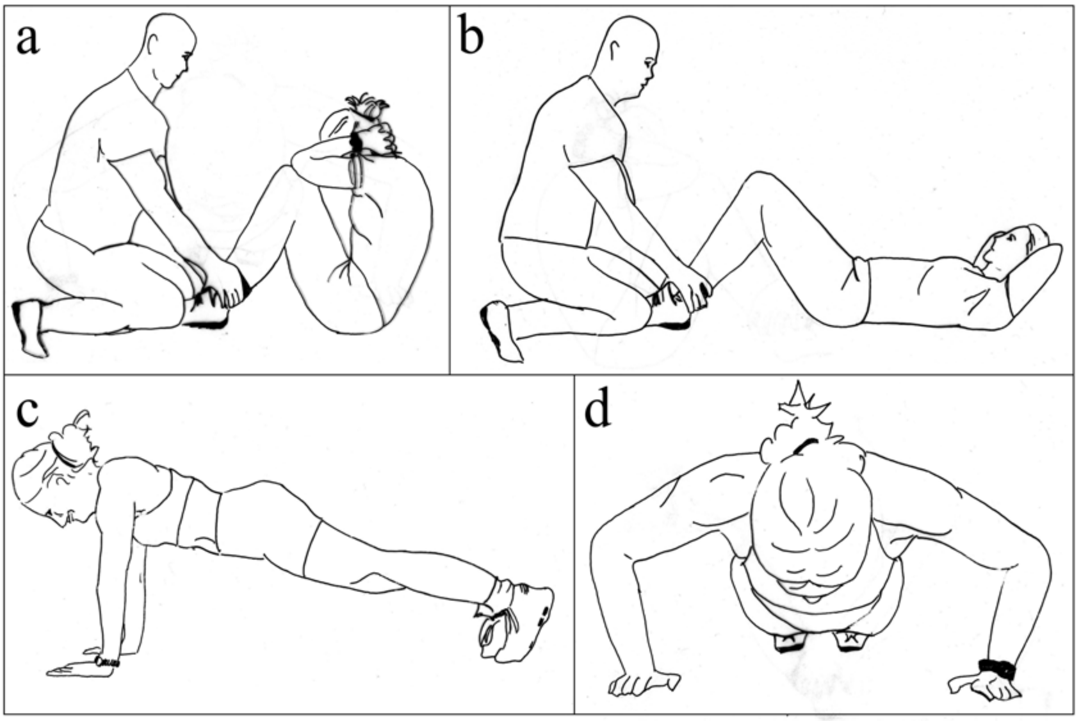



**Figure 6.** Positions of the tests: (a) starting position and (b) finish of the sit-ups, (c) starting position and (d) finish of the push-ups.

In Study III, a test battery was used to assess the players' physical performance for pre- and post-testing to evaluate the intervention. In addition to sit-ups and push-ups as described above, the test battery included vertical jumps to measure functional performance and power and a 1 RM squat and a 1 RM bench press for maximum strength assessment of the lower and upper extremities respectively. The tests were performed in the same order on both test occasions: vertical jump, 1 RM squat, 1 RM bench press, push-ups and sit-ups The tests were chosen as they were considered to be specific to the tasks associated with volleyball (such as jumping height and overhead activities) and to the intervention (Wisløff et al., 2004; Granados et al., 2008; Rousanoglou et al., 2008). The test battery was thus designed to measure maximum muscular strength in the lower and upper extremities, functional performance and muscular power in the lower and upper extremities and in the trunk flexors.

*Vertical jump*

The vertical jump test was performed as a counter-movement jump (Figure 7). We used the same laboratory with the same equipment as Gustavsson et al. (2006), who noted a high test-retest reliability level (ICC=0.95). Players performed the jump from an upright and extended leg position with their hands placed on their waist. The players quickly bent their knees and then immediately jumped upwards for maximum height. A computerised system

(MuscleLab®, Ergotest Technology Oslo, Norway) using a field of infrared light (approximately 10 mm above the floor), serving as a contact mat, made it possible to measure the flight time. The system was connected to a timer that was triggered when the light field were interrupted. The system then converted the flight time into jump height in centimetres. The response time is better than or equal to 2 ms. The players were tested to the point at which no more improvement was made, 3-10 trials. The best attempt was used for further analysis.

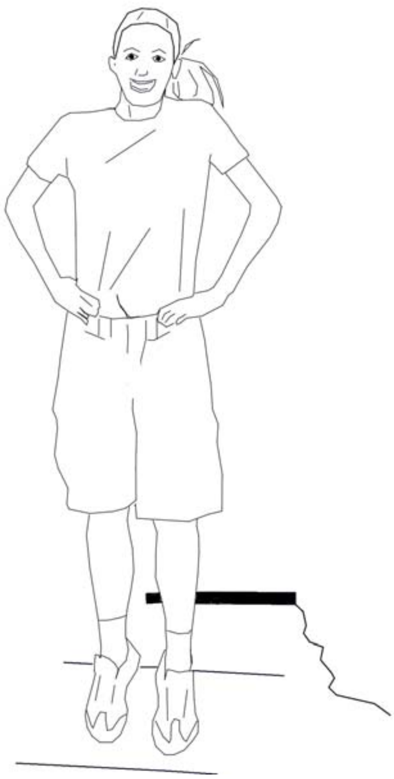


**Figure 7.** The vertical jump test using a contact mat.

*1 RM squat*

The 1 RM squat test began with a standing back extension warm-up exercise consisting of 20 repetitions with no extra load. Further, 20 repetitions of the squat exercise were performed with no extra load. For the test, the player stood in an upright starting position with an Olympic barbell on her shoulders placed high on the trapezius muscle (Figure 8). The player's feet were shoulder width apart, with the chest up and the eyes fixed straight ahead. The player performed the squat by descending to a parallel squat position, approximately 110º of knee flexion, by bending her knees and hips until the greater trochanter of the femur reached the same horizontal plane as the superior border of the patella (Mazzetti et al., 2000). The player then ascended to the starting position following a verbal signal from the test leader. A board (2 cm thick) elevating the heels of the player was used, thereby facilitating the parallel squat position. In addition, a tight weight belt supporting the trunk was obligatory. The player was instructed to be as upright as possible. A mirror placed 1.5 m in front of the player enabled visual feedback. The test leader stood behind the player, with his arms placed around the waist of the player during the lift to secure the exercise and to ensure that the proper form and technique was maintained. Any trials failing to meet the standardised technique criteria were discarded. The weight lifted for each trial was increased by 5-10 kg until failure occurred. 1 RM was determined within two to seven attempts, using one-minute resting periods between trials. For the post-test, the bar was loaded to 75% of the 1 RM performance from pre-test as the starting load. The reliability of the parallel squat test has previously been noted as high ($r$=0.95) (Hickson et al., 1994).

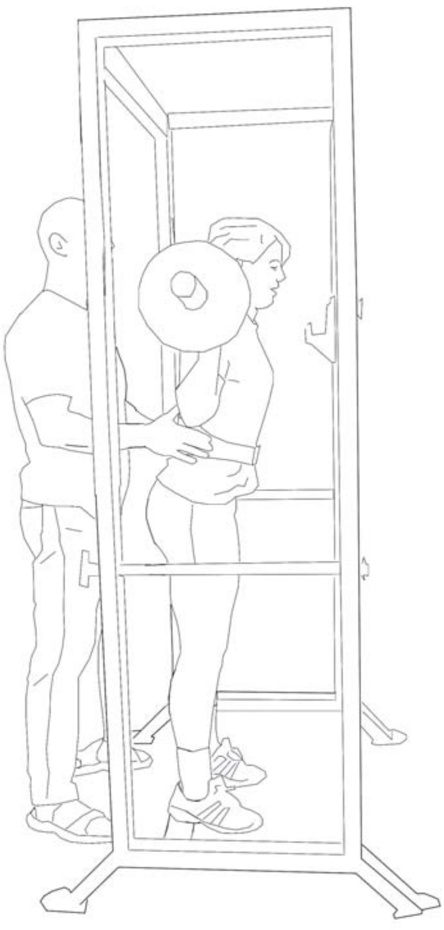


**Figure 8.** The starting position of the squat test.

*1 RM bench press*

The 1 RM bench press test began with a warm-up consisting of one set of 15 repetitions using a 10 kg barbell. The starting position for the bench press test was lying supine on a bench with the arms held straight. The test was performed with a 20 kg Olympic barbell. To standardise the bench press technique, the subjects were required to use the same hand placement for each trial, as determined by the distance between the index finger and barbell striations. The barbell was lowered by the player until it touched her mid-chest and, following a hand-clap signal from the test leader, it was then pressed into a full arm extension. The player's shoulders and buttocks had to be in contact with the bench during the test. The test leader stood over the player to secure the exercise and to make sure that the proper form and technique was maintained. Any trials failing to meet the standardised technique criteria were discarded. The weight lifted for each trial was increased by 2.5-10 kg until failure occurred. The 1 RM was determined within two to six attempts, using a one-minute resting period between trials. For the post-test, the bar was loaded to 75% of the 1 RM result from the pre-test. In a pilot study, twenty-one young female university students (mean age 25), who were not included in the study, were recruited prior to the study to perform the tests on two separate occasions within one week to evaluate the test-retest reliability of the 1 RM bench-press test. The bench-press test produced an excellent $ICC_{2,2}$ value of 0.99 (Augustsson et al., unpublished work).

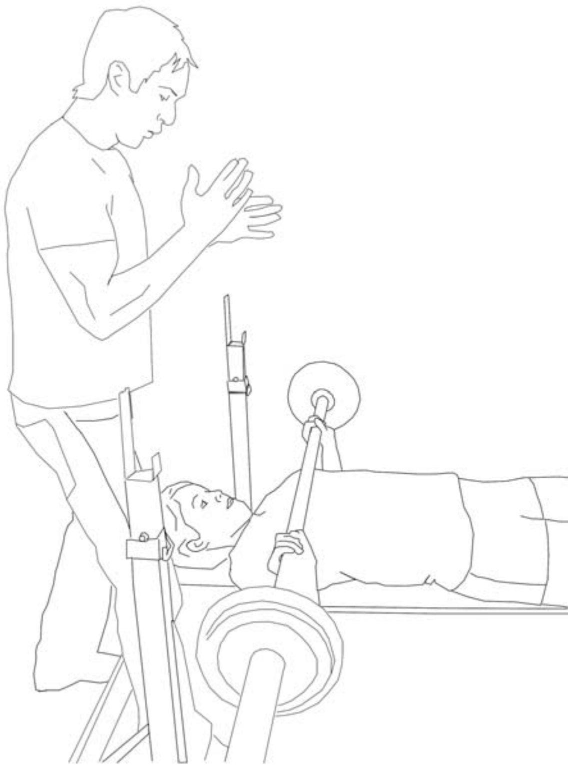


**Figure 9.** The bench press test.

**Periodised, individualised resistance training**
The intervention in Study III consisted of 26 weeks of progressive resistance training divided into three phases, familiarisation phase, progression phase 1 and progression phase 2 (Figure 10). A physiotherapist (S.R.A) supervised the players and was responsible for ensuring that exercise prescriptions were properly carried out and achieved during a particular workout (e.g. velocity of movement, appropriate spotting and technique, as well as safety considerations, intensity of the training and prescribed rest periods). At every training session, the players noted the number of sets, reps and training load for each exercise in a training diary.

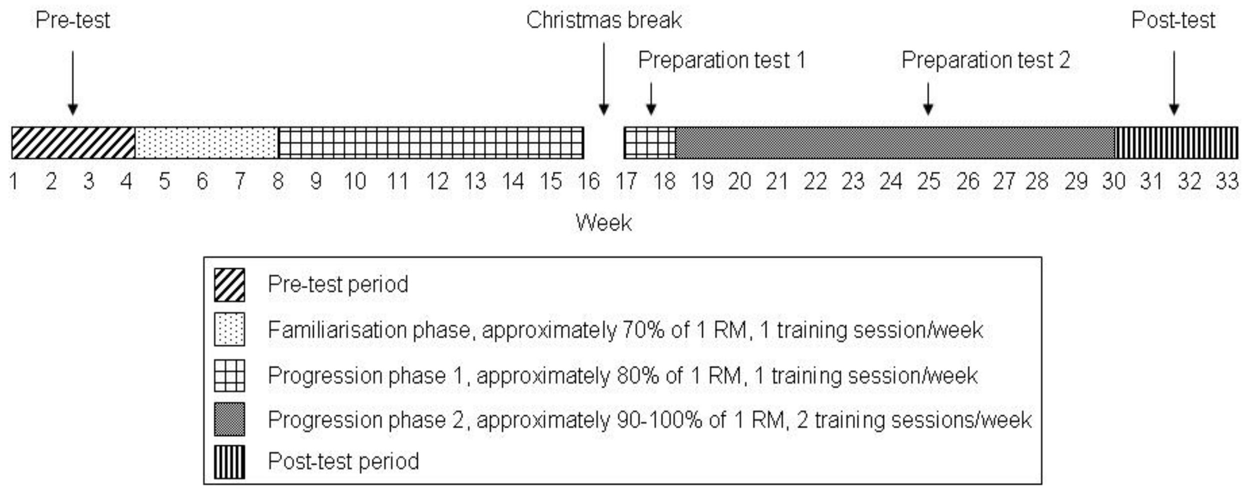



**Figure 10.** Testing and training schedule for the experimental group during the intervention season.

Baseline information relating to the players in the experimental group was collected at the beginning of the intervention season. This information included injuries that did not cause absence from practice or games. The pain level of these injuries was then estimated by the players using a 100 mm Visual Analog Scale (VAS), where 0 is no pain and 100 is the worst pain imaginable. The estimation was made three times during the intervention season, in September 2007, in January 2008 and in April 2008. The result from the pain estimations were registered by the first author (S.R.A). This information was then used as a tool when designing the individualized training programs (e.g. players experiencing anterior knee pain were given neuromuscular exercises for the knee).
The programme was periodised, starting with a four-week familiarisation phase with one training session a week. During this phase, the players performed exercises with approximately 70% of 1 RM (15 repetitions). The familiarisation phase consisted of a basic programme with 10 exercises which

was given to each player in both the experimental group and the control group (Table 1). The basic programme was the same for the control group apart from the rest periods were no guidelines were given. The familiarisation phase focused on the correct technique and form and adaptation of the load. After the familiarisation phase, the players in the experimental group were given an individual training programme (Appendix 2) that was designed by the first author (S.R.A) and included most of the exercises from the basic programme. The individual training programmes were partly based on the pre-test results, but they also took account of the players' court position and the injury screening (VAS). For progression phase 1, the aim of the training was progression in strength and power with one training session a week for 10 weeks. The training load was approximately 80% of 1 RM (10 repetitions) and was increased, if possible, in a progressive manner every two weeks to maintain the 80% level. Progression phase 2 consisted of 12 weeks of high-intensity resistance training, with two training sessions a week, focusing on maximum strength and power gains. The individual programme for each player did not change during this phase, but the training intensity increased. The players increased the training load to 90-100% of 1 RM in some of the multiple-joint exercises, such as the squat and the bench press. The players were instructed to complete all repetitions of all sets, even if assistance was required for the last few repetitions of a particular set (so-called forced reps). The players in the experimental group were tested by the physiotherapist, in week 12 and in week 20, in squat, bench press, push-ups and sit-ups to determine any flaws and to evaluate performance enhancement.

**Table 1.** Basic program (4 w) for the players in the experimental group presented by exercise, number of sets and repetitions and rest periods between sets.

| Exercise | Sets | Repetitions | Rest (min) |
|---|---|---|---|
| Squat | 3 | 15 | 3 |
| Bench press* | 3 | 15 | 2 |
| Push-ups* | 2 | max | 1 |
| Lat pulldown | 3 | 15 | 1 |
| Seated cable row | 3 | 15 | 1 |
| Overhead dumbbell press** | 3 | 12 | 2 |
| Machine overhead press** | 2 | 15 | 1 |
| Bodyweight back extension | 3 | 15 | 1 |
| Machine crunch | 3 | 15 | 1 |
| Sit-ups | 2 | max | 1 |

* Exercises that were performed in supersets for the experimental group.
** Exercises that were alternated every second training session for the experimental group.

## Interview data collection

In Study IV, the data were collected using semi-structured interviews conducted by one independent interviewer. The interviews were performed within three weeks after the intervention. The interviewer was not involved in the larger intervention study and had no previous contact with the interviewed participants. The interviewer was a physiotherapist with previous experience of conducting qualitative interviews and was also familiar with strength training. Each interview lasted approximately 45 minutes and took place in a conference room at the laboratory, which was also the location for the physical performance testing and was therefore familiar to the participants. All the interviews were audio-taped and transcribed verbatim. The interview guide was based on the clinical experience of the authors (Table 2). The interview guide was not tested in advance, but, after the first interview, one of the authors listened to the interview to ensure that the research questions were covered and that the interview addressed the purpose. The author then gave feedback to the interviewer on how to improve the forthcoming interviews. Each interview began by asking the participant "Can you describe one of your strength-training sessions?" More specific questions, which focused on the participants' feelings, experiences and beliefs in relation to strength training, physical performance, injury prevention and questions about the physical coach, were then asked.

**Table 2.** The interview guide.

| |
|---|
| **Can you describe one of your strength training sessions?**<br>Expectations? Challenges? Advantages? / Disadvantages? Learned something? What was good/bad? Missing something? How would you like it to be/Suggestion for improvements? The individual programme? The most important thing about strength training?<br><br>**What is your general opinion of strength training?**<br>Advantages? / Disadvantages? Easy? / Hard? Challenging? Things that could influence?<br><br>**What is your opinion of an injury prevention programme?**<br>Influences on injuries? Advantages? / Disadvantages? The individual programme? Influence on other training regimes?<br><br>**How is an excellent physical coach?**<br>Experience of/with the physical coach? Good/bad relationship?<br><br>**What is your opinion of the coach's knowledge in strength training? / injury prevention? / volleyball?**<br><br>**Advice to other physical coaches?**<br><br>**The future?**<br>Continue strength training? / injury prevention? / other physical performance enhancement activities?<br><br>**Any aiding information?** |

## Statistical methods

### Study I

Descriptive information about the injuries was based on information gathered from the questionnaire. Means and SDs were used to describe continuous data. The duration of each particular game was collected from the Swedish volleyball federation’s website. The total match exposure was calculated for every team as the sum of the duration of each match over the entire season, multiplied by six players. Injury prevalence was calculated as the number of injuries reported per volleyball player. An independent samples t-test was used to compare means.

### Study II

Independent-samples t-tests were used to compare men and women with regard to the number of sit-ups and push-ups. The meaningfulness of the group differences was determined by calculating eta squared ($\eta 2$). Intraclass correlation coefficients ($ICC_{2,2}$) and 95% confidence intervals (CI) were calculated and used for analyses of the test-retest reliability. Differences between the number of repetitions of sit-ups and push-ups performed at test-retest were computed using paired-samples t-tests.

### Study III

To evaluate changes in physical performance, sample size calculations to detect a difference of 50% between experimental group and control group were made using power analysis. The number of players needed to obtain sufficient power (90%) was determined before the start of the study (n=17/group). The descriptive data relating to the players were based on registration at the pre-test session. Pre- and post-intervention data were analysed with Wilcoxon’s signed-rank test. The Mann-Whitney *U* test was used to determine significant differences between the groups for the various tests in the test battery. Standardised Z-scores were used when calculating the total score for the test battery and the total score differences were analysed using the one-way ANOVA test. The relationships between the tests in the test battery were also investigated, using Pearson’s correlation coefficient, to determine whether they measured different aspects of physical performance. Injury incidence rates were calculated taking exposure into account and expressed as the number of injury occurrences per 1,000 h of volleyball practice and game. Injury prevalence was calculated as the number of injury occurrences per volleyball player. Fisher’s exact test was used to compare the percentage of injured players in the experimental group and the control group in the baseline season and the intervention season.

The Statistical Package for the Social Sciences statistical software package, version 15 (SPSS Inc., Chicago, U.S.A), was used for statistical calculations in Studies I-III. The significance was considered at the level of $p<0.05$ in all studies.

### Study IV

*Interview analysis*

The transcribed interviews in Study IV were analysed using qualitative conventional content analysis, with an inductive approach, as athletes' experiences of supervised, individualised strength training are lacking in the literature (Elo & Kyngäs, 2008). Content analysis does not require an underlying theory (Sandelowski, 2000) and conventional content analysis can be used when existing theory or research literature on a phenomenon is limited (Hsieh & Shannon, 2005). In addition, content analysis is "a research method that uses a set of procedures to make valid inferences from text" (Weber, 1990). To begin with, the interviews were read several times as a whole by both authors (S.R.A & C.W), in order to become familiar with the material and obtain a sense of the whole. This was followed by the identification of meaning units addressing the aim of the study. This process was performed separately by both authors (S.R.A and C.W) and cross-checked for agreement. The units were condensed and labelled with a code. Next, the various codes were compared on the basis of differences and similarities and sorted into ten sub-themes. Finally, the sub-themes were formulated into three overarching themes. The interviews were re-read for reflection and to ensure that the themes matched the purpose of the study and that the meaning units could be outlined in the themes. Both authors (S.R.A and C.W) took part in the entire process. One of the authors (S.R.A) was involved in the larger intervention study as the physical coach, whereas the other author (C.W) was not involved and had had no previous contact with the interviewed participants and had no experience of volleyball. Both authors are physiotherapists and have clinical experience of strength training, physical performance and injury prevention.

## Summary of the papers

### Study I: Injuries and preventive action in elite Swedish volleyball

**Introduction:** To our knowledge, there are few studies registering injuries and preventive action in volleyball players. The purpose of this study was to examine the prevalence of injury and the extent of preventive action in elite Swedish volleyball players.
**Methods:** Injuries to players in the elite male and female Swedish division, during the 2002-2003 seasons, were registered using a questionnaire.
**Results:** Of the 158 volleyball players (70% response rate), a total of 82 players (52%) reported 121 injuries, during a total exposure time of 24,632 h, representing an overall incidence of 0.77 injuries per player. The majority of the injuries were located in the ankle (23%), followed by the knee (18%) and the back (15%). Most injuries (62%) were classified as being of minor severity. Most injuries occurred during training (47%) and 41% of the injuries had a gradual onset. Fifty-four per cent of the injuries that could be related to a specific court situation occurred during blocking and 30% during spiking. Most players (96%) participated in injury-prevention training of some kind, generally performed without supervision (58%).
**Conclusion:** Although most players took part in some kind of preventive action, one in every two players incurred an injury during the season, which indicates that the risk of suffering an injury in elite volleyball is relatively high.

### Study II: Gender differences and reliability of selected physical performance tests in young women and men

**Introduction:** Although push-ups and sit-ups are among the most commonly used body-weight exercises to improve and assess strength and fitness, there is a lack of reproducible test protocols in the scientific literature. The purpose of this study was to evaluate the test-retest reliability of sit-ups and push-ups and to investigate performance differences in muscular endurance (maximum number of repetitions) and power (timed maximum number of repetitions in 30 s) in young women and men.
**Methods:** Thirty-eight women and 25 men, 18-35 years of age, participated in the study. Thirteen female participants performed two test sessions of each test using a test-retest design.
**Results:** High reliability was noted for both the sit-up and the push-up tests (intraclass correlation values ranged from 0.92 to 0.95). There were no significant differences between the men and the women in the mean number of sit-ups (42 and 41 repetitions respectively for endurance and 16 and 14 repetitions respectively for power), whereas the men performed significantly

more push-ups than the women (39 and 17 repetitions respectively for endurance and 29 and 13 repetitions respectively for power).

**Conclusion:** In conclusion, sit-ups and push-ups are tests with high reliability, which are easy to perform and can be recommended for clinical use to evaluate muscular endurance and power in young men and women. Moreover, the fact that men performed twice as many push-ups as women indicates that, when designing training programmes generally for women, attention should probably be focused on strengthening exercises for the upper body.

### Study III: Performance enhancement following a strength and injury-prevention programme: a 26-week individualised and supervised intervention in adolescent female volleyball players

**Introduction:** To our knowledge, there are no previously published studies that have examined the influence of supervision and individualisation during one season of resistance training in young female athletes. The purpose of the study was to evaluate the effects of a 26-week individualised and supervised strength and injury-prevention programme on performance enhancement in adolescent female volleyball players. The injury panorama was also documented.

**Methods:** Two groups of young female volleyball players completed resistance training with either a supervised, individualised training programme (experimental group, n=10, age 17) or an unsupervised, non-individualised training programme (control group, n=17, age 16). Exposure and injury data were collected during the 2006-2007 season (baseline season) and the 26-week programme was conducted during the 2007-2008 season (intervention season). All players were tested for physical performance.

**Results:** After the intervention, the players in the experimental group had improved significantly more than the players in the control group in squat ($p<0.0001$), bench press ($p=0.048$), push-ups ($p=0.02$) and sit-ups ($p<0.0001$) but not in the vertical jump test. Thirty-five per cent (6/17) of the players from the control group and 80% (8/10) of the players in the experimental group completed the resistance training with compliance of no less than 50%.

**Conclusion:** The present study shows the importance of individualisation and supervision for resistance training in young female athletes when it comes to compliance, strength gains and performance.

## Study IV: Athletes' experience of individualised, supervised strength training for physical performance and injury prevention

**Introduction:** To our knowledge, there is no previous publication studying the athletes' experience of an individualised, supervised strength-training programme and the presence of a physical coach. So, to obtain a greater understanding of the fundamentals of strength training and the role of the physical coach, we conducted interviews with the players that participated in Study III. The purpose of the present study was to explore and describe volleyball players' experience of an individualised, supervised strength-training programme aimed at physical performance and injury prevention. The purpose was also to use the players' observations to obtain an understanding of the role of a physical coach.

**Methods:** The study comprised nine participants (age 19) from the experimental group in the intervention study. Data were collected using semi-structured interviews conducted by one independent interviewer. The transcribed interviews were analysed using qualitative conventional content analysis.

**Results:** From the analysis, three overarching themes describing the content of the text emerged: being in an enjoyable, relaxed situation, interaction between coach and athlete and mental and physical achievements.

**Conclusion**: From the athlete's perspective, the performance in strength training is dependent on many factors, such as team spirit, individual goal-setting and bonding with the coach. Moreover, when designing strength-training intervention studies, it is important to be aware of the fear and feeling of uncertainty that could exist among the participants and the fact that strength training could be used to improve self-esteem among young females.

## Results

### Study I

The total exposure time for training and matches was 31,972 h. The mean number of training hours was 9.9 ±2.4 h/week for the men and 9.4 ±2.7 h/week for the women, whereas the mean time of match play was 0.7 h/week for the men and 0.6 h/week for the women. No significant differences between genders were found in terms of age, exposure time or the number of training hours or amount of match play.

Of the 158 volleyball players, a total of 82 players (43% men, 57% women) sustained 121 injuries during the 2002-2003 season. Of the men and women reporting injuries, 68% (56/82) experienced one injury during the season, whereas 20% (16/82) sustained two injuries, 9% (7/82) incurred three injuries and 4% (3/82) sustained four injuries. The prevalence of injury was 0.77 injuries per player (0.86 injuries per player for women and 0.68 injuries per player for men). The majority of injuries were located in the ankle (23%), followed by the knee (17%) and the back (16%) (Figure 11). Sixty-two per cent were classified as being of minor severity. Seventeen per cent of the injuries were of major severity and 21% of moderate severity. Of the 19 major injuries, seven (37%) injuries were located in the foot (4/7) and ankle complex (3/7). Forty-seven per cent of all injuries (57/121) occurred during training, seven per cent (9/121) occurred during match participation and 5% (6/121) occurred during the warm-up before the match, whereas 41% of all injuries (49/121) had a gradual onset, which means that the participants were not able to state when the injury occurred (during training, match participation or during warm-up). The injuries with a gradual onset were mostly located in the knee (33%), shoulder (20%) and back (18%). Forty-seven per cent of the major injuries (9/19) occurred during training and 37% (7/19) had a gradual onset. Only one of the major injuries (1/19) occurred during match participation and 11% (2/19) during the warm-up before the match. Forty-five per cent of all the injuries noted in this study (54/121) could be related to a specific court situation and, furthermore, 54% of these injuries (29/54) occurred during blocking and 30% (16/54) during spiking. Seventy-three per cent of the injuries related to a specific court position and involved the three front players (attackers and blockers). Sixty-one per cent of all ankle injuries (17/28) occurred during blocking, whereas 57% of the ankle injuries (16/28) occurred during contact with another player.

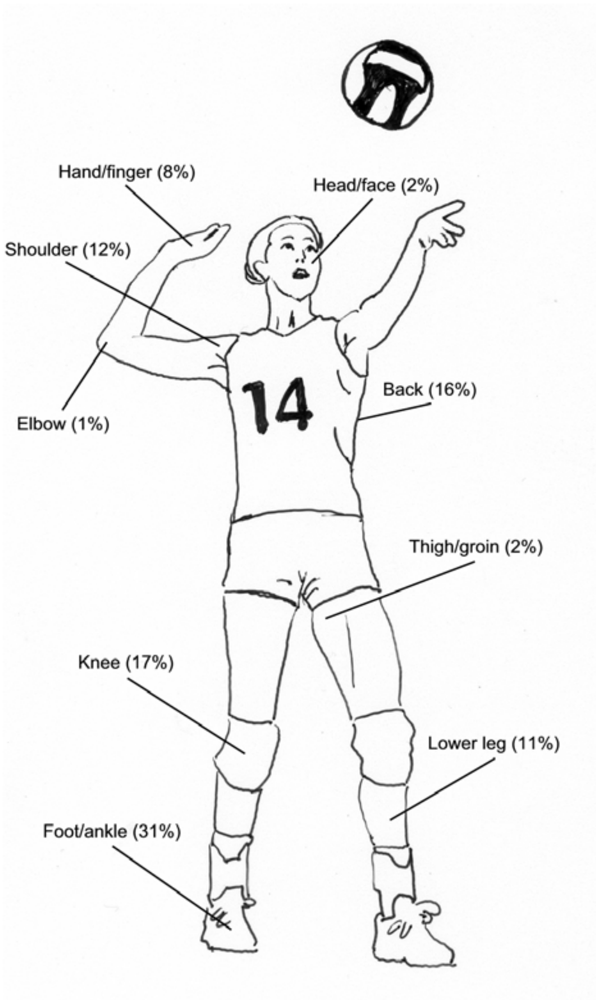



**Figure 11.** Location and rate of injuries occurring during the season of 2002–2003 in elite Swedish volleyball players.

Ninety-six per cent of the players reported that they participated in some kind of prevention programme during the pre-season, whereas 97% took part in a prevention programme during the season. The prevention programme consisted primarily of strength training, technique drills and plyometric exercises. More than 90% of the players performed strength training. Fifty-eight per cent (49% of the men, 66% of the women) of the prevention training was performed without supervision (i.e. without a coach). Forty-three per cent of the players (68/158) participated in other sports activities, such as aerobics, beach volleyball, running and strength training, which were not included in normal volleyball training. Sixty-three per cent of these players (43/68) took part in strength training.

## Study II

*Test-retest for sit-ups and push-ups*

The $ICC_{2,2}$ value for the maximum number of sit-ups was 0.92, with a 95% CI of 0.73-0.98. The $ICC_{2,2}$ value for 30-s timed sit-ups was 0.93, with a 95% CI of 0.77-0.98. The mean number (±SD) of maximum sit-ups for the 13 participants was 48 (±25) on the first occasion and 53 (±38) on the second occasion, with no significant difference between test and re-test (p=0.295). The mean number of 30-s timed sit-ups for the 13 participants was 14 (±4) on the first occasion and 13 (±3) on the second occasion, with no significant difference between test and re-test (p=0.085). The $ICC_{2,2}$ value for push-ups was 0.95, with a 95% CI of 0.85-0.99. The $ICC_{2,2}$ value for the 30-s timed push-ups was 0.93, with a 95% CI of 0.62-0.96. The number of push-ups for the 13 participants was 17 (±9) on the first occasion and 19 (±10) on the second occasion, with no significant (p=0.131) difference between test and re-test. The mean number of 30-s timed push-ups for the 13 participants was 14 (±7) on the first occasion and 15 (±6) on the second occasion, with no significant (p=0.222) difference between test and re-test.

*Gender comparison of sit-ups and push-ups*

The mean number of sit-ups was 42 (±17) for men and 41 (±23) for women. There were no significant differences between the number of sit-ups performed by the men and women (p=0.898; $\eta2$=0.0002). The mean number of 30-s timed sit-ups was 16 (±3) for men and 14 (±4) for women, with no significant difference between men and women (p=0.110; $\eta2$=0.038). The mean number of push-ups was 39 (±13) for men and 17 (±10) for women, with a significant difference between men and women (p=0.001; $\eta2$=0.504). The mean number of 30-s timed push-ups was 30 (±8) for men and 13 (±6) for women (p=0.001; $\eta2$=0.615).

## Study III

*Physical performance*

No significant differences between the experimental group and control group were noted at the pre-test for any individual tests or for the total score (p=0.495) for the test battery. After the intervention, the players in the experimental group had improved significantly more than the players in the control group in the squat (p<0.001), bench press (p=0.042), push-ups (p=0.002) and sit-ups (p<0.001) but not in the vertical jump test (p=0.412) (Table 3). The total score for the test battery was also significantly higher in the experimental group compared with the control group (p<0.001). For the experimental group, a significant performance enhancement (p<0.05) of 2 cm (8%) was noted for the vertical jump test, 28 kg (67%) in squat, 5 kg (16%) in bench press, 11 repetitions (122%) in push-ups and 6 repetitions (55%) in sit-ups. For the control group, a non-significant performance change of 1 cm (4%) was noted for the vertical jump test, 6 kg (12%) in squat, 3 repetitions (30%) in push-ups and 1 repetition (8%) in sit-ups. A significant performance enhancement ($p<0.05$) of 2 kg (6%) in bench press was noted in the control group. Three of the players in the control group were unable to attend the post-test occasion due to injuries.

**Table 3.** Mean (±SD) results of the vertical jump, 1 repetition maximum squat, 1 repetition maximum bench press, 30-sec timed push-ups and 30-sec timed sit-ups tests.

| | Experimental (n=10) | | Control (n=14) | |
|---|---|---|---|---|
| | Pre | Post | Pre | Post |
| Vertical jump (cm) | 26 (±4) | 28 (±4) ‡ | 27 (±4) | 28 (±4) |
| Squat (kg) | 42 (±14) | 70 (±13)*‡ | 50 (±14) | 56 (±17) |
| Bench press (kg) | 31 (±5) | 36 (±6)*‡ | 32 (±5) | 34 (±5) ‡ |
| Push-ups | 9 (±4) | 20 (±5)*‡ | 10 (±4) | 13 (±5) |
| Sit-ups | 11 (±3) | 17 (±3)*‡ | 13 (±3) | 14 (±2) |

*Difference in increase between groups ($p<0.05$).
‡Intragroup difference ($p<0.05$).

*Pre-test and post-test correlation between tests*

A significant relationship was found between the vertical jump test and the squat test ($r=0.42$, $p=0.026$) at the pre-test. No significant correlations were found for any of the other tests in the test battery at the pre-test.

*Compliance*

Thirty-five per cent (6/17) of the players from the control group performed the resistance training programme to which they were assigned during the intervention season, with 50% or more compliance during the season. All the players (n=10), excluding drop-outs, from the experimental group carried out the resistance-training programme during the entire season. Eighty per cent (8/10) of these players had at least 50% compliance. When comparing players who were compliant, (6 in the control group and 8 in the experimental group) we found that the experimental group improved its physical performance for the total test battery significantly more than the control group ($p=0.002$).

*Injury data*

*Baseline season 2006-2007*

During 3,546 hours of exposure time (practice and games), nine (29%) players sustained 15 injuries during the baseline season. There was no significant difference in the percentage of injured players between the experimental group and control group (p=0.437). The most common injury was localised in the knee area (7 of 15 injuries). There were also injuries to the ankles (2/15), shoulders (2/15), lower leg (2/15) and wrist (2/15). Of all the injuries, 71% were overuse symptoms and 29% were of a traumatic nature. Seventy-two per cent of the injuries were of moderate severity, while 21% were of minor severity and 7% were of major severity.

*Intervention season 2007-2008*

For the intervention season, an exposure time of 3,242 h was noted during which six players sustained eight injuries. There was a significant difference (p=0.042) in the percentage of injured players between the experimental group and the control group in the intervention season. Fifty per cent (4/8) were ankle injuries of a traumatic nature, whereas the other injuries were overuse injuries located in the knee (2/8), shoulder (1/8) and thigh (1/8) areas. Seventy-five per cent of the injuries were evenly distributed between minor and moderate severity, while 25% were of major severity.

**Study IV**

From the analysis, three overarching themes emerged describing the content of the text: “Being in an enjoyable, relaxed situation”, “Interaction between coach and athlete” and “Mental and physical achievements”.

**Being in an enjoyable, relaxed situation**

This theme is described in three sub-themes.

*Feelings of delight about the training*

All the participants said that the training as a whole was enjoyable and some of them said that the feelings of pleasure related to strength training were unexpected. They also said that the excitement was partly caused by the unexpected physical achievements.

*Training with the group*

All the participants mentioned that the often enjoyable moments during the training sessions were partly due to the solidarity of the group. They also said that the other team members’ performance was inspiring.

*Having a break from the ordinary*

Some of the participants also stated that they were able to progress in their training, in spite of other obligations, and that, conversely, the training sessions were experienced as a temporary break from everyday tasks.

**Interaction between coach and athlete**
This theme is described in three sub-themes.

*Being motivated, encouraged and challenged*
The participants pointed out that one of the main tasks for the coach was to motivate and encourage. Despite tiredness and bad moods, the coach was able to give the participants working energy and fighting spirit through verbal encouragement. The coach also set challenges that motivated the participants, as they described a sense of triumph when they were able to lift a heavier weight or do more repetitions.

*Being acknowledged*
The encouragement the participants experienced was also often described as a result of acknowledgment and attention from the individual. The participants felt that the coach was involved in the individual and had knowledge of individual needs and capabilities. In addition, they said that a coach's ability to develop individual exercise programmes and make sure that personal goals were realised was important. The participants also appreciated the friendly, personal side of the coach, but they also pointed out that, as the coach was present, they felt obliged to attend the training session.

*Feeling secure*
All the participants felt that the coach provided safety and that the coach was available for technique instructions and securing exercises. The participants also described the coach's ability to set boundaries and motivate the participants to work to their maximum without exceeding their safe potential. This provided a feeling of safety and the courage to progress with the training (lifting heavier weights).

**Mental and physical achievements**
This theme is described in four sub-themes.

*Improving confidence*
The majority of the participants expressed a sense of fear and uncertainty when starting the training period. However, they all said that they had become more secure in themselves, as they described a feeling of improving confidence and self-esteem.

*Feeling physically stronger*
All the participants said that they felt physically stronger and more alert than they had before the training period.

*Increasing capacity in daily life and experiencing advanced performance in sport*

The experience of physical achievements described by the participants was also expressed in the day-to-day day activities and other sports activities. The participants felt that they had more strength to participate in everyday activities and that volleyball-specific tasks had improved.

*Having less pain*

The participants said that the increase in strength had helped to reduce pain and that, in return, they had obtained greater staying power.

# Discussion

## Strength and conditioning programmes for physical performance and injury prevention

The main finding in Study III was that the players in the experimental group had improved strength and power significantly more than the players in the control group in all tests except for the vertical jump test, after individualised, supervised resistance training.

Designing an optimal resistance-training programme in sports can be a complex process in itself. It has previously been suggested that a periodised resistance-training design is superior to a non-periodised design when it comes to sports-specific issues (Kraemer et al., 2000, Hoffman et al., 2009). A high-volume, periodised, multiple-set, resistance-training programme has also previously been noted to be superior to low-volume, single-set programmes, especially when it comes to increasing muscular strength. It appears that a high volume of exercise may be vital for several important parameters, such as strength, power and lean body mass, not least in relation to continued changes over time (Kraemer et al., 2000). To optimise the training results, the training programmes for the experimental group in Study III were periodised in terms of exercises, frequency, intensity, volume and rest intervals. Exercise testing was carried out by the physical coach twice during the period to determine intervention progress and strength and, moreover, to evaluate the athletes' performance enhancement. Furthermore, the experimental study group in Study III recorded all the workouts in a training diary. The diary was collected by the physical coach after each workout and feedback was given on changes in exercise loading. Taken together, it is concluded that the comprehensive monitoring (e.g. periodised progressive programmes, exercise testing and training diary) of the training could be one factor that contributed to the progress observed in the experimental group in Study III.

The training programme in Study III was conducted for 26 weeks and was designed to increase the players' physical performance and also to prevent injuries. The resistance training prescribed for the players at the beginning (i.e. basic programme) of the study was the same for both the experimental group and the control group. A simple programme design is recommended when resistance training is introduced (Kraemer & Ratamess, 2004). Consequently, the basic programme used in Study III consisted of no more than nine exercises and focused on the correct technique and form of each exercise and adaptation of the load. After the familiarisation phase, the players in the experimental group received an individual training programme. The programme included most of the exercises from the basic programme with additional individual exercises. As described in the introduction section, it has been suggested that training with loads corresponding to >80% of 1 RM or more are effective for increasing maximum strength (Campos et al., 2002). Although strength also increases using loads corresponding to 70-80% of 1 RM, it is believed that this range may not be as effective in increasing maximum strength in highly strength-trained athletes compared with heavier loading (≥85% of 1 RM). Since the athletes in Study III were inexperienced in terms of resistance training, the starting load was set at 70% of 1 RM, in order to begin gradually, learn the proper technique and allow sufficient recovery time. However, the more advanced the athletes become in performing the exercises, the more variation (i.e. structuring the training in specific cycles) may be necessary to avoid performance plateaus (Kraemer & Ratamess, 2004). For this reason, the training load was increased to approximately 80% of 1 RM (progression phase 1) after the familiarisation phase to augment progress. The training load was then increased, if possible, every two weeks to maintain the 80% level and optimise strength gains. Moreover, after progression phase 1, the load increased even more to an intensity corresponding to 90-100% of 1 RM (progression phase 2) in some of the multiple-joint exercises (squat, bench press and leg press). Progression phase 2 consisted of 12 weeks of heavy resistance training, with two training sessions a week, focusing on maximum strength and performance mainly in the multiple-joint exercises. Study III revealed no significant differences at the pre-test for any tests between the experimental group and the control group. After the intervention, the players in the experimental group had improved significantly more than the players in the control group in all tests except for the vertical jump test. However, the improvements noted in the vertical jump test between pre- and post-test were significant in the experimental group but not in the control group. The difference in the vertical jump test between the experimental group and the control group might perhaps have been significant if the study had comprised a larger sample. Nevertheless, the pre-test sessions were performed during the pre-season and after the summer break, when the players in both groups were more likely to be de-trained. Post-test, after one season of regular training, the players had probably improved their jumping performance as a normal adaptation to sport (volleyball). This is in accordance with previous studies which have shown that sports-specific physical performance, such as jumping performance and throwing velocity, were enhanced during one season of ordinary training or preparation for competition in sports (Stanganelli et al., 2008; Granados et al., 2008) and that an interruption in normal training can result in physical capacity reductions (Kovacs et al., 2007; Hoffman et al., 2009). Since jumping is one of the most important tasks in volleyball, it is likely that this ability will improve after one season of volleyball training and that any differences between groups in Study III would therefore have been difficult to detect.

Studies I and III addressed the injury panorama and preventive action in volleyball. In Study I, it was found that the majority of the injuries were located in the ankle, knee and back. This is in accordance with previous studies (Bahr & Bahr, 1997; Verhagen et al., 2004). Although the results in Study I are applied to elite volleyball players, there is no evidence suggesting that the injury panorama would be different in lower divisions as the localisation of injuries appears to be similar despite the level of play (Bahr & Bahr, 1997; Verhagen et al., 2004; Augustsson et al., 2006). In Study I, we found that 96% of the elite volleyball players performed injury-prevention actions. However, more than 50% of the injury-prevention programmes were performed without a trainer. With this knowledge as the starting point, a new theory emerged and it was addressed in Study III.

No significant differences were found in the percentage of injured players after the baseline season, whereas there was a significant difference in the percentage of injured players during the intervention season between the experimental group and the control group. In Study IV, players in the experimental group experienced improved capacity in their day-to-day and sporting activities, which was partly described as a result of reduced pain (mostly from the knee, back and shoulder areas). Some of the participants had experiences of everyday pain which inhibited daily working situations and sporting abilities. All the participants with these experiences also claimed that they experienced a reduction in pain after the training period. For some of these participants, the pain decreased rapidly. These pain experiences were, however, not recorded as injuries in Study III, as they did not lead to absence. Based on the information from Study IV, the time-loss injury definition used in Studies I and III may not be the optimal way to define an injury for these athletes. Although players elect to continue practice despite experiencing musculoskeletal pain, it is obvious that these “minor” injuries still have an impact on the athlete’s sporting performance. Taken as a whole, there appears to be a gap between the scientific way of reporting injuries and the athletes’ own experiences of injuries, which warrants a new injury definition.

**Individualisation, supervision and compliance**

When it comes to strengthening, it appears to be important that the resistance is set individually from an individual maximum in order to be sufficiently challenging (Kraemer et al., 2000). In addition, the starting point and progression of a strength-training programme might benefit from being individualised. It has been our observation that, in team sports, the programmes in injury-prevention studies are rarely individualised or progressive (Wedderkopp et al., 1999; Olsen et al., 2005; Gilchrist et al., 2008; Soligard et al., 2008; Steffen et al., 2008a; Steffen et al., 2008b). Although using the same starting point for the participants in a study makes sense from a scientific viewpoint, it is then difficult to make the training effective and challenging enough for the stronger subjects.

Individually designed programmes depend on factors such as initial performance and health status (Deschenes, 2002). The training programmes in Study III were individualised on the basis of the pre-test results (vertical jump, squat, bench press, sit-ups and push-ups) and also while taking the players' court position, previous injuries and the injury screening into account. All training performed by the players was recorded in both groups, but, whereas all the players in the experimental group documented their exercises, training volume and training intensity in a diary, the players in the control group did not. The fact that the players in the experimental group recorded each training session thoroughly may have resulted in greater compliance with the programme compared with the control group. The use of a training diary could have helped the athlete to remind herself of the current exercise prescription, training load and number of sets and repetitions. The diary could also have promoted goal-oriented issues (strength enhancement and injury prevention). Using the visible keeping of a diary (e.g. becoming aware of the progress made) may also have facilitated and encouraged the athlete to complete every training session to the fullest.

Study III also provides more evidence supporting the importance of supervision during resistance training in order to optimise strength gains. The influence of direct supervision on muscular strength, power and running speed has previously been investigated during a 12-week resistance-training programme involving young rugby league players (Coutts et al., 2004). The results of the study by Coutts et al. (2004) are in accordance with those in Study III and revealed that the direct supervision of resistance training in young athletes resulted in greater training adherence and increased strength gains when compared with unsupervised training. However, in the study by Coutts et al. (2004), the players in the intervention group were directly one-on-one coach-to-athlete supervised. The opportunity for athletes to have direct coach-to-athlete supervision in strength and conditioning programmes, as well as the sports-specific training routine, is limited, especially in team sports. One challenge for the coach when strength and conditioning programmes are being introduced is therefore to have quick access to those in the greatest need of support.

We found greater compliance with the resistance-training sessions in the experimental group ($8/10 \geq 50\%$ of training session participation) compared with the control group (6/17 ≥ 50% of training session participation). In addition, the compliant players in the experimental group improved their physical performance significantly more than the compliant players in the control group. Due to the restricted sample size in the compliant control group, it is, however, not possible to determine whether this difference was due to the individualised, supervised programme or was just a random effect. Nevertheless, we believe that the higher compliance rate seen in the experimental group might be due to the direct supervision of each training session. Further, we believe that the presence of a physical coach is probably a factor that motivates players to attend the training sessions. In Study IV, some of the participants in the experimental group mentioned that they felt obliged to attend each training session. This is in accordance with previous research which has affirmed that bonding with the coach influences athletes' participation (Crespo & Reid, 2007). All the participants in Study IV said that they felt acknowledged on an individual basis by the coach. They also experienced support from the coach and felt that they had a good relationship with the coach. They also attached great importance to the coach's knowledge when it came to strength training and the ability to see the athlete's potential. All the participants clearly stated that they attributed great significance to the coach as someone who could motivate and encourage the athletes. This was thought to be achieved by verbal encouragement and involvement in the individual athlete as a result of the coach's participation. The encouragement was sometimes experienced as dominant and focused on performance, when the coach added more weight and pushed the participant throughout a set, for example. This was, however, described as a good thing that challenged the athletes and helped them to keep the training intensity high. The motivating factor during rehabilitation has previously been discussed after ACL reconstruction, as patients expressed a desire for more support regarding personal goals and motivation (Heijne et al., 2008). Taken as a whole, the coach plays an important role when it comes to motivating athletes, where goal-setting, verbal encouragement and attention to the individual are thought to be of significance. The feeling of bonding and obligation between players and between player and coach might be essential when it comes to training compliance.

**Team players' experience of a strength-training programme**

Enjoyment, fun, passion and love of the game have previously been ranked as very important issues for successful athletic performance (Crespo & Reid, 2007). In Study IV, the players in the experimental group described a feeling of enthusiasm towards the training. All the participants said that they generally had fun during the workout. In addition, most of the participants were surprised about these positive feelings. Some participants said that, before they started the strength-training period, strength training constituted well-trained men behaving in a boring, egocentric manner, in their world view. This may very well be an expression of uncertainty and ignorance about strength training among young women. However, most of the participants pointed out that the results of the strength training (strength and power improvements) were unexpected and that the results helped to generate a feeling of joy. The progress during the training period exceeded the participants' expectations and they were generally proud of what they had accomplished. Moreover, all the participants said that training together with the other team players to work together during the training sessions encouraged them to perform better.

An accepting, caring climate has previously been described as a climate of mastery, whereas winning and beating others has been described as a performance climate (Nicholls, 1989). Mastery and performance climates are elements of achievement goal theory that distinguish two different viewpoints, task orientation and ego orientation. An individual who is task oriented adopts a self-referenced notion of success, believing that ability is demonstrated through the development and/or mastery of new skills, putting in maximum effort and improving one's performance. In contrast, an individual who is ego oriented takes on a normative conception of ability and believes that skills are demonstrated by exceeding the performance of others (Nicholls, 1989). Clearly, the presence of other team members appears to influence the athletes' performance and motivation. Other factors that the participants in Study IV felt could affect the atmosphere and workout performance were other obligations outside sports. Some of the participants said that, if they had a bad or good day at school or work, it would probably affect the training session. However, they also stressed that, after a bad day, it was a kind of relief to be at the gym and do the strength training in order to, as described by one participant, "…get away and put one's mind at rest".

Taken together, the 26-week strength-training period in Study III was experienced as enjoyable and meaningful. In addition, the environment and physical performance were affected by the team spirit and the present mental condition.

**Muscle strength and functional performance testing**

In Study II, we examined the test-retest reliability of push-ups and sit-ups. The tests of both maximum number and the 30-s timed push-ups and sit-ups showed high test-retest reliability ($ICC_{2,2}$ values above 0.90 for all tests). An ICC value below 0.40 has previously been described as ‘‘poor’’, from 0.40 to 0.75 as ‘‘fair’’ to ‘‘good’’ and above 0.75 has been described as ‘‘excellent’’ (Fleiss, 1986). The results in Study II suggest that the tests are highly reliable for both muscular endurance, as in maximum number, and power testing, as in timed tests, in young adults.

Functional performance tests resemble many sports-specific movements and are important measurements in sport preparation. Sit-ups and push-ups require strong trunk stabilisation muscles (Andersson et al., 1997; Karst et al., 2004; Freeman et al., 2006; Howarth et al., 2008). In addition, push-ups also impose heavy demands on the shoulder/scapular stabilisation muscles (Lear & Gross, 1998). For this reason, we believe that both sit-ups and push-ups might be useful tests of physical performance in sports requiring well-developed trunk and upper extremity strength. Functional performance tests, such as sit-ups and push-ups, are easy to perform and require no special equipment and are therefore attractive for clinical use in sports. Although sit-ups and push-ups are frequently used as tests of physical performance in sports, Study II is, to our knowledge, the first study that has examined the test-retest reliability of maximum number performed in young women and men.

Although functional tests are helpful tools for clinical use in sports, they do not provide answers about maximum strength, for example. Maximum strength can be tested with isometric, isokinetic and isotonic dynamometry. Even though isometric and isokinetic tests have been frequently used in sports science, these tests have also been criticised. The main argument against both isometric and isokinetic testing is the absence of acceleration and that they differs from the dynamic nature of most sports (Kannus, 1994; Abernethy et al., 1995; Wilson & Murphy, 1996; Özçakar et al., 2003). In addition, isotonic testing has been criticised for having poor reliability due to problems related to standardisation (Abernethy et al., 1995). However, it has been argued that isotonic testing is the most similar to the characteristics of sports and also reflects most exercises in strength and conditioning programmes (Wisløff et al., 2004). Further, it has been suggested that closed-kinetic chain exercises, such as squat, are superior to open-kinetic chain exercises, such as seated knee extension, when it comes to improving functional performance parameters (e.g. vertical jump) (Augustsson et al., 1998; Blackburn & Morrissey, 1998). In addition, multiple joint exercises such as maximum squat strength has been shown to have a strong relationship with vertical jump height (Wisløff et al., 2004) and maximum bench press has been reported to be related to ball-throwing velocity (r=0.64) (Marques et al., 2007). The test battery used in Study III (vertical jump, squat, bench press, sit-ups and push-ups) was constructed to reflect the exercises performed by the players in order to fully detect any eventual improvements as a result of training. The test battery was also thought to be sport specific and related to the specific injury panorama in volleyball. Since only one significant relationship was found (the vertical jump test and the squat test) between the tests, the test battery appeared to measure different aspects of physical performance. In sports, the 1 RM test is often described as the golden standard and it is suggested as a suitable test to determine the initial load in strength and conditioning programmes and may also be used to evaluate strength after an exercise period (Wisløff et al., 2004; Tagesson & Kvist, 2007; Granados et al., 2008), whereas isokinetic testing is thought to be the golden standard in rehabilitation (Kannus, 1994). Since the reliability of 1 RM strength assessments of bench press was lacking in the literature, we decided to evaluate 1 RM bench-press test-retest reliability in a pilot study before Study III. In the pilot study, twenty-one young females, who were not included in the study, performed the 1 RM bench-press test on two separate occasions within one week to evaluate the test-retest reliability. The bench-press test produced an excellent $ICC_{2,2}$ value of 0.99 (Augustsson et al., unpublished work). Bench press is one of the most frequently performed strength training exercises there is and it is used in many sports test batteries for physical performance assessment. The test-retest reliability described in this study is therefore a valuable tool for clinical sport use as it does not require laboratory equipment.

**Gender considerations**

It has been reported that adolescent and adult female athletes have a 2-fold to 5-fold higher incidence of sustaining a serious knee ligament injury, such as ACL injury, compared with male athletes participating in the same sport (Arendt & Dick, 1995; Myklebust et al., 1998; Gwinn et al., 2000). Further, it has been noted that the muscle strength development in the lower extremities among adolescent female athletes is only half that of adolescent males (Barber-Westin et al., 2006). Poor muscle strength development among adolescent female athletes may be one of several factors responsible for the gender disparity in knee ligament injury rates. Future studies that examine the benefits of resistance training for injury prevention are therefore warranted. However, in Study I, no significant differences between genders were found in terms of injury prevalence among volleyball players. The prevalence of injury was 0.86 injuries per player for women and 0.68 injuries per player for men. Although there appeared to be a higher incidence of lower leg and back injuries among female players compared with men in Study I, no definitive answers regarding injury distribution could be obtained from the study because of the relatively small number of injuries.

In Study II, there was a significant difference between men and women in the push-up test, but no differences were found in the sit-up test, regardless of whether the tests were timed or performed to the maximum. The result indicates that younger women's muscular endurance, as well as muscular power in the upper body, is less than that of younger men and that women's abdominal endurance and power is similar to that of men. Differences between men and women in terms of muscular endurance and strength have been reported in earlier studies (Stanish et al., 1999; Kraemer et al., 2001; Sinaki et al., 2001). It has been noted that women's (age 19-36) upper-body strength averages 50-55% of men's and that their lower-body strength averages 65-80% of men's (age 19-36) (Stanish et al., 1999; Sinaki et al., 2001). In Study II, the men performed more than twice as many push-ups as the women, which is in agreement with previous observations (Stanish et al., 1999; Kraemer et al., 2001). Women's upper-body muscular endurance averaged no more than 44% of men's in Study II. Since one of the key risk factors for work-related injuries, as well as training injuries, appears to be inadequate physical fitness (Bell et al., 2000; Kraemer et al., 2001), the results of Study II (that men are twice as strong as women in the upper body when it comes to both local muscular endurance and power) suggest that more attention should be paid to upper-body training in women. Interestingly, there were, however, no differences between the genders in terms of sit-up performance. The result is in accordance with some recent studies in which it has been noted no differences in the mean number of sit-ups (Stanish et al., 1999; Laughlin & Busk, 2007). On the contrary, other studies have estimated that abdominal muscle strength in young women is approximately 70-80% compared with that of young men (mean age 20) (Andersson et al., 1988; Bell et al., 2000). One explanation for the fact that women performed as many sit-ups as men in our study could be that the women performed physical activities involving the abdominal muscles to the same or an even greater extent than the men. We have noted that, until a few years ago, women's physical conditioning programmes (aerobics training) frequently contained sit-ups, whereas other strengthening exercises were limited. However, we only investigated the amount of physical activity and not the form of physical activity, which would have been interesting to know. Taken together, the values in Study II could be used as an indication that young women tend to be relatively strong in the abdominal area and in fact equally strong compared with young men, but unfortunately young women do not have even half the strength and endurance in the upper body compared with young men.

**Generalising the results**

This thesis suggests that female volleyball players can improve their strength and power during the competition season by implementing a well-designed resistance-training programme. Even though the sample sizes were relatively small in Study III, the results are strengthened by the players' compliance with the study and the intervention protocol (periodised, individualised and monitored). Study I comprised all the volleyball teams (10 men's teams and nine women's teams) who played in the elite Swedish division during the 2002-2003 season. The response rate was 70%, which is similar to or higher than that in other retrospective studies (Aagaard & Jørgensen, 1996; Smith & Krabak, 2002). Based on this information, we suggest that our results can be generalised to Swedish elite volleyball players. In Study II, we believe that our results can be applied to young men and women aged 18-35 who are training on average twice a week.

**Methodological issues**

In Study I, the data were collected retrospectively and voluntarily, which could be a limitation. One problem with this study design is that there might have been players who did not receive the questionnaire because of a major early season injury. Although the response rate in Study I is similar to or higher than that in other retrospective studies (Aagaard & Jørgensen, 1996; Smith & Krabak, 2002), we cannot rule out the difficulties involved in gathering data retrospectively, where some players may already have ended their season. Another problem with retrospective studies might be players forgetting minor injuries because of a major injury. Retrospective studies may, however, lead to increased compliance by the participants compared with prospective studies, because of the short and simple gathering of injury data using a retrospective design. In addition, retrospective studies might be preferable when gathering data from whole populations. For example, in our study, all the teams agreed to participate, which is not always the case in prospective studies (Bahr & Bahr, 1997; Verhagen et al., 2004). Further, we believe that, due to the injury definition (absence from play), elite players most probably remember these kinds of injury as they are rarely absent.

In Study II, some of the participants were recruited from health-related education programmes and might not be fully representative of the normal population; men and women aged 18-35 years. It is likely that participants who are enrolled in this type of study have a greater interest in physical activity and are perhaps more enthusiastic about testing their maximum capacity compared with less physically active persons. The values obtained may therefore be slightly overestimated. On the other hand, this is always a risk in voluntary studies examining aspects of physical performance.

In Study III, one potential weakness was the small sample size. The power for detecting injury incidence, prevalence and frequency was limited and we are unable to draw any definite conclusions from the injury results. However, for the purpose of investigating physical performance changes, we felt that the sample size was adequate. Further, with respect to the study design, players in Study III were not randomised. However, it is difficult to split the team members into different training regimens without the possibility of interference. Consequently, we chose to randomise the teams instead of individual players in order to reduce the risk of confounding factors.

In Study IV, one limitation was that the participants comprised a small sample of nine players. However, these participants were the only ones under consideration, as they were the particular players exposed to and experienced in the specific training regimen. Moreover, the sample size in content analysis is regarded as less important than the variation in data generated by the sample (Graneheim & Lundman, 2004). There are no rules for sample size in qualitative studies. The sample size is determined by the research question and depends on the information that is required (Patton, 2002). According to Patton (2002), the sample size in qualitative research is selected purposefully, which provides the power to select information-rich cases. This contrasts with quantitative investigations where the sample size often is larger and selected randomly. Study IV's sample strategies can be described as criterion sampling (Patton, 2002). Criterion sampling means picking all the cases that comply with some criterion, in this case exposed and experienced volleyball players. Although the participants in Study IV were all playing in the same team, they were thought to create dissimilarity in the data since they all had different tasks and roles to play within the team. Further, Study IV only addresses women's experiences and, when it comes to strength training, we do not know whether the result would have been different if we had investigated men as well.

**Assessing validity in qualitative studies**

Another issue of concern in Study IV is that the first author that took part in the analysis was involved in the intervention study as the physical coach. This might be a potential source of bias. Ideally, the analysts should not be involved in the participant intervention, if this is the context that is being investigated. However, the literature emphasises that it is not possible to be completely free of bias (Strauss & Corbin, 1998). In addition, insight, expertise and experience in a research field are thought to provide a broader understanding of the phenomena and multiple meanings are always present in data (Downe-Wamboldt, 1992). In Study IV, to obtain trustworthiness, we decided to read the interviews separately and then seek agreement in the research group (Graneheim & Lundman, 2004). We also selected representative quotations from the transcribed text. One of the strengths of Study IV is that the participants were interviewed a relatively short time, within three weeks, after the intervention. Since the participants were interviewed retrospectively, it is important that the interviews were carried out shortly after the intervention to avoid loss of recollections.

## Conclusions

- One in every two elite volleyball players incur an injury during a season, which indicates that the risk of suffering an injury in elite volleyball is relatively high. Most injuries do not, however, keep the players away from training or game play for more than a short period of time (≤one week). The ankles, knees and back are the most frequently injured regions.

- Most elite volleyball players take part in some kind of preventive action, especially strength training. The level of supervision in these preventive programmes is, however, relatively limited (58% without supervision).

- Sit-ups and push-ups are tests with high test-retest reliability. They are easy to perform and, furthermore, require no special equipment and may therefore be recommended for clinical use. Women do not appear to differ from men in the local endurance or power of the abdominal muscles. Since one of the key risk factors for work-related injuries, as well as training injuries, appears to be inadequate physical fitness (Bell et al., 2000; Kraemer et al., 2001), the results of the push-up test (that men are twice as strong as women in the upper body when it comes to both local muscular endurance and power) suggest that more attention should be paid to upper-body training in women.

- Female volleyball players can improve their strength and power during a competition season by implementing a well-designed resistance-training programme. Both the individualisation and supervision of resistance training appear to produce greater training adherence and strength gains when compared with non-individualised, unsupervised training.

- From the female team athlete's perspective, the willingness to perform strength training is dependent on many factors, such as mental condition, team spirit, individual goal-setting, physical pain and a good relationship with the coach, which also appears to be important for the athlete's compliance. Strength training, on the one hand, might be used to improve self-esteem among young females. On the other hand, when designing strength-training intervention studies, it is important to be aware of the fear and feeling of uncertainty that can exist among the participants. Consequently, more attention should be focused on the coach's ability when it comes to improving confidence among the players and compliance with the prevention programme.

## Clinical relevance

It is important that strength and conditioning, as well as injury-prevention programmes, are effective in team sports. Because of the demanding practice and play schedule, the programmes should be short and concise to best avoid overtraining and to enhance compliance. For this reason, we suggest that the strength and conditioning programme should be intertwined with the injury-prevention programme. The programme should focus on a small number of carefully individualised, goal-oriented exercises. Further, when designing training programmes in sports, the injury profile for the individual athlete should be defined, as well as the athlete's physical strengths and weaknesses. It might also be important to be able to assess the individual athlete's mental status to provide optimal coaching. One important factor for a sports team to be successful is therefore a well-educated, professional coach who is both injury and performance oriented. This means that the coach has to be able to carry out performance testing and injury screening/registration, design training programmes and have the ability to optimise the motivational climate for the athlete. Designing studies of individually based training programmes is therefore difficult and requires knowledge in many areas, including designing programmes (e.g. correct manipulation of programme variables). Studies with individually set programmes are difficult to reproduce, since all the players have different problem areas. However, it is important to remember that the reproducibility is not only a problem when designing studies of individually set programmes. No training studies can be reproduced exactly, as subjects do not improve at the same rate even though they perform the same protocol. Further, since humans are complex beings, it is not possible to control every factor within the subject. Because of this, even when it comes to basic programme variables (i.e. intensity, volume and frequency), it is still impossible today to give a clear-cut prescription based on research. Nutrition, sleep and current mental state are some of the other issues that could contribute to the erroneous prescription of muscle actions, intensity, volume, exercise selection and order, rest periods between sets and frequency, for example. In all kinds of science involving humans, we therefore need to share our results in a humble, scholarly manner.

## The future

In the future, it seems vital to continue to develop well-designed studies in which theoretical knowledge is combined with practical application. It is important to see how we can better design comprehensive training intervention studies, for example. How can we design high-quality training intervention studies and still achieve the quantitative statistical power to generalise our studies? Although seldom discussed, it may actually be that what small sample-sized training intervention studies lack in quantity may be counterbalanced by higher quality, i.e. better compliance, more placebo effect, a higher level of know-how supervision and so on. To obtain the benefits of a small study and still have a large sample size, a multicentre study in which several small research groups perform the same intervention might therefore be a possibility. Further, in the future, it will be necessary to find a way to design studies of high quality that examine strength and conditioning programmes, as well as injury-prevention actions, on an individual basis. In team sports, one approach would be to target the most exposed players only when investigating the effect of preventive action. For example, it would probably be wise to select only front players in volleyball when investigating the effects of preventive action on “jumper’s knee”, since these are the players who run the greatest risk of suffering this particular injury. By pinpointing both the players at risk and the preventive action, it would probably be less difficult to detect the effects of the injury-prevention programme. Further, we would probably not need quite the same sample sizes as if all the players were included.

Finally, although we need to be humble when it comes to what we think we know about strength training and injury prevention in sports, there is every reason to feel proud of what we have achieved so far.

## Summary in Swedish

Syftet med denna avhandling var att få ökad kunskap om individualiserad och övervakad styrketräning som prestationshöjande och skadeförebyggande åtgärder inom idrotten.

Det finns studier som pekar på att träningsprogram, med syfte att förbättra fysisk prestationsförmåga och förebygga skador, bör vara individualiserade och övervakade. Trots detta saknas ofta individualiserade och övervakade träningsprogram i idrottsvetenskapliga undersökningar på atleter inom lagidrotter. Enligt vår kännedom finns inga tidigare publicerade studier som undersöker effekten av övervakad och individualiserad styrketräning under en säsong hos unga kvinnliga lagidrottare.

Innan ett styrketräningsprogram införs i syfte för att förbättra fysisk prestationsförmåga och förebygga skador, bör omfattning av skadeproblematiken definieras. Eftersom volleyboll är en liten idrott i Sverige, med mindre ekonomiska resurser än många andra länder, kan vi inte förutsäga att svenska volleybollspelare har samma skadepanorama som rapporterats från andra länder. Det är oklart i vilken omfattning skadeförebyggande träning bedrivs inom volleyboll i Sverige. Enligt vår kännedom finns det inga tidigare studier som har registrerat skador och skadeförebyggande åtgärder hos svenska volleybollspelare.
För att erhålla utgångsstatus hos idrottaren och för att optimera progression i ett styrketräningsprogram är det viktigt att testa fysisk prestationsförmåga. Trots att armhävningar och sit-ups är ibland de vanligaste övningarna för att förbättra och utvärdera fysisk prestationsförmåga saknas det idag reproducerbara testprotokoll med god reliabilitet.
Det är generellt vedertaget att en fystränare har en viktig roll för att förbättra idrottarens prestationsförmåga, men det saknas enligt vår kännedom studier som undersöker idrottarens egen upplevelse av ett individualiserat och övervakat styrketräningsprogram och fystränarens närvaro.

**Studie I:** Syftet med delarbete I var att kartlägga och analysera uppkomst och frekvens av skador hos volleybollspelare på elitnivå, samt att beskriva i vilken omfattning och form skadeförebyggande träning bedrivs.
**Metod:** Studien genomfördes som en retrospektiv enkätundersökning av samtliga manliga respektive kvinnliga svenska elitserielag under säsongen 2002-2003. Etthundrafemtioåtta (70%) volleybollspelare (medelålder 25 ±4) returnerade enkäten. Enkäten bestod av 19 frågor, uppdelad i två delar. I del 1 fick spelaren uppge lagnamn, födelseår, längd och vikt, hur många år han/hon spelat volleyboll, hur många tillfällen i veckan han/hon tränade, om spelaren bedrev någon form av skadeförebyggande träning och om denna bedrevs

övervakad. I del 2 besvarades frågor rörande tidpunkt för skada, typ av skada, vilken kroppsdel som skadats, spelsituation och spelarens position vid skadetillfället. Vidare bestod enkäten av frågor gällande om match och träning kunnat fullföljas efter skadan.
**Resultat:** Under 24632 timmars exponeringstid, ådrog sig 82 spelare (52%) 121 skador. Frekvensen av skador var 0,77 skador per spelare (0,86 för kvinnor och 0,68 för män). Majoriteten av skador var lokaliserade till fotled (23%), knä (17%) och rygg (16%). De flesta skador (62%) klassificerades som lätta i svårighetsgrad. Fyrtiosju procent av skadorna inträffade under träning och 41% uppstod successivt. Femtiofyra procent av de skador som kunde relateras till en specifik spelarposition inträffade under block och 30% under spike. De flesta spelarna (96%) deltog i någon form av skadeförebyggande träning, mestadels utförd på egen hand (58%). Fyrtioen procent av spelarna tränade andra aktiviteter som inte var relaterade till volleyboll.
**Slutsats:** Trots att de flesta volleybollspelare utförde skadeförebyggande träning var risken att drabbas av en skada i volleyboll relativt hög (>50%).

**Studie II:** Syftet med delarbete II var att utvärdera test-retest reliabiliteten för sit-ups och armhävningar och att undersöka skillnaden mellan yngre kvinnor och män avseende muskulär uthållighet (maximalt antal repetitioner) och explosiv styrka (maximalt antal repetitioner efter 30 sekunder).
**Metod:** Tjugofem friska män och 38 friska kvinnor i åldrarna 18 till 35 år deltog i studien. Deltagarnas fysiska prestationsförmåga bedömdes med två olika test: sit-ups och armhävningar. Tretton kvinnor utförde testerna vid två tillfällen inom en vecka för att utvärdera test-retest reliabiliteten för de två testen. Maximalt antal repetitioner dokumenterades för att utvärdera muskulär uthållighet och antalet repetitioner under 30 sekunder dokumenterades för att utvärdera explosiv styrka.
**Resultat:** Test-retest reliabilitet för sit-ups- och armhävningstesterna visade ett mycket starkt samband (ICC 0,92-0,95). Ingen signifikant skillnad ($p=0,898$) noterades mellan kvinnor och män vid maximalt antal sit-ups (41 respektive 42 repetitioner), eller vid 30 sek testet för sit-ups (14 respektive 16 repetitioner). Männen utförde signifikant fler ($p<0,001$) armhävningar än kvinnorna vid testet av maximalt antal (17 respektive 39 repetitioner för kvinnor respektive män) samt vid 30 sek testet för armhävningar (13 respektive 30 repetitioner för kvinnor respektive män).
**Slutsats:** Sit-ups och armhävningar är tester med god reliabilitet som är enkla att utföra och kan rekommenderas för användning i kliniken för att utvärdera både muskulär uthållighet och explosiv styrka. Vidare utförde männen i studien mer än dubbelt så många armhävningar som kvinnorna medan antal repetitioner av sit-ups var den samma mellan könen.

**Studie III:** Syftet med delarbete III var att utvärdera effekten av ett 26 veckor individualiserat och övervakat styrketränings- och skadeförebyggandeprogram på prestationsförmågan hos unga kvinnliga volleybollspelare.
**Metod:** Unga kvinnliga volleybollspelare deltog i studien och genomförde styrketräning med antingen ett övervakat och individualiserat träningsprogram (experimentgrupp; n=10, medelålder 18±2) eller ett oövervakat och icke individualiserat träningsprogram (kontrollgrupp; n=17, medelålder 16±2). Studien genomfördes under säsongen 2006-2007 som ett baseline-år och 2007-2008 där den 26 veckors långa interventionen introduceras. Skador och närvaro noterades prospektivt, för varje enskild spelare, för all träning och matchtid under båda säsongerna. Deltagarnas fysiska prestationsförmåga testades vid två tillfällen med första testomgången i september 2007 och andra efter avslutad säsong 2008.
**Resultat:** Vid testtillfälle två hade spelarna i experimentgruppen förbättrat sin prestationsförmåga i knäböj, bänkpress, armhävningar och sit-ups signifikant mer ($p<0,05$) än spelarna i kontrollgruppen. Följsamheten var också högre hos experimentgruppen jämfört med kontrollgruppen.

**Studie IV:** Syftet med delarbete IV var att upptäcka och beskriva volleybollspelares upplevelse av ett individualiserat och övervakat styrketräningsprogram.
**Metod:** Nio deltagare (17-21 år) från experimentgruppen i delarbete III deltog i studien. För datainsamling genomfördes halvstrukturerade intervjuer vilka analyserades med kvalitativ konventionell innehållsanalys.
**Resultat:** Tre övergripande teman utkristalliserades vilka beskriver innehållet i texten: ”vara i en glädjefylld och avslappnande situation”, ”samspel mellan tränare och atlet”, ”mentala och fysiska prestationer”.

**Sammanfattning studier III och IV:**
Individualisering och övervakning verkar vara viktiga faktorer för följsamheten, styrkeutvecklingen och prestationsförmågan vid styrketräning. Likväl kan det finnas flera andra faktorer som kan påverka resultatet vid styrketräning. Från den kvinnliga idrottarens perspektiv verkar prestationsförmågan vid styrketräning framför allt vara beroende av: laganda, individuell målsättning och relationen mellan tränaren och idrottaren. När man skall utforma en interventionsstudie med styrketräning för unga kvinnliga idrottare, bör man dessutom vara medveten om rädslan och osäkerheten som kan finnas bland deltagarna. Studie IV väcker också nya tankar om att styrketräning kanske kan användas för att förbättra självkänslan och kroppsmedvetenheten hos unga kvinnor.

## Acknowledgements

I would like to express my sincere gratitude to everyone who has made this thesis possible.

**Ulla Svantesson**, PT, Associate Professor at the Institute of Neuroscience and Physiology, and my main supervisor, for initiating these studies and introducing me to the world of science. Thank you for your enthusiasm and encouragement and for believing in my capability to do this work.

**Jon Karlsson**, Professor and Head of the Department of Orthopaedics, for your generous support and for constructive and valuable comments on the study design and manuscripts. Thank you for sharing your great knowledge of research and for quick correspondence at any time of the day.

**Roland Thomeé**, PT, Associate Professor at the Department of Orthopaedics, for your involvement and generous help in trying to guide me in the field of science. Thank you for stimulating scientific discussions and for your constructive criticism.

**Carin Willén**, PT, PhD at the Institute of Neuroscience and Physiology, for your kind support, interesting scientific meetings and your guidance in the world of qualitative research.

**Bengt I Eriksson**, Professor at the Department of Orthopaedics, for your brilliance, great support and sharp analysis of my work. Despite your huge dedication to science, you still manage to have a positive and relaxed approach to life, which is (to me) impressive.

**Ellen Bersås**, co-author and dear friend. Thank you for introducing me to the art of volleyball and for all the good laughs during and after the PT education. Every morning at “coffee”, I think of you.

**Margareta Sahlberg**, co-author, for your encouragement and friendship and for interesting discussions about science and everyday life.

**Elin Magnusson Thomas**, co-author, for your friendship and kind support and many laughs during our combination of work and pregnancy.

**Mathias Wernbom**, co-worker at the Lundberg Laboratory, for sharing your ideas and great knowledge of strength training. Thank you for many interesting discussions and for the passion and hard work that went into our book.

**Alexander Gustavsson, Annelie Brorsson** and **Martin Bergqvist,** co-workers, for your excellence in muscle function tests. Thank you for your support and work at the Lundberg Laboratory.

**Maria Landén,** co-worker, for conducting the interviews with great enthusiasm.

All the **persons** who participated in the studies, especially those who trained so hard at the gym and for sharing their experiences.

**Jane Carlsson**, PT, Professor at the Institute of Neuroscience and Physiology, for your encouragement, constructive criticism and interest in my work and for many interesting discussions about science and training. Keep up the training spirit!

**Cecilia Elam-Edwén** and **Ingrid Klintberg-Hultenheim**, for your friendship and support. Thank you for sharing hard work, good dinners and wine and, Ingrid, for the morning swims in Gran Canaria.

**Lennart Svantesson** for welcoming me into your home, for friendly discussions and for being supportive to our research group.

All my other **colleagues** and **staff** at the Institute of Neuroscience and Physiology, for your kind support throughout these years. Special thanks to the **PhD students** (some of whom now have a PhD degree) for many interesting round-table discussions.

**Jeanette Kliger**, for your excellent revision of the English text.

**Björn Rydevik**, Professor at the Department of Orthopaedics, for giving me the opportunity to work at the Lundberg Laboratory.

**Karin Grävare Silbernagel**, **Karin Larsson** and **Eva Runesson,** colleagues at the Lundberg Laboratory, for your enthusiasm and kind support and for sharing your experience of science and daily life.

**Ann-Charlotte Bengtsson** and **Linda Johansson** for your great administration and assistance with practical matters throughout these years.

**Anneli Virenheim** and **Ulla-Britt Andreasson**, heads at Hälsans Hus, for the education in conditioning training and for giving me the opportunity to work with strength and conditioning programmes. You are such an inspiration when it comes to what life is really all about.

**Jessica, Malena** and **Aina**, former colleagues at Hälsans Hus, for kind support and many laughs during these years.
**Monica Sivertsson**, my dearest friend, for your endless support and for showing me what "friends" are all about. Thank you for the many laughs between Marabou chocolate and wine. I love you!

**Cecilia Kindell-Svanevik**, my dear friend, for your kind support and many interesting discussions about children, education and daily life.

**Lina Rundström** and **Tina Lungström,** for sharing your experience as PTs, great support, many laughs, for popping new ideas into my head, but most of all for being who you are and making me feel less of a stranger in this world.

**Jenny Wickford, Anna Behn, Linda Robertsson, Veronica Markusson**, for your kind support and for sharing your experience of daily life.

**Ulla Engelberg**, my mother-in-law, for your kind support and for the many hours of babysitting.

My parents, **Eva** and **Christer Ryman**, for your love and generous support throughout my life. I do believe that I'm the strongest woman on earth, although I have never really been able to lift a car. Thanks for making me a fighter. My sister **Anna** and brother **Erik**, for your kind support and many laughs throughout life. I love you all.

**Rasmus** and **Marcus,** my favourite boys, for welcoming me into your life. You mean so much to me and have brought so much joy into my life. I love you!

**Liv**, my adorable daughter, I am somewhat at a loss for words about you, except that I love you. Without you, I am nothing.

**Jesper Augustsson**, my beloved husband, partner in work and co-author, for endless support in science and daily life and for giving me the most important things in life. I love you!

**Financial support:**
This thesis has been supported by grants from the Swedish Centre for Research in Sports. The thesis has also been supported by grants from the Lundgrenska Foundations, the Royal Society of Arts and Science in Göteborg, the Västra Götaland (research and education) Research Fund, Johan and Jakob Söderbergs foundation, and the Adlerbert Assistance Fund.

# References


Aagaard H, Jørgensen U. Injuries in elite volleyball. Scand J Med Sci Sports 1996: 6: 228–232.

Aagaard H, Scavenius M, Jørgensen U. An epidemiological analysis of the injury pattern in indoor and in beach volleyball. Int J Sports Med 1997: 18: 217-221.

Abernethy P, Wilson G, Logan P. Strength and power assessment. Issues, controversies and challenges. Sports Med 1995: 19: 401-417.

Agel J, Palmieri-Smith RM, Dick R, Wojtys EM, Marshall SW. Descriptive epidemiology of collegiate women's volleyball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004. J Athl Train 2007: 42: 295-302.

Alricsson M, Werner S. The effect of pre-season dance training on physical indices and back pain in elite cross-country skiers: a prospective controlled intervention study. Br J Sports Med 2004: 38: 148-153.

American College of Sports Medicine. ACSM's guidelines to exercise testing and prescription, 8th ed. Baltimore, MD: Lippincott Williams & Wilkins, 2009a.

American College of Sports Medicine. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. Med Sci Sports Exerc 2009b: 41: 687-708.

Andersson E, Swärd L, Thorstensson A. Trunk muscle strength in athletes. Med Sci Sports Exerc 1988: 20: 587-593.

Andersson EA, Nilsson J, Ma Z, Thorstensson A. Abdominal and hip flexor muscle activation during various training exercises. Eur J Appl Physiol Occup Physiol 1997: 75: 115-123.

Arendt E, Dick R. Knee injury patterns among men and women in collegiate basketball and soccer: NCAA data and review of literature. Am J Sports Med 1995: 23: 694-701.

Árnason A, Andersen TE, Holme L, Engebretsen R, Bahr R. Prevention of hamstring strains in elite soccer: an intervention study. Scand J Med Sci Sports 2008: 18: 40-48.

Astorino TA, Tam PA, Rietschel JC, Johnson SM, Freedman TP. Changes in physical fitness parameters during a competitive field hockey season. J Strength Cond Res 2004: 18: 850-854.

Askling C, Karlsson J, Thorstensson A. Hamstring injury occurrence in elite soccer players after preseason resistance training with eccentric overload. Scand J Med Sci Sports 2003: 13: 244-250.

Augustsson J. Kinetic chain weight training, strength assessment, and functional performance testing. With reference to sports and rehabilitation, in Department of Orthopaedics, Institute of Surgical Science and Rehabilitation Medicine, Institute of Clinical Neuroscience, 2003. The Sahlgrenska Academy at Göteborg University: Gothenburg, Sweden.

Augustsson SR, Augustsson J, Thomeé R, Karlsson J, Eriksson B, Svantesson U. Performance enhancement following a strength and injury prevention programme: a 26-week individualized and supervised intervention in adolescent female volleyball players, unpublished observation, 2009.

Augustsson SR, Augustsson J, Thomeé R, Svantesson U. Injuries and preventive actions in elite Swedish volleyball. Scand J Med Sci Sports 2006: 16: 433-440.

Augustsson J, Esko A, Thomeé R, Svantesson U. Weigth training of the thigh muscles using closed vs. open kinetic chain exercises: a comparison of performance enhancement. J Orthop Sports Phys Ther 1998: 27: 3-8.

Bahr R, Bahr IA. Incidence of acute volleyball injuries: a prospective cohort study of injury mechanisms and risk factors. Scand J Med Sci Sports 1997: 73: 166-171.
Bahr R, Fossan B, Løken S, Engebretsen L. Surgical treatment compared with eccentric training for patellar tendinopathy (Jumper's Knee). A randomized, controlled trial. J Bone Joint Surg Am 2006: 88: 1689-1698.
Bahr R, Karlsen R, Lian Ø, Ovrebø RV. Incidence and mechanisms of acute ankle inversion injuries in volleyball. A retrospective cohort study. Am J Sports Med 1994: 22: 595-600.
Barber-Westin SD, Noyes FR, Galloway M. Jump-land characteristics and muscle strength development in young athletes: a gender comparison of 1140 athletes 9 to 17 years of age. Am J Sports Med 2006: 34: 375-384.
Barnes JL, Schilling BK, Falvo MJ, Weiss LW, Creasy AK, Fry AC. Relationship of jumping and agility performance in female volleyball athletes. J Strength Cond Res 2007: 21: 1192-1196.
Bell NS, Mangione TW, Hemenway D, Amoroso PJ, Jones BH. High injury rates among female army trainees: A function of gender? Am J Prev Med 2000: 18: 141-146.
Bellardini H, Henriksson A, Tonkonogi M. Motoriska tester och mätmetoder. In: Tester och mätmetoder. Stockholm: Sisu Idrottsböcker, 2009, pp 34-240.
Blackburn JR, Morrissey MC. The relationship between open and closed kinetic chain strength of the lower limb and jumping performance. J Orthop Sports Phys Ther 1998: 27: 430-435.
Bompa TO, Carrera MC. Peak conditioning for volleyball. In: Volleyball. Reeser JC. Bahr R. ed. Oxford: Blackwell Scientific, 2003, pp 29-44.
Briner, W.W, Kacmar, L. Common injuries in volleyball: Mechanisms of injury, prevention and rehabilitation. Sports Med 1997: 24: 65-71.
Campos G. E. R., Luecke T. J., Wendeln H. K., Toma K, Hagerman FC, Murray TF, Ragg KE, Ratamess NA, Kraemer WJ, Staron RS. Muscular adaptations in response to three different resistance-training regimens: specificity of repetition maximum training zones. Eur J Appl Physiol 2002: 88: 50-60.
Cates W, Cavanaugh J. Advances in rehabilitation and performance testing. Clin Sports Med 2009: 28: 63-76.
Christou M, Smilios I, Sotiropoulos K, Volaklis K, Pilianidis T, Tokmakidis SP. Effects of resistance training on the physical capacities of adolescent soccer players. J Strength Cond Res 2006: 20: 783-791.
Coleman SGS, Benham AS, Northcott SR. A three-dimensional cinematographical analysis of the volleyball spike. J Sports Sci 1993: 11: 295-302.
Coutts AJ, Murphy AJ, Dascombe BJ. Effect of direct supervision of a strength coach on measures of muscular strength and power in young rugby league players. J Strength Cond Res 2004: 18: 316–323.
Crespo M, Reid M. Motivation in tennis. Br J Sports Med 2007: 41: 769-772.
CSEP. Available at: http://www.csep.ca/English/view.asp?x=718. Accessed 16 August 2009.
Dane S, Can S, Gürsoy R, Ezirmik N. Sport injuries: relations to sex, sport, injured body region. Percept Mot Skills 2004: 98: 519-524.
Deschenes MR, Kraemer WJ: Performance and physiologic adaptations to resistance training. Am J Phys Med Rehabil 2002: 81: 3–16.
Downe-Wamboldt. Content analysis: method, applications and issues. Health Care Women Int 1992: 13: 313-321.
Duncan MJ, Woodfield L, al-Nakeeb Y. Anthropometric and physiological characteristics of junior elite volleyball players. Br J Sports Med 2006: 40: 649-651.

Eitzen I, Holm I, Risberg MA. Preoperative quadriceps strength is a significant predictor of knee function two years after anterior cruciate ligament reconstruction. Br J Sports Med 2009: 43: 371-376.
Elo S, Kyngäs H. The qualitative content analysis process. J Adv Nurs 2008: 62: 107-115.
Engebretsen AH, Myklebust G, Holme I, Engebretsen L, Bahr R. Prevention of injuries among male soccer players: a prospective, randomized intervention study targeting players with previous injuries or reduced function. Am J Sports Med 2008: 36: 1052-1060.
Eurofit. Handbook for the Eurofit tests of physical. Rome: Edigraf Editoriale Grafica; 1988.
Ferretti A, Puddu G, Mariani PP, Neri M. Jumper's knee: an epidemiological study of volleyball players. Phys Sportsmed 1984: 12: 97–106.
Fleck SJ, Kraemer WJ. Designing resistance training programs, 3rd ed. Champaign, IL: Human Kinetics, 2004.
Fleiss JL. Reliability of measurements. In: Fleiss JL. The design and analysis of clinical experiments. New York: John Wiley & Sons, 1986, pp 2-31.
Forthomme B, Croisier JL, Ciccarone G, Crielaard JM, Cloes M. Factors correlated with volleyball spike velocity. Am J Sports Med 2005: 33: 1513-1519.
Fredberg U, Bolvig L, Andersen NT. Prophylactic training in asymptomatic soccer players with ultrasonographic abnormalities in Achilles and patellar tendons: the Danish Super League Study. Am J Sports Med 2008: 36: 451-460.
Freeman S, Karpowicz A, Gray J, McGill S. Quantifying muscle patterns and spine load during various forms of the push-up. Med Sci Sports Exerc 2006: 38: 570-577.
Frohm A, Saartok T, Halvorsen K, Renström P. Eccentric treatment for patellar tendinopathy: a prospective randomised short-term pilot study of two rehabilitation protocols. Br J Sports Med 2007: 41: e7.
Fry AC. The role of resistance exercise intensity on muscle fibre adaptations. Sports Med 2004: 34: 663-679.
Fry AC, Newton RU. A brief history of strength training and basic principles and concepts. In: Strength training for sports. Kraemer WJ, Häkkinen K, ed. Oxford: Blackwell Scientific, 2002, pp 1-19.
Gabbett T, Georgieff B. Physiological and anthropometric characteristics of Australian junior national, state, and novice volleyball players. J Strength Cond Res 2007: 21: 902-908.
Gabbett TJ, Johns J, Riemann M. Performance changes following training in junior rugby league players. J Strength Cond Res 2008: 22: 910-917.
Gilchrist J, Mandelbaum BR, Melancon H, Ryan GW, Silvers HJ, Griffin LY, Watanabe DS, Dick RW, Dvorak J. A randomized controlled trial to prevent noncontact anterior cruciate ligament injury in female collegiate soccer players. Am J Sports Med 2008: 36: 1476-1483.
Gorostiaga EM, Granados C, Ibañez J, González-Badillo JJ, Izquierdo M. Effects of an entire season on physical fitness changes in elite male handball players. Med Sci Sports Exerc 2006: 38: 357-366.
Gorostiaga EM, Granados C, Ibáñez J, Izquierdo M. Differences in physical fitness and throwing velocity among elite and amateur male handball players. Int J Sports Med 2005: 26: 225-232.
Granados C, Izquierdo M, Ibáñez J, Ruesta M, Gorostiaga EM. Effects of an entire season on physical fitness in elite female handball players. Med Sci Sports Exerc 2008: 40: 351-361.

Graneheim UH, Lundman B. Qualitative content analysis in nursing research: concepts, procedures and measures to achieve trustworthiness. Nurse Educ Today 2004: 24: 105-112.
Gwinn DE, Wilckens JH, McDevitt ER, Ross G, Kao TC. The relative incidence of anterior cruciate ligament injury in men and women at the United States Naval Academy. Am J Sports Med 2000: 28: 98-102.
Haff G. Roundtable Discussion: Periodization of Training. Part 2. National Strength and Conditioning Association 2004: 26: 56-70.
Harringe ML, Renström P, Werner S. Injury incidence, mechanism and diagnosis in top-level teamgym: a prospective study conducted over one season. Scand J Med Sci Sports 2007: 17: 115-119.
Heijne A, Axelsson K, Werner S, Biguet G. Rehabilitation and recovery after anterior cruciate ligament reconstruction: patients' experiences. Scand J Med Sci Sports 2008: 18: 325-335.
Hetu FE, Christie CA, Faigenbaum AD. Effects of conditioning on physical fitness and club head speed in mature golfers. Percept Mot Skills 1998: 86: 811-815.
Hewett TE, Myer GD, Ford KR. Reducing knee and anterior cruciate ligament injuries among female athletes: a systematic review of neuromuscular training interventions. J Knee Surg 2005: 18: 82-88.
Hoff J, Gran A, Helgerud J. Maximal strength training improves aerobic endurance performance. Scand J Med Sci Sports 2002: 12: 288-295.
Hoff J, Helgerud J, Wisløff U. Maximal strength training improves work economy in trained female cross-country skiers. Med Sci Sports Exerc 1999: 31: 870-877.
Hoffman JR, Ratamess NA, Klatt M, Faigenbaum AD, Ross RE, Tranchina NM, McCurley RC, Kang J, Kraemer WJ. Comparison between different off-season resistance training programs in Division III American college football players. J Strength Cond Res 2009: 23: 11-19.
Howarth SJ, Beach TA, Callaghan JP. Abdominal muscles dominate contributions to vertebral joint stiffness during the push-up. J Appl Biomech 2008: 24: 130-139.
Hägglund M, Waldén M, Ekstrand J. Injury incidence and distribution in elite football--a prospective study of the Danish and the Swedish top divisions. Scand J Med Sci Sports 2005: 15: 21-28.
Hägglund M, Waldén M, Ekstrand J. Injuries among male and female elite football players. Scand J Med Sci Sports 2008: 13. [Epub ahead of print].
Iwamoto J, Takeda T, Sato Y, Matsumoto H. Retrospective case evaluation of gender differences in sports injuries in a Japanese sports medicine clinic. Gend Med 2008: 5: 405-414.
Jones M, Stratton G, Reilly T, Unnithan V. The efficacy of exercise as an intervention to treat recurrent nonspecific low back pain in adolescents. Pediatr Exerc Sci 2007: 19: 349-359.
Jung AP. The impact of resistance training on distance running performance. Sports Med 2003: 33: 539-552.
Kaminski TW, Buckley BD, Powers ME, Hubbard TJ, Ortiz C. Effect of strength and proprioception training on eversion to inversion strength ratios in subjects with unilateral functional ankle instability. Br J Sports Med 2003: 37: 410-415.
Kannus P. Isokinetic evaluation of muscular performance: implications for muscle testing and rehabilitation. Int J Sports Med 1994: 15: 11-18.
Karst GM, Willett GM. Effects of specific exercise instructions on abdominal muscle activity during trunk curl exercises. J Orthop Sports Phys Ther 2004: 34: 4-12.

Kovacs MS, Pritchett R, Wickwire PJ, Green JM, Bishop P. Physical performance changes after unsupervised training during the autumn/spring semester break in competitive tennis players. Br J Sports Med 2007: 41: 705-710.
Kraemer WJ, Häkkinen K. Preface. In: Strength training for sports. Kraemer WJ, Häkkinen K, ed. Oxford: Blackwell Scientific, 2002.
Kraemer WJ, Mazzetti SA, Nindl BC, Gotshalk LA, Volek JS, Bush JA, Marx JO, Dohi K, Gómez AL, Miles M, Fleck SJ, Newton RU, Häkkinen K. Effect of resistance training on women's strength/power and occupational performances. Med Sci Sports Exerc 2001: 33: 1011-1025.
Kraemer WJ, Ratamess N, Fry NC, Triplett-McBride T, Koziris LP, Bauer JA, Lynch JM, Fleck SJ. Influence of resistance training volume and periodization on physiological and performance adaptations in collegiate women tennis players. Am J Sports Med 2000: 28: 626-633.
Kraemer WJ, Ratamess NA, French DN. Resistance training for health and performance. Curr Sports Med Rep 2002: 1: 165-171.
Kraemer WJ, Ratamess NA. Fundamentals of resistance training: progression and exercise prescription. Med Sci Sports Exerc 2004: 36: 674-688.
Kugler A, Kruger-Franke M, Reininger S, Trouillier HH, Rosemeyer B. Muscular imbalance and shoulder pain in volleyball attackers. Br J Sports Med 1996: 30: 256-259.
Lanese RR, Strauss RH, Leizman DJ, Rotondi AM. Injury and disability in matched men's and women's intercollegiate sports. Am J Public Health 1990: 80: 1459-1462.
Laughlin NT, Busk PL. Relationships between selected muscle endurance tasks and gender. J Strength Cond Res 2007: 21: 400-404.
Lear LJ, Gross MT. An electromyographical analysis of the scapular stabilizing synergists during a push-up progression. J Orthop Sports Phys Ther 1998: 28: 146-157.
Lees A, Nolan L. The biomechanics of soccer: a review. J Sports Sci 1998: 16: 211-234.
Les Mills™ Group Fitness System. Available at http://www.lesmills.com. Accessed 24 July 2007.
Leyk D, Rohde U, Gorges W, Ridder D, Wunderlich M, Dinklage C, Sievert A, Rüther T, Essfeld D. Physical performance, body weight and BMI of young adults in Germany 2000-2004: Results of the physical-fitness-test study. Int J Sports Med 2006: 27: 642-647.
Lian OB, Engebretsen L, Bahr R. Prevalence of jumper's knee among elite athletes from different sports: a cross-sectional study. Am J Sports Med 2005: 33: 561-567.
Lian Ø, Refsnes PE, Engebretsen L, Bahr R. Performance characteristics of volleyball players with patellar tendinopathy. Am J Sports Med 2003: 31: 408-413.
Lombardi I Jr, Magri AG, Fleury AM, Da Silva AC, Natour J. Progressive resistance training in patients with shoulder impingement syndrome: a randomized controlled trial. Arthritis Rheum 2008: 15: 59: 615-622.
Malliou PC, Giannakopoulos K, Beneka AG, Gioftsidou A, Godolias G. Effective ways of restoring muscular imbalances of the rotator cuff muscle group: A comparative study of various training methods. Br J Sports Med 2004: 38: 766-772.
Marques MC, Tillaar R, Vescovi JD, González-Badillo JJ. Changes in strength and power performance in elite senior female professional volleyball players during the in-season: a case study. J Strength Cond Res 2008: 22: 1147-1155.
Marques MC, van den Tilaar R, Vescovi JD, Gonzalez-Badillo JJ. Relationship between throwing velocity, muscle power, and bar velocity during bench press in elite handball players. Int J Sports Physiol Perform 2007: 2: 414-422.

Mazzetti S, Kraemer W, Volek J, Duncan N, Ratamess N, Gómez A, Newton R, Häkkinen K, Fleck S. The influence of direct supervision of resistance training on strength performance. Med Sci Sports Exerc 2000: 32: 1175-1184.
Melrose DR, Spaniol FJ, Bohling ME, Bonnette RA. Physiological and performance characteristics of adolescent club volleyball players. J Strength Cond Res 2007: 21: 481-486.
Mountcastle SB, Posner M, Kragh JF Jr, Taylor DC. Gender differences in anterior cruciate ligament injury vary with activity: epidemiology of anterior cruciate ligament injuries in a young, athletic population. Am J Sports Med 2007: 35: 1635-1642.
Myer GD, Chu DA, Brent JL, Hewett TE. Trunk and hip control neuromuscular training for the prevention of knee joint injury. Clin Sports Med 2008: 27: 425-448.
Myer GD, Ford KR, Palumbo JP, Hewett TE. Neuromuscular training improves performance and lower-extremity biomechanics in female athletes. J Strength Cond Res 2005: 19: 51-60.
Myklebust G, Maehlum S, Holm I, Bahr R. A prospective cohort study of anterior cruciate ligament injuries in elite Norwegian team handball. Scand J Med Sci Sports 1998: 8: 149-153.
Nicholls, J. G. The competitive ethos and democratic education. Cambridge, MA: Harvard University Press, 1989.
Niederbracht Y, Shim AL, Sloniger MA, Paternostro-Bayles M, Short TH. Effects of a shoulder injury prevention strength training program on eccentric external rotator muscle strength and glenohumeral joint imbalance in female overhead activity athletes. J Strength Cond Res 2008: 22: 140-145.
Nuzzo JL, McBride JM, Cormie P, McCaulley GO. Relationship between countermovement jump performance and multijoint isometric and dynamic tests of strength. J Strength Cond Res 2008: 22: 699-707.
Olsen OE, Myklebust G, Engebretsen L, Holme I, Bahr R. Exercises to prevent lower limb injuries in youth sports: cluster randomised controlled trial. Br J Sports Med 2005: 26: 330(7489):449.
Parkkari J, Kujala UM, Kannus P. Is it Possible to prevent sports injuries? Review of controlled clinical trials and recommendations for future work. Sports Med 2001: 31: 985-995.
Patton MQ. Qualitative Research & Evaluation Methods. (3rd ed.), London: Sage Publications, 2002.
Peterson MD, Rhea MR, Alvar BA. Applications of the dose-response for muscular strength development: a review of meta-analytic efficacy and reliability for designing training prescription. J Strength Cond Res 2005: 19: 950-958.
Pfeifer K, Banzer W. Motor performance in different dynamic tests in knee rehabilitation. Scand J Med Sci Sports 1999: 9: 19-27.
Prokopy MP, Ingersoll CD, Nordenschild E, Katch FI, Gaesser GA, Weltman A. Closed-kinetic chain upper-body training improves throwing performance of NCAA Division I softball players. J Strength Cond Res 2008: 22: 1790-1798.
Quarrie KL, Alsop JC, Waller AE, Bird YN, Marshall SW, Chalmers DJ. The New Zealand rugby injury and performance project. VI. A prospective cohort study of risk factors for injury in rugby union football. Br J Sports Med 2001: 35: 157-166.
Reeser JC. Introducution: a brief history of the sport of volleyball. In: Volleyball. Reeser JC. Bahr R. ed. Oxford: Blackwell Scientific, 2003, pp 1-7.
Reeser JC, Verhagen E, Briner WW, Askeland TI, Bahr R. Strategies for the prevention of volleyball related injuries. Br J Sports Med 2006: 40: 594-600.

Riksidrottsförbundet. Availble at: http://www.rf.se/templates/Pages/InformationPage____610.aspx. Accessed 16 May 2009.
Rousanoglou EN, Georgiadis GV, Boudolos KD. Muscular strength and jumping performance relationships in young women athletes. J Strength Cond Res 2008: 22: 1375-1378.
Sallis RE, Jones K, Sunshine S, Smith G, Simon L. Comparing sports injuries in men and women. Int J Sports Med 2001: 22: 420-423.
Santos EJ, Janeira MA. Effects of complex training on explosive strength in adolescent male basketball players. J Strength Cond Res 2008: 22: 903-909.
Schafle MD. Common injuries in volleyball. Treatment, prevention and rehabilitation. Sports Med 1993: 16: 126-129.
Sheppard JM, Cronin JB, Gabbett TJ, McGuigan MR, Etxebarria N, Newton RU. Relative importance of strength, power, and anthropometric measures to jump performance of elite volleyball players. J Strength Cond Res 2008: 22: 758-765.
Sinaki M, Nwaogwugwu NC, Phillips BE, MokriM. Effect of gender, age, and anthropometry on axial and appendicular muscle strength. Am J Phys Med Rehabil 2001: 80: 330-338.
Smith J, Krabak B. Tug of war: introduction to the sport and an epidemiological injury study among elite pullers. Scand J Med Sci Sports 2002: 12: 117-124.
Smith CE, Nyland J, Caudill P, Brosky J, Caborn DN. Dynamic trunk stabilization: a conceptual back injury prevention program for volleyball athletes. J Orthop Sports Phys Ther 2008: 38: 703-720.
Snellman K, Parkkari J, Kannus P, Leppälä J, Vuori I, Järvinen M. Sports injuries in floorball: a prospective one-year follow-up study. Int J Sports Med 2001: 22: 531-536.
Solgård L, Nielsen AB, Møller-Madsen B, Jacobsen BW, Yde J, Jensen J. Volleyball injuries presenting in casualty: a prospective study. Br J Sports Med 1995: 29: 200-204.
Soligard T, Myklebust G, Steffen K, Holme I, Silvers H, Bizzini M, Junge A, Dvorak J, Bahr R, Andersen TE. Comprehensive warm-up programme to prevent injuries in young female footballers: cluster randomised controlled trial. Br J Sports Med 2008: 9: 337: a2469.
Stanganelli LC, Dourado AC, Oncken P, Mançan S, da Costa SC. Adaptations on jump capacity in Brazilian volleyball players prior to the under-19 World Championship. J Strength Cond Res 2008: 22: 741-749.
Stanish HI, Wood TM, Campagna P. Prediction of performance on the RCMP physical ability requirement evaluation. J Occup Environ Med 1999: 41: 669-677.
Steffen K, Bakka HM, Myklebust G, Bahr R. Performance aspects of an injury prevention program: a ten-week intervention in adolescent female football players. Scand J Med Sci Sports 2008b: 18: 596-604.
Steffen K, Myklebust G, Olsen OE, Holme I, Bahr R. Preventing injuries in female youth football - a cluster-randomized controlled trial. Scand J Med Sci Sports 2008a: 18: 605-614.
Stickley CD, Hetzler RK, Freemyer BG, Kimura IF. Isokinetic Peak Torque Ratios and Shoulder Injury History in Adolescent Female Volleyball Athletes. J Athl Train 2008: 43: 571–577.
Strauss A, Corbin J. Basics of qualitative research (2nd ed.), London: Sage Publications, 1998.

Tagesson S. Dynamic knee stability after anterior cruciate ligament injury. Emphasis on rehabilitation, in Division of Physiotherapy, Department of Medical and Health Sciences, 2008. Linköping University, Linköping, Sweden.

Tagesson SK, Kvist J. Intra- and interrater reliability of the establishment of one repetition maximum on squat and seated knee extension. J Strength Cond Res 2007: 21: 801-807.

Thomson K, Watt A, Liukkonen J. Skill-related differences between athletes and nonathletes in speed discrimination. Percept Mot Skills 2008: 107: 893-900.

Tomkinson GR, Olds TS. Secular changes in pediatric aerobic fitness test performance: the global picture. Med Sport Sci 2007: 50: 46-66.

Toth AP, Cordasco FA. Anterior cruciate ligament injuries in the female athlete. J Gend Specif Med 2001: 4: 25-34.

Tsigilis N, Douda H, Tokmakidis SP. Test-retest reliability of the Eurofit test battery administered to university students. Percept Mot Skills 2002: 95: 1295-1300.

Van Mechelen W. Aetiology and prevention of running injuries [dissertation].Amsterdam: Free University of Amsterdam, 1992.

Verhagen EA, Van der Beek AJ, Bouter LM, Bahr RM, Van Mechelen W. A one season prospective cohort study of volleyball injuries. Br J Sports Med 2004: 38: 477-481.

Wedderkopp N, Kaltoft M, Lundgaard B, Rosendahl M, Froberg K. Prevention of injuries in young female players in European team handball. A prospective intervention study. Scand J Med Sci Sports 1999: 9: 41-47.

Wells L, Dyke JA, Albaugh J, Ganley T. Adolescent anterior cruciate ligament reconstruction: a retrospective analysis of quadriceps strength recovery and return to full activity after surgery. J Pediatr Orthop 2009: 29: 486-489.

Wernbom M, Augustsson J, Thomeé R. The influence of frequency, intensity, volume and mode of strength training on whole muscle cross-sectional area in humans. Sports Med 2007: 37: 225-264.

Wictor R. Lägg vikt på tyngden. Gefle Dagblad. 2008. Available at: http://gd.se/nyheter/halsa/1.369133. Accessed 1 June 2009.

Wilson GJ, Murphy AJ. The use of isometric tests of muscular function in athletic assessment. Sports Med 1996: 22: 19-37.

Wisløff U, Castagna C, Helgerud J, Jones R, Hoff J. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. Br J Sports Med 2004: 38: 285-288.

Young MA, Cook JL, Purdam CR, Kiss ZS, Alfredson H. Eccentric decline squat protocol offers superior results at 12 months compared with traditional eccentric protocol for patellar tendinopathy in volleyball players. Br J Sports Med 2005: 39: 102-105.

Özçakar L, Kunduracyoolu B, Cetin A, Ulkar B, Guner R, Hascelik Z. Comprehensive isokinetic knee measurements and quadriceps tendon evaluations in footballers for assessing functional performance. Br J Sports Med 2003: 37: 507-510.

**Appendix 1.** Summary of recent research measuring performance enhancement of maximal strength and muscular power following in season resistance training programmes in athletes.

| Reference | Gender | Sport | Study design | Study duration | Training frequency (times/week) | Intervention (Group 1) | Intervention (Group 2) | Outcome measurement | Results |
|---|---|---|---|---|---|---|---|---|---|
| Kramer et al., 2000 | Female | Collegiate tennis | Intervention Prospective, longitudinel, RCT | 9 months | 2-3 | Periodised, free weights and machines, 14 exercises, 6-15 reps *N*=8 | Single set Circuit,free weights and machines, 14 exercises 8-10 reps *N*=8 | Vertical jump, Ball velocity, 1RM BP, LP, free weight SP | Significant increase in vertical jump (53%) and ball velocity (30%) was observed after 9 months in group 1. Significant increase in 1RM BP (30%), SP (30%), and LP (45%) in group 1, (8%) in BP, (16%) in SP and (6%) in LP was observed in group 1. |
| Astorino et al., 2004 | Felame | Division III field hockey | Prospective | 1 year | 2-3 (pre-and inseason) | Periodised, free weights and machines, 17 exercises, 5-15 reps *N*=13 | | 1RM BP and LP | No significant change was observed during the season. However, the athletes were 10% stronger during pre- and inseason compared with postseason. |
| Coutts et al., 2004 | Male | Rugby | Intervention Prospective Longitudinel RCT | 12 weeks | 3 | Periodised supervised Free weights and machine 7 exercises 4-16 reps *N*=21 | Periodised non-supervised Free weights and machine 7 exercises 4-16 reps *N*=21 | Vertical jump, maximal chin-ups, 3RM BP and squat | Significant increase in vertical jump (10%), chin-ups (97%), 1RM BP (30%) and squat (40%) was observed in group 1. Significant increase in vertical jump (7%), chin-ups (46%), 1RM BP (15%) and squat (26%) was observed in group 2 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Gorostiaga et al., 2006 | Male | Elite Handball | Prospective, longitudinel | 45 weeks | 1-2 | Periodised, free weights and machines, 4-8 exercises, 3-10 reps *N*=15 | | Vertical jump, Ball velocity, 1RM conc BP, conc half squat | Significant increase in 1RM BP (1.9%) and ball velocity (6.5%). |
| Christou et al., 2006 | Male | Soccer | Intervention Prospective longitudinal RCT | 16 weeks | 2 | Strength-soccer Periodised, free weights and machines, 10 exercises, 8-15 reps *N*=9 | Soccer *N*=9 | Vertical jump, 1RM BP, LP | Significant increase in vertical jump (31%), 1RM BP (52%), and LP (59%) were noted in group 1. Significant and LP (34%) were noted in group 2. |
| Marques et al., 2008 | Female | Elite Volleyball | Intervention Prospective | 12 weeks | 2 | Periodised, free weights and unloaded explosive exercise, 4 exercises, 3-10 reps *N*=15 | | Vertical jump, overhead medicine ball throw, 4RM BP and squat | Significant increase in vertical jump (3.8%), medicine ball throw (11.8%), 4RM BP (15%), and squat (11.5%). |

Appendix 1 (continued)

Appendix 1 (continued)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Granados et al., 2008 | Female | Elite Handball | Prospective longitudinal | 45 weeks | 1-2 | Periodised, free weights and machines, 4-8 exercises, 3-10 reps *N*=16 | | Vertical jump, Ball velocity, 1RM conc BP, power-load parallell squat | Significant increase in vertical jump (12%), ball velocity (8%) 1RM BP (11%) and squat (13%). |
| Hoffman et al., 2009 | Male | Div III, American football | Intervention, Proscpective Longitudinell RCT | 15 weeks | 4 (off-season) | Linear periodised, free weights and machines, 18 exercises, 3-12 reps *N*=17 | Nonlinear periodised, free weights and machines, 18 exercises, 1-12 reps *N*=17 | Vertical jump, 1RM BP and squat, medicine ball throw | Significant increase in medicine ball throw (6%), 1RM BP (8-9%), and squat (11-21%). No differences between group1, 2 or control. |
| Augustsson et al., 2009 | Female | Div III volleyball | Intervention Prospective Longitudinel | 26 weeks | 1-2 | Periodised, supervised individualise d, free weights and machines, 10-30 exercises, 1-15 reps *N*=10 | Non period, non-sup, non-ind, free weights and machines, 10 exercises, 15 reps *N*=17 | Vertical jump, 30-sec sit-ups and push ups, 1RM BP and squat | Significant increase in vertical jump (8%), sit-ups (55%), push-ups (122%), 1RM BP (16%), and squat (67%) was observed in group 1. Significant increase in 1RM BP (6%) was observed in group 2. |

**Appendix 2.** Progression and individualisation during the resistance training period for each player in the experimental group presented by exercise, number of sets, repetitions and rest periods between sets. Phase 1 represents progression phase 1 (10 w) and phase 2 represents progression phase 2 (12 w).

| Exercise | Player 1 | | Player 2 | | Player 3 | |
|---|---|---|---|---|---|---|
| | Phase 1 | Phase 2 | Phase 1 | Phase 2 | Phase 1 | Phase 2 |
| Squats | 3x10, 2 min | 3x1-6, 3 min | 3x10, 2 min | 3x1-6, 3 min | 3x10, 2 min | 3x1-6, 3 min |
| Bench press | 3x10, 2 min* | 3x1-6, 3 min | 3x10, 2 min* | 3x1-6, 3 min | 3x10, 2 min* | 3x1-6, 3 min |
| Push-ups | 3xmax, 2 min* | 2xmax 1 min | 3xmax, 2 min* | 2xmax 1 min | 3xmax, 2 min* | 2xmax 1 min |
| Lat pulldown | 3x10, 1 min | 2x10, 1 min | 3x10, 1 min | 2x10, 1 min | 3x10, 1 min | 2x10, 1 min |
| Seated cable row | 2x10, 1 min | | 3x10, 1 min | 2x10, 1 min | 3x10, 1 min | 2x10, 1 min |
| Overhead dumbbell press | 3x10**, 2 min | 2x8, 2 min | 3x10**, 2 min | 2x8, 2 min | 3x10**, 2 min | 2x8, 2 min |
| Machine overhead press | 2x10**, 1 min | | | | 2x10**, 1 min | |
| Cable curl (biceps) | | | 3x10, 30 sec | | | |
| Overhead cable extension | | | 3x10, 30 sec | | | |
| Bodyweight back extension | 3x15*, 1 min | 3x15*, 1 min | 3x15*, 1 min | 3x15*, 1 min | 3x15*, 1 min | 3x15*, 1 min |
| Sit-ups | 3xmax*, 1 min | 3xmax*, 1 min | 3xmax*, 1 min | 3xmax*, 1 min | 3xmax*, 1 min | 3xmax*, 1 min |
| Machine crunch | | | | | | |
| Seated leg extension | 3x10, 1 min | | 3x10, 1 min | | 3x10, 1 min | 3x10, 1 min |
| Lying leg curl | | | | | 3x10, 1 min | 3x10, 1 min |
| Leg press | | | | | | |
| One-leg leg press | 2x10/leg, no rest | | | | 2x10/leg, no rest | |
| Machine seated calf raise | 3x10, 1 min | | | | | |
| Bodyweight one leg squat | 2x10, 30 sec | | 2x10, 30 sec | | 2x10, 30 sec | |
| One-arm seated row | 2x10/arm, no rest | 2x10/arm, no rest | | | | |
| Dumbbell row | 2x10/arm, no rest | | 2x10/arm, no rest | | | |
| Bent-over lateral raise | 3x10, 30 sec | 2x10, 30 sec | 3x10, 30 sec | 2x10, 30 sec | | |
| Hanging leg raise | | | 2x10, 30 sec | 3x15, 30 sec | | |
| E ball reverse back extension | | | 2x10, 1 min | 2x10, 1 min | | |
| E ball crunch | | | | | | |
| E ball jackknife | | | 2x10, 30 sec | 2x10, 30 sec | 2x10, 30 sec | 2x10, 30 sec |
| E Ball opposite arm and leg lift | | | 2x20, 1 min | | | |
| E ball prone walk out | 10, 5 sec | 10, 5 sec | | | 10, 5 sec | 10, 5 sec |
| Reverse crunch | | | 2x10, 30 sec | 2x10, 30 sec | | |
| Balance board jumping | 1x10 | 1x10 | | | | |
| Barbell vertical jumps | 1x10 | 2x10, 2 min | 1x10 | 2x10, 2 min | 1x10 | 2x10, 2 min |

* Exercises that were performed in supersets.

** Exercises that were alternated every second training session.

Appendix 2 (continued)

| Exercise | Player 4 | | Player 5 | | Player 6 | |
|---|---|---|---|---|---|---|
| | Phase 1 | Phase 2 | Phase 1 | Phase 2 | Phase 1 | Phase 2 |
| Squats | 3x10, 2 min | 3x1-6, 3 min | 3x10, 2 min | 3x1-6, 3 min | 3x10, 2 min | 3x1-6, 3 min |
| Bench press | 3x10, 2 min* | 3x1-6, 3 min | 3x10, 2 min* | 3x1-6, 3 min | 3x10, 2 min* | 3x1-6, 3 min |
| Push-ups | 3xmax, 2 min* | 2xmax 1 min | 3xmax, 2 min* | 2xmax 1 min | 3xmax, 2 min* | 2xmax 1 min |
| Lat pulldown | 3x10, 1 min | 2x10, 1 min | 3x10, 1 min | 2x10, 1 min | 3x10, 1 min | 2x10, 1 min |
| Seated cable row | 3x10, 1 min | 2x10, 1 min | 2x10, 1 min | | 2x10, 1 min | |
| Overhead dumbbell press | 3x10**, 2 min | 2x8, 2 min | 3x10**, 2 min | 2x8, 2 min | 3x10, 2 min | 2x8, 2 min |
| Machine overhead press | 2x10**, 1 min | | 2x10**, 1 min | | | |
| Cable curl (biceps) | | | | | | |
| Overhead cable extension | | | | | | |
| Bodyweight back extension | 3x15*, 1 min | 3x15*, 1 min | 3x15*, 1 min | 3x15* | 3x15*, 1 min | 3x15*, 1 min |
| Sit-ups | 3xmax*, 1 min | 3xmax*, 1 min | 3xmax*, 1 min | 3xmax*, 1 min | 3xmax*, 1 min | 3xmax*, 1 min |
| Machine crunch | 3x15 | 2x15 | | | | |
| Seated leg extension | | | 3x10, 1 min | | | |
| Lying leg curl | | | 3x10, 1 min | 3x10, 1 min | | |
| Leg press | 3x10, 1 min | 2x10, 1 min | | | 3x10, 1 min | 2x10, 1 min |
| One-leg leg press | | | 2x10/leg, no rest | | | |
| Machine seated calf raise | | | 3x10, 1 min | | | |
| Bodyweight one leg squat | | | 2x10, 30 sec | | 2x10, 30 sec | |
| One-arm seated row | | | | | | |
| Dumbbell row | | | | | | |
| Bent-over lateral raise | 3x10, 30 sec | 2x10, 30 sec | | | 3x10, 30 sec | 2x10, 30 sec |
| Hanging leg raise | 2x10, 30 sec | 3x15, 30 sec | | | 2x10, 30 sec | 3x15, 30 sec |
| E ball reverse back extension | | | 2x10, 1 min | 2x10, 1 min | | |
| E ball crunch | | | | | | |
| E ball jackknife | | | 2x10, 30 sec | 2x10, 30 sec | | |
| E Ball opposite arm and leg lift | | | | | | |
| E ball prone walk out | | | 10, 5 sec | 10, 5 sec | | |
| Reverse crunch | | | | | | |
| Balance board jumping | | | 1x10 | 1x10 | | |
| Barbell vertical jumps | 1x10 | 2x10, 2 min | 1x10 | 2x10, 2 min | 1x10 | 2x10, 2 min |

* Exercises that were performed in supersets.
** Exercises that were alternated every second training session.

Appendix 2 (continued)

| Exercise | Player 7 | | Player 8 | | Player 9 | | Player 10 | |
|---|---|---|---|---|---|---|---|---|
| | Phase 1 | Phase 2 | Phase 1 | Phase 2 | Phase 1 | Phase 2 | Phase 1 | Phase 2 |
| Squats | 3x10, 2 min | 3x1-6, 3 min | 3x10, 2 min | 3x1-6, 3 min | 3x10, 2 min | 3x1-6, 3 min | 3x10, 2 min | 3x1-6, 3 min |
| Bench press | 3x10, 2 min* | 3x1-6, 3 min | 3x10, 2 min* | 3x1-6, 3 min | 3x10, 2 min* | 3x1-6, 3 min | 3x10, 2 min* | 3x1-6, 3 min |
| Push-ups | 3xmax, 2 min* | 2xmax 1 min | 3xmax, 2 min* | 2xmax 1 min | 3xmax, 2 min* | 2xmax 1 min | 3xmax, 2 min* | 2xmax 1 min |
| Lat pulldown | 3x10, 1 min | 2x10, 1 min | 3x10, 1 min | 2x10, 1 min | 3x10, 1 min | 2x10, 1 min | 3x10, 1 min | 2x10, 1 min |
| Seated cable row | 3x10, 1 min | 2x10, 1 min | 3x10, 1 min | 2x10, 1 min | 3x10, 1 min | 2x10, 1 min | 3x10, 1 min | 2x10, 1 min |
| Overhead dumbbell press | 3x10, 2 min | 2x8, 2 min | | | 3x10, 2 min | 2x8, 2 min | 3x10**, 2 min | 2x8, 2 min |
| Machine overhead press | | | 2x10, 1 min | 3x10, 1 min | | | 2x10**, 1 min | |
| Cable curl (biceps) | | | | | 3x10, 30 sec | | | |
| Overhead cable extension | | | | | 3x10, 30 sec | | | |
| Bodyweight back extension | 3x15*, 1 min | 3x15*, 1 min | 3x15*, 1 min | 3x15*, 1 min | 3x15*, 1 min | 3x15*, 1 min | 3x15*, 1 min | 3x15*, 1 min |
| Sit-ups | 3xmax*, 1 min | 3xmax*, 1 min | 3xmax*, 1 min | 3xmax*, 1 min | 3xmax*, 1 min | 3xmax*, 1 min | 3xmax*, 1 min | 3xmax*, 1 min |
| Machine crunch | 3x15 | | | | | | | |
| Seated leg extension | | | | | 3x10, 1 min | 3x10, 1 min | 3x10, 1 min | |
| Lying leg curl | | | | | | | 3x10, 1 min | 3x10, 1 min |
| Leg press | 3x10, 1 min | 2x10, 1 min | 3x10, 1 min | 2x10, 1 min | | | | |
| One-leg leg press | | | 2x10/leg, no rest | | | | 2x10/leg, no rest | |
| Machine seated calf raise | | | | | | | 3x10, 1 min | |
| Bodyweight one leg squat | 2x10, 30 sec | | 2x10, 30 sec | | | | 2x10, 30 sec | |
| One-arm seated row | | | | | | | | |
| Dumbbell row | | | | | 2x10/arm, no rest | 2x10/arm, no rest | | |
| Bent-over lateral raise | 3x10, 30 sec | 2x10, 30 sec | | | | | | |
| Hanging leg raise | | | | | 2x10, 30 sec | 3x15, 30 sec | | |
| E ball reverse back extension | | | 2x10, 1 min | 2x10, 1 min | | | | |
| E ball crunch | 2x10 | 3x10 | | | | | | |
| E ball jackknife | | | | | | | | |
| E Ball opposite arm and leg lift | | | | | | | | |
| E ball prone walk out | | | 10, 5 sec | 10, 5 sec | | | 10, 5 sec | 10, 5 sec |
| Reverse crunch | | | | | 2x10, 30 sec | 2x10, 30 sec | | |
| Balance board jumping | | | | | | | | |
| Barbell vertical jumps | 1x10 | 2x10, 2 min | 1x10 | 2x10, 2 min | 1x10 | 2x10, 2 min | | |

* Exercises that were performed in supersets.

** Exercises that were alternated every second training session.