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**Traditional versus resisted sprint training in highly-trained, female team handball players:**

Effects on performance and muscle architecture

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## Preface

I'm grateful that I got the opportunity to write my master thesis at the Norwegian School of Sport Sciences, in a great environment with a lot of wonderful people, both students and employees. I've learned a lot during my studies, and maybe the most important thing I've learnt is that there is a lot that I don't know.

In the process of collecting data and writing the thesis I've had a lot of good help and support, and you all deserve my thanks:

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To my family and friends: I thank you for supporting me in school, in sports and in life in general.

To the population at the strength training room: thank you! It's always a relief to go down in the basement, and don't have to worry about anything else than to lift the bar.

To the reader: If you read this, you have at least read one of the pages in my thesis. Thank you!

Live S. Luteberget, Oslo, May 2014

## Abstract

Physical factors are an important aspect of handball, however, research regarding training methods for handball players are scarce. Resistance sprint training is a method often used to improve acceleration, an important factor for performance in handball. The purpose of this master thesis is to compare the effects of resistance sprint training (RST) against traditionally sprint training (TST) in semi-professional, female handball players on sprint performance, and to determine whether these effects are reflected in muscle architectural measurements.

A group of semi-professional female handball players (n=18) was assigned to either RST group (sled towing, with  $12.4 \pm 0.2$  % of body mass) or TST group matched on 10-m sprint performance. The participants completed two sprint sessions per week for 10 weeks. Sessions included 10-m and 20-m sprints, with a total sprint distance of 240-280 m per session, equal for both groups. Sprint tests (10-m and 30-m), vertical and horizontal jumps, 20-m shuttle run test and muscle architecture were performed pre- and post-training.

Beneficial effects were found in 30-m sprint test for both groups (TST= $-0.31 \pm 0.19$  s, RST= $-0.16 \pm 0.13$  s; mean $\pm 90\%$  CL). Only TST had a beneficial effect on 10-m time ( $-0.04 \pm 0.04$  s, ES=0.51). Pennation angle decreased for both groups ( $-6.0\% \pm 3.3$  ES: 0.38 for TST and  $-2.8\% \pm 2.0$  ES: 0.19 for RST), which had a nearly perfect correlation with percentage change in sprint performance ( $r=0.92$ ). A small increase in fascicle length ( $5.3 \pm 3.9\%$ , ES=0.26 and  $4.0 \pm 2.1\%$ , ES=0.46 for TST and RST, respectively) was also found. Both groups obtained a small beneficial effect for agility performance (TST:  $-1.7 \pm 1.9\%$ , ES=0.46 and RST:  $1.2 \pm 0.8\%$ , ES=0.28)

Sprint training was highly effective in enhancing short distance (10-30 m) sprints in female handball players, and TST appeared to be more effective than RST. A similar, yet small, effect of sprint training on muscle architecture was observed in both groups, possibly reflecting velocity-specific adaptation, present in concurrently training athletes.

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# 1. Introduction

Since handball was introduced in the Summer Olympic Games in 1972, the sport has grown, and has become more popular. Handball is now played in over 180 countries around the world (IHF, 2014). The sport is also played professional in many countries, especially in Europa. Handball consists of many different aspects, and performance in handball is dependent on many diverse attributes. Technical and tactical attributes are important factors, as well as psychological and social abilities. In addition, a handball athletes' performance depends directly on diverse physiological attributes, thus to fully exploit all technical/tactical qualities there is a need for superior physical conditioning.

As handball is a complex sport, there are many aspects of the individual athlete and the team as a whole that needs attention during the training process. This places an additional demand on coaches to streamline the training, so that the complexity of the game is reflected in the everyday training. Coaches thereby seek the most beneficial and effective training methods. On this basis it may be helpful to look at different training methods and their impacts for players. For sprint and acceleration training, resisted sprint training (RST) is a popular method that has been used in training and research settings. However, the beneficial effects of RST on sports performance are inconclusive (Hrysmallis, 2012), and further research into this type of training are required to provide a clearer overview on the specific effects on physical performance. In addition, the impact of sprint training on the architectural features of the muscles involved, is not well studied, although it is established a relationship between muscle architecture and sprint performance in cross sectional studies.

Based on this, the general aim of this thesis was to investigate the effect of a 10-week RST program compare to the effect of a 10-week traditional sprint training (TST) program in female handball players.

## **1.1 Purpose**

The purpose of this master thesis was to examine the effect of specific acceleration training on female handball players ability to perform sprints (0-30 m), agility efforts, jumps (vertically and horizontal) and handball specific endurance (20-MST), and also to investigate if there is a difference between acceleration training with additional load (resistance) and acceleration training without any additional load. Furthermore, muscle architectural measurements were undertaken, to determine whether any effects in performance changes are reflected in muscle architectural changes.

### **1.1.1 Research questions**

- 1) Does 10-weeks of specific RST or TST enhance performance in initial sprint speed (10-m), sprint (30-m), vertical and horizontal jumps and handball specific endurance?
- 2) Does thickness, pennation angle and fascicle length in *m. vastus lateralis* change due to a 10-week specific RST or TST program?
- 3) Is there a difference in the effects on the aforementioned variables of the RST and TST program?



## 2. Theory

### 2.1 *Handball match analysis*

Knowledge of the working demands of a sport is important for the planning and execution of optimal training. In handball the level of performance is determined by many different factors and physiological attributes are important factors, especially in high-level performance. Analysis of in-game movement profile of team-sport athletes has been an interest of many researchers and sports scientists since the early 1970's (Brooke & Knowles, 1974). The analysis of in-game movements can help estimate the working demands of the sport. Many team sports have been extensively studied, and especially soccer-matches are well described in the literature. However, the scientific knowledge of the working demands in team handball is limited, and specifically, the demands of female handball players are not well studied. Therefore, both studies of male and female handball players, in addition to other team sports, will be used to provide to overview of the physiological attributes important in handball.

Heart rate (HR) measurement is one of the most used methods to monitor the load of handball players during matches. Continuous recordings of HR during match play allow an analysis and estimate of the aerobic performance. Studies have reported mean HR between 75 – 91 % of maximal HR, with a large variation between players and positions. Peak HR has been reported as high as 95-98 % of maximal HR (Manchado et al., 2013;Manchado, Hoffmann, Valdivielso, & Platen, 2007; Michalsik, Madsen, & Aagaard, 2013; Michalsik, Aagaard, & Madsen, 2013; Póvoas et al., 2012; Póvoas et al., 2014).

Time motion analysis of handball players during games has shown considerable variation. The total distance covered during a match is reported to be from 3.3 – 4.4 km for men, with a large variation among players (Michalsik, Aagaard, et al., 2013; Póvoas et al., 2012, 2014). For women the range in total distance is reported to be from 2.0 km to 5.2 km (Michalsik, Madsen, et al., 2013; Manchado, Navarro-Valdivielso, Pers, & Platen, 2008). Specific playing position is shown to account for some of the variation in the total distance covered, specifically backcourt players were found to cover 15 % and 21 % more, respectively, than wings and pivots (Póvoas et al., 2014). Position-related demands might be a main contributor to the large variation displayed in total distance

covered, but also individual variation in conditioning capacities and their movement patterns not related to playing position should be acknowledged (Póvoas et al., 2014).

A review of 22 handball studies demonstrate that the average running pace in handball is relatively low ( $53 \pm 7$  to  $90 \pm 9$  m·min<sup>-1</sup>) compared to other team sports, such as rugby ( $89 \pm 4$  to  $95 \pm 7$  m·min<sup>-1</sup>) or basketball ( $115 \pm 9$  m·min<sup>-1</sup>) (Karcher & Buchheit, 2014). Most of the total distance covered is executed with low-intensity activity. For men, 56.2-73.1 % of the total distance covered was classified as walking or jogging (Michalsik, Aagaard, et al., 2013; Póvoas et al., 2012; Póvoas et al., 2014), and for women it is reported to be as high as 80.4 % (Michalsik, Madsen, et al., 2013). Only 0.2 % of the total distance covered for women and 1.5-3.9 % for men was classified as sprinting. Fast running accounted for approximately 6.0 – 16.0 % of the total distance for men, and 2.3 % for women. The large variation between studies of distance in the different locomotive categories might be due to the varying classification of the categories among different researchers. Thus, the higher the speed of sprint classification, the lower the distance is classified as sprint. In summary, the literature shows that the amount of high intensity running is low during match play in handball.

Distance covered and speed can be good indicators of the workload in a handball game, but the majority of movements in competition are high intensity micro-movements that are not easy to measure using video camera systems, which is the common method used in handball studies. High intensity movements have typically been recorded only at high running velocities, and thereby do not take into account all accelerations that occur at low speed. The estimation of an athletes' energy cost and metabolic power output when accelerating during a soccer match suggest that a maximal acceleration commencing from low velocity is a high-intensity task (Varley & Aughey, 2013). However, it would not be classified as such, in traditionally time-motion analysis. Research of soccer players show frequent maximal accelerations at low velocities during match play, and thereby proposes a substantial underestimation of the amount of high intensity actions during a match (Osgnach, Poser, Bernardini, Rinaldo, & di Prampero, 2010; Varley & Aughey, 2013). This may hold true for handball as well.

Due to the various movements of handball, it is difficult to measure these micro-movements with accuracy. In soccer, the number of high-intensity actions has been quantified using a tracking system, based on GPS-measurements and Inertial Movement

Analysis (IMA). IMA are measurements of triaxial movements, which are quantified in jumps, accelerations, decelerations or changes of direction. High intensity actions were defined as sprints ( $\geq 4.17 \text{ m}\cdot\text{s}^{-1}$ ) and accelerations ( $> 2.78 \text{ m}\cdot\text{s}^{-2}$ ), and the number of actions is reported to be high, ranging from 145 to 220 (Varley & Aughey, 2013). To my knowledge, only one study (Póvoas et al., 2014) has reported the number of such events in handball match play, although not with the use of a tracking system. The number of jumps was reported to be 10.4 per player on average, however, there was a large difference between playing positions, with backcourt players and pivots completing a high number of jumps (19.1 and 14.0 jumps, respectively) compared to wings (3.8 jumps). The number of changes of direction was reported to be 30.6 on average for each player. In addition, Póvoas et al. reported other high-intensity actions, including shots, stops (when preceded by high-intensity activities) and one-on-one situations. When combining all of these actions, it is evident that the players on average perform 98.8 high-intensity actions during one match (Póvoas et al., 2014). Pivot players, the playing position with the highest number of high-intensity actions per game, on average performed 128 actions. The data were attained by video analysis in this study and there are some methodical limitations to quantifying the intensity of these actions using this technique. However, this study does provide an indication that handball players perform a high number of high-intensity actions during match play. The number of accelerations was not reported, and to my knowledge, no data have been published in handball regarding this important variable. In soccer, the number of maximal accelerations ( $> 2.78 \text{ m}\cdot\text{s}^{-2}$ ) have been reported to be 56-90 in match play, differing from playing positions, with wide defenders doing the highest number of accelerations (Varley & Aughey, 2013).

### **2.1.1 Physical demands in handball**

In light of the match analysis available, researchers have tried to elucidate the physical demands of handball players. There seems to be good evidence to underpin a need for aerobic conditioning, due to HR-analysis. Michalsik et al. (2013) concluded that handball places a moderate-to-high demand on the players' aerobic energy production. It's also shown that athletes with a high level of aerobic capacity have an advantage during international handball competitions, as they can work on a lower percentage of their maximum aerobic capacity, and thereby be more likely to optimize handball-specific performance during the matches (Manchado et al., 2013). Even though

researchers acknowledge the importance of a functional aerobic capacity, it is also suggested that it is not a pivotal factor for performance, and that there might be a threshold for necessary levels of aerobic capacity (Manchado et al., 2013; Michalsik, Aagaard, et al., 2013). Other factors, such as strength, speed and acceleration are given a much greater role in determining performance. The challenges of quantifying high-intensity movements in handball, does not change the perception that high-intensity activities are important performance factors. The ability to accelerate, quickly change direction, jump, and throw are factors that often are mentioned in published studies as important for top-level playing performance (Manchado et al., 2013; Michalsik, Madsen, et al., 2013; Michalsik, Aagaard, et al., 2013; Póvoas et al., 2012; Póvoas et al., 2014).

*“The fact that the amount of high-intensity running was low in the present study does not mean that high-intensity running is not important in modern male elite TH (Team Handball) ... The ability to work at high intensity (together with high muscular strength) is possibly the most important factor that separates superior teams from less superior teams” - (Michalsik, Aagaard, et al., 2013)*

Even though the accelerative nature of handball is poorly described in the available literature, there appears to be no doubt that acceleration and other high intensity actions are an important part of the game, and that handball players performance depend on these variables. Researchers studying the characteristics of top-level handball players have shown that top-level handball players score better than there non-elite peers in acceleration tests (5-m, 15-m and 30-m) (Granados, Izquierdo, Ibañez, Bonnabau, & Gorostiaga, 2007; Massuca, Fragoso, & Teles, 2013), which also indicate that accelerative abilities are important.

## **2.2 Speed and acceleration**

Speed and high maximal running velocity is an important predictor for performance in various sports. Speed can be defined as an athlete's ability to execute a rapid displacement of the body, over a shorter distance (Enoksen & Tønnessen, 2007). In a 100-m sprint, for example, the speed of the athlete is of great importance for the outcome of the competition. The 100-m sprint race can be divided into four different phases; reaction phase, acceleration phase, top speed phase and retardation phase (Enoksen & Tønnessen, 2007). All of these phases have different demands to the athletes' physical and technical skills, and all of the phases are important for a good

competition outcome. The reaction phase consists of the athletes' reaction to a stimulus (start signal), and is followed by the acceleration phase. In the acceleration phase the goal is to have a high rate of change in velocity, to quickly as possible get to top speed. The acceleration phase for sprinters is approximately 30 m (Nytrøy, Enoksen & Hetland, 1988), and thereafter the top speed phase commences. A highly trained sprinter can hold the top speed to approximately 60-70-m, afterwards the retardation phase starts, and the speed will gradually lower to the finish line (Enoksen & Tønnessen, 2007). Also in many team sports, such as football, handball, field hockey and rugby, speed is frequently associated with successful performance (Upton, 2011). However, the playing fields and the nature of the game presents a different kind of sprint compared to a 100-m sprint. The playing field for handball is 20x40-m with an even smaller effective playing field, as the court players are not allowed inside the goalkeepers designated area. Given that the required distance to achieve maximal velocity for field athletes is ~40 m from a standstill start and ~29 m from a running start (Benton, 2000) and the playing field in handball is small, top speed is not likely to be achieved very often. Consequently, the ability to accelerate is considered to be a more fundamental factor for performance in team sports, rather than top speed (Cronin & Hansen, 2005). This is also true for other team sports (West et al., 2013).

Acceleration can be defined as the rate of change in velocity, and is dependent on the ability to develop high forces in a short period of time. The ability to contract the muscle with high velocity and high force is often referred to as power. Power, defined as the amount of work performed per unit of time, is the ultimate parameter influencing acceleration. During a maximal 5-s sprint, 50 % of total work is achieved within the first 1.5 s. Furthermore, at low speed the contractile component of the muscle seems to be mainly responsible for the power output, while at higher speed power from the series elastic elements seems to play a bigger role (Cavagna, Komarek, & Mazzoleni, 1971). The energy needed to accelerate, thereby, exceeds the energy cost of constant-velocity movement (Osgnach et al., 2010). Also, muscle involvement will differ between the acceleration phase and the phase of maximum running speed, due to changes in the lean of the body (Delecluse, 1997). In sprints, the lower limb muscles (muscles surrounding hip, knee and ankle joints) have to accelerate the body and generate momentum in a horizontal direction. In the phase of initial acceleration, when the athlete still runs with a pronounced forward leaned body, the knee extensors (e.g. including *m. vastus lateralis*),

the *m. gluteus maximus* and *m. triceps surae* are the main accelerators. However, when reaching higher running velocities, this relationship changes. Due to the upright position, forward propulsion in full speed sprinting is mainly determined by the action of hamstring muscles, the *m. gluteus maximus* and the *m. adductor magnus*. This is supported by the findings of Delecluse (1997). Strength tests of knee extensors and knee flexors, and a 40-m sprint test were performed by 58 physical education students. The correlation coefficients between the strength variables and running speed were calculated for every 2 m of running distance. Figure 2.1 shows the determination coefficients between the strength variables and running speed.

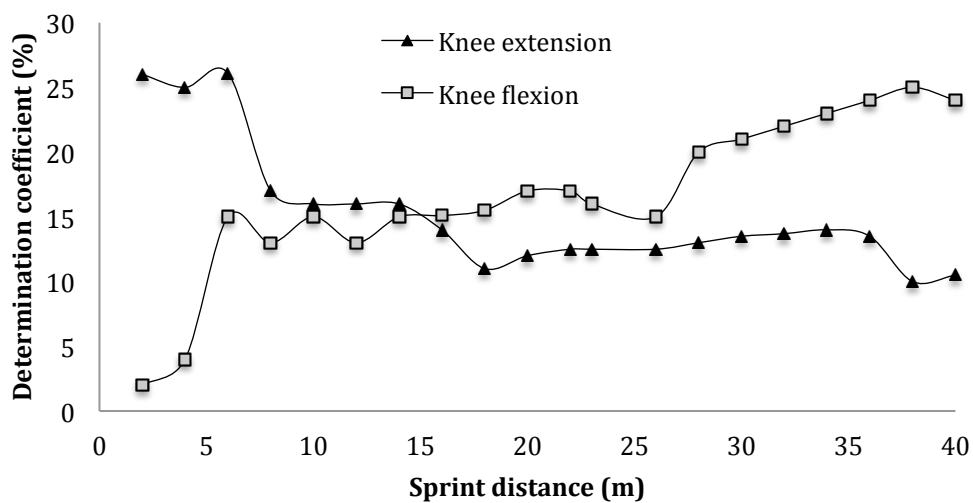


Figure 2.1: Determination coefficient between speed variables over 40-m sprint and two strength test results. The 20 speed variables, 1 per 2-m of running distance, are arranged in order of running distance on the x-axis. (Adapted from Delecluse, 1997).

These data indicate that the variance in running speed in the first 10 to 15-m are determined more by the strength of the knee, ankle and hip extensors, while the strength of the hamstring muscles are more significant during the final 20 m of a 40-m sprint.

### 2.2.1 Agility

In sports that involve unpredictable movements, the movement patterns of the athletes contain changes of direction and changes in running technique and speed. The ability to change direction in a rapidly and accurate manner have been defined as agility (Gabbet & Sheppard, 2013). Both linear sprint and agility are important parts of a handball player's speed performance, and both are dependent on power. There are several studies

that have attempted to establish the relationship between sprint and agility performance, with varying results (Buttifant, Graham, & Cross, 1995, 1999; Pauole, Madole, Garhammer, Lacourse, & Rozenek, 2000; Young, Hawken, & McDonald, 1996). Pauole et al. (2000) found significant correlations between performance in an agility T-test and 40-yard sprint time in both men and women ( $r=0.53$ ). In contrast, Buttifant et al. (1995) and Young et al. (1996) reported no significant correlations between linear sprinting and agility speed tests in either Australian soccer ( $r=0.33$ ) or Australian Rules football players ( $r=0.19$ ). The exercise variety and the variation in participants in these studies may contribute to the conflicting results. This large variation in reported correlations makes it difficult to establish a reliable relationship between these qualities, and presents the possibility that sprint and agility are distinct and specific motoric qualities (Sheppard & Young, 2006).

However, low correlation of two qualities does not necessarily mean that training of one does not affect the other, which might be a more interesting question. Some studies have found a beneficial effect of sprint training on agility performance, however this is in untrained individuals (Jones, Bampouras, & Marrin, 2009; Markovic, Jukic, Milanovic, & Metikos, 2007). Markovic et al (2009) showed that 10 weeks of sprint training gave beneficial effects on drop jump, isometric squat strength, 20-m sprint time and 20-yard shuttle sprint. This indicates that the participants in this study had an overall increase in their performance-level. Thus, untrained subjects can obtain a beneficial effect on agility by sprint training. Young et al (2001) investigated the same relationship, however the subjects were physically active students. The participants performed either linear sprints or agility sprints (involving 3-5 changes of direction) over a 6-week period. It was found that the linear sprint training enhanced running speed significantly by approximately 3 %, but did not produce any beneficial effect in the agility-test. These findings indicate that although it is possible for untrained individuals to obtain beneficial effects of linear sprint on agility performance, trained athletes might need specific training to enhance performance in agility (Young, McDowell, & Scarlett, 2001).

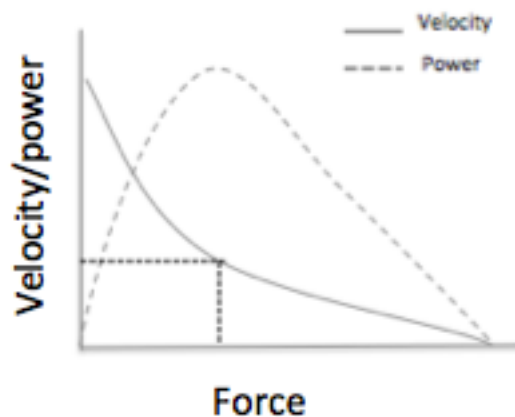
### **2.3 Speed and acceleration training**

Until the 1970s, there was limited research regarding the development of sprinting speed and power. At that time, speed components were considered as mainly genetically

predetermined, and that training sensitivity to such stimulus was low (Delecluse, 1997). Nowadays, it is generally accepted that speed in sprint and acceleration can be considerably improved by means of training. Such training is common among athletes, and there are numerous types of different training regimes used to obtain this goal. A general recommendation is that the athlete should be sufficiently rested before undertaking the training, and before each sprint in the training session, to maximize the benefits of the training (Enoksen & Tønnessen, 2007). Studies have seen a decrease in performance during sessions when having a too low rest/work-ratio. This underlines the need for sufficient rest periods between each sprint, and between sessions (Abt, Siegler, Akubat, & Castagna, 2011; Balsom, Seger, Sjödin, & Ekblom, 1992).

Various longitudinal sprint-specific training protocols have been implemented with the goal of increasing sprinting speed. However, coaches and athletes continue to seek the most effective means for enhancing sprint performance. Power is the product of force and velocity, and thus, the development of one of these factors could be beneficial for power output. High-intensity strength training has been proposed several times as a method for improving power in sprints, and has been shown by some researchers to increase an athlete's sprint performance (Young, Benton, Duthie, & Pryor, 2001). However, we know that peak power is produced at only a fraction of maximal force and contraction velocity (figure 2.2). Thus, enhancing maximal force without a concomitant increase in contraction velocity will not be optimal for speed performance. Also, neural factors play a role in generation of maximal power. The nervous system controls the activation of muscles primarily through changes in motor unit recruitment, firing frequency, motor unit synchronization and inter-muscular coordination (Cormie, McGuigan, & Newton, 2011). These factors are task dependent. Therefore, the training principle of specificity is well accepted, and many coaches and researchers argue for the need of movement-specific training exercises (Delecluse, 1997; Young et al., 2001).





*Figure 2.2: The force-velocity and force-power relationship for contractions of skeletal muscle. Force is normalized to the maximum isometric force, velocity is normalized to maximum velocity of shortening and power is normalized to maximum power output. Dotted black lines indicates the velocity and force at maximum power (Adapted from Cormie, McGuigan, & Newton, 2011).*

### **2.3.1 Resisted sprint training**

In addition to traditional sprint training (TST), strength and conditioning coaches and researchers have focused on resisted sprint training (RST) as a training method to improve acceleration and speed. Resisted movement training, such as RST, provides a greater resistance than normal training, and may, therefore provide a greater stimulus to the working muscles. RST includes uphill sprinting, sprinting with parachutes, weighted sleds or other overload effects (Alcaraz, Palao, Elvira, & Linthorne, 2008; Clark, Stearne, Walts, & Miller, 2010; West et al., 2013). The objective of this overload is to develop the specific strength requirements of the sprint. It's been reported that RST increases the force output of the knee and hip extensors during sprints (Zafeiridis et al., 2005), and it has been suggested that this might be due to a greater neuromuscular activation and an enhancement of the recruitment of fast twitch-fibres. In addition, sprint training might contribute to velocity-specific changes in the muscle architecture (see 2.4 Muscle architecture).

Although the theoretical benefits of RST are attractive, the practical validations of these methods are not currently convincing. To date, the published research has shown conflicting results (Clark et al., 2010; Harrison & Bourke, 2009; Hrysomallis, 2012;

Upton, 2011; West et al., 2013) regarding the effectiveness of RST on sprint performance. West et al. (2013) compared RST (sled towing) versus TST, with a 6 weeks intervention in the pre-season period for a group of professional rugby players. They measured performance of 10-m and 30-m sprints, and reported improvements for both groups. However, the improvements for the RST group were greater than for the TST group. The RST group had an improvement of  $0.04 \pm 0.01$  s (10-m) and  $0.10 \pm 0.03$  s (30-m) while the TST group had improvements of  $0.02 \pm 0.01$  s (10-m) and  $0.05 \pm 0.03$  s (30-m). Conversely, Clark et al. (2010) did not find RST to be as effective as TST on sprint performance. After 7 weeks of training in male collegiate lacrosse players, the RST groups only had trivial effects on sprint time (-0.13 %), while the TST group had a small effect (-1.09 %). However, in this study the sprint distance was longer (measured from approximately 18 m to 55 m). Thus, as previously suggested, TST and RST may both improve sprint times, but at shorter distances (5-10m) RST may provide a superior training stimulus (Hrysomallis, 2012; West et al., 2013). To my knowledge, there are no studies concerning RSTs effect on handball players.

The different loads used in RST-studies might contribute to the varying results. The load is important for overloading the athlete, however a too high load can affect the biomechanics of the sprint, and thereby lose the specificity. The optimal load for RST have not been determined using longitudinal studies, but it is proposed that the horizontal sprint velocity of an athlete should only fall to approximately 90 % of their maximum when training RST. This is to maintain specific high-speed muscular adaptations (Clark et al., 2010). Lockie et al. (2003) studied the acute effects of resisted sled towing on sprint kinematics in field sport athletes. Their aim was to determine the kinematic variables that were altered as a result of the resistance applied, and to investigate if two different loads would create different changes (Lockie, Murphy, & Spinks, 2003). They used loads of 12.6 % (load 1) and 32.2 % (load 2) of body mass, and sprints in an unloaded state was used as a reference. As expected, they found that sprint velocity decreased with increasing load. In load 1, the decrease was 9 %, thus the velocity did not drop under 90 %, but load 2 decreased sprint velocity to 76 %. They also found a reduction in stride length and stride frequency, and an increase in trunk lean, hip flexion, and over-extremity action for both loaded condition, compared with unloaded condition. Load 2 gave more kinematic changes than load 1. The study found that load 1 (12.6 % of body mass) resulted in minimal disruption to sprint kinematics,

while still overloading the key aspects, and they recommended this load as a guide for loading athletes in RST.

## **2.4 Muscle architecture**

Skeletal muscle is a highly organized structure; not only at micro-level, but also at macro-level and it demonstrates a high degree of organization. This macro-level arrangement of muscle fibres is known as muscle architecture (Lieber & Fridén, 2000). When we compare various muscles, certain factors such as fibre type distribution are important, but in determining whole muscle contractile properties there is no doubt that the muscle's architecture also is an important factor (Burkholder, Fingado, Baron, & Lieber, 1994). Skeletal muscle architecture is the structural properties of whole muscles and plays a role in controlling their function (Lieber, 2010; Lieber & Fridén, 2000).

Muscles in the human body can be categorized after their macro structure as parallel-fibred or pinnate-fibred (figure 2-1). In parallel fibered, the fibres lie in the longitudinal axis of the muscle belly (MacIntosh, Gardiner, & McComas, 2006). In these muscles, shortening of an individual muscle fibre can thereby be translated to shortening of the muscle. However, in some muscles the fibres are obliquely inserted into the tendon (the aponeurosis). They are called pennate muscles, and can be either unipennate or multipennate (see figure 2.3).

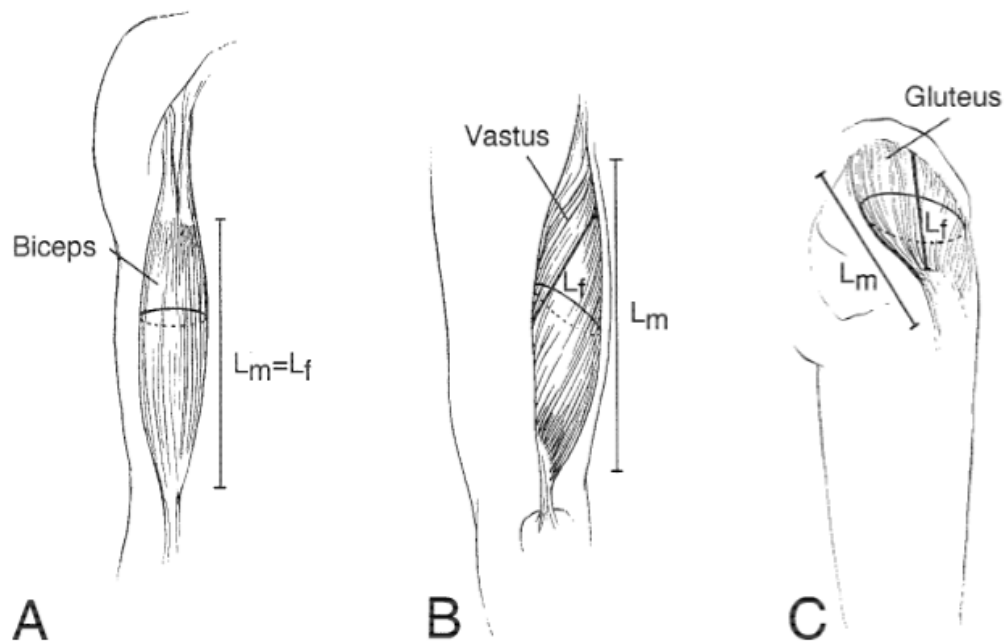


Figure 2.3: Generalized picture of muscle architecture types. (a) Parallelfibred architecture (longitudinal) in which muscle fibres run parallel to the muscle's force-generating axis. (B) Pennate architecture with a fixed angle relative to the force-generating axis. (C) Multipennate architecture with multiple angles relative to the force-generating axis. Each of these drawings of muscle architecture represents an idealized view, and probably does not adequately describe any single muscle.  $L_m$  = muscle length,  $L_f$  = muscle fiber length (Reprinted with permission (Appendix IV) Lieber, 2010).

The architecture of a muscle affects the functional characteristics of that muscle. Each shape of muscle has advantages and disadvantages that influence the functional performance. There are three major architectural components that need to be taken in consideration when talking about muscle architecture (Wickiewicz, Roy, Powell, & Edgerton, 1983). (1) The physiological cross-sectional area of a muscle is directly related to the amount of force that the muscle can produce. (2) The length of the fibres in the muscle affects the shortening-velocity of the muscle fibre. The maximum velocity of a muscle fibre is proportional to its length, and a longer fibre (with more sarcomeres in series), and can thereby influence power output (Cormie et al., 2011). And (3) the pennation angle of the muscle fibre insertion into the tendon affects the muscles output of force and velocity.

Movement pattern- and velocity-specific adaptations to training have previously been explained by changes in the nervous system, or by intra-muscular changes such as fibre-

type transformation or alterations in the length-force characteristics of sarcomeres. Early research suggested that there were little changes in muscle architecture in response to training. Rutherford & Jones, (1992) found no changes in *m. vastus lateralis* or *m. intemedius* pennation angle or length after three months of resistance training. The authors reported a moderately high coefficient of variation (13.5 %), making small changes difficult to detect, which may have influenced their findings. More recent research has found architectural adaptations in pennate muscles including changes in pennation angle and in fascicle length after extended periods of resistance training. Aagaard et al. 2001 investigated the effect of 14 weeks of heavy-resistance strength training of the lower limbs. They measured the cross-sectional area and volume of the muscle, and the pennation angle of *m. vastus lateralis* was measured using an ultrasound-device. The pennation angle was observed to increase in response to the resistance training. This allowed maximal contractile strength to increase more (+16 %) than anatomical muscle CSA and volume (+10 %) (Aagaard et al., 2001). Also other investigators have found similar adaptations as a result of heavy-load resistance training (Blazevich & Giorgi, 2001; Kawakami, Abe, Kuno, & Fukunaga, 1995). An increase in pennation angle is thought to improve the force-generating capacity of a muscle by allowing a greater muscle mass to attach to a given area of the tendon (more sarcomeres in parallel) or, because fibres in pennate muscles rotate during contractions, by allowing a lower velocity of fibre shortening for a given muscle shortening velocity (Kawakami, Abe, & Fukunaga, 1993). Under such conditions, it would also be possible for fibres to remain at lengths closer to their optimum, and thereby affect the force generation in a positive manner. However, changes in pennation angle can also affect the contraction velocity (Cormie et al., 2011). Greater pennation angles are associated with slower contractions (Cormie et al., 2011), thus a negative contributor in power development. The rotation of fibres about the muscle line of action allow a higher contraction velocity of the muscle, than that of the fibres (Muhl, 1982). The pennation angle in a muscle affects this rotation, and an increase in pennation angle will lead to less rotation, and thus can lead to a less velocity advantage.

Changes in fibre length would also affect the force-generating capacity of the muscle. Studies performed on animals reveal that this is largely because longer fibres can contract at higher velocities than shorter fibres (Sacks & Roy, 1982). In humans, fascicle length, measured as an indicator of fibre length, has been shown to be greater in

top 100-m sprinters than in long-distance runners (Abe, Kumagai, & Brechue, 2000). In addition, a significantly negative relationship between fascicle length and 100-m personal record is evident, in both male and female sprinters (Abe, Fukashiro, Harada, & Kawamoto, 2001; Kumagai et al., 2000). This relationship has been found in *m. gastrocnemius lateralis* ( $r=-0.44$ ), in addition to *m. vastus lateralis* ( $r=-0.51$ ).

It is therefore possible that the type of training performed affects the muscle architecture. Given that strength training is associated with an increase in pennation angle, whereas athletes who perform a high quantity of speed training appear to have the opposite architecture, it is possible that muscle architectural changes are velocity specific. However, although a significant relationship between fascicle length and sprint velocity is established, the literature regarding the effect of sprint training on muscle architecture is scarce. To my knowledge, only one study has investigated the effect of combined resistance training and jump/sprint training versus jump/sprint training alone (Blazevich, Gill, Bronks, & Newton, 2003). The participants were divided in three different groups; one group conducted only jump/sprint training (four sessions per week), the other two groups had two different resistance training programs that mimicked either jump (squats) or sprint (forward hack squat) (two sessions per week) training and, in addition, jump/sprint training (two sessions per week). They trained for 5 weeks and muscle architecture measurements were conducted before and after the training intervention. They found a significant decrease in pennation angle in *m. vastus lateralis* (distal part) for the group that only trained jump/sprint, but not in any of the other groups. As the training exercises were similar between all the groups, they concluded that the force and velocity characteristics of the exercises rather than the movement patterns most likely influenced the muscle architecture (Blazevich et al., 2003). Nimphius et al. (2012) investigated the changes in muscle architecture during a competitive season in female softball players. After a 3-week general preparation period they conducted pre-measurements of muscle thickness and pennation angle in *m. vastus lateralis*. The first 8 weeks, the participants completed two resistance-training sessions per week, in addition to 2-3 sessions per week of normal skill training, and 1-2 conditioning sessions. Mid-testing (week 9) showed an increase in pennation angle (1.34 %, ES= 0.21), and only trivial changes in muscle thickness and fascicle length. After the mid-testing, the participants implemented more power training (2 sessions per week), instead of the resistance training. The post measurements (week 19, two weeks

before the main tournament of the year) displayed a decrease in pennation angle from the pre- measurements of 4.22 % (ES=0.27) and from mid-testing (5.22 %, ES=0.47). At the post measurements, the fascicle length was also found to be longer (8.57 %, ES =0.77). They also found a significant relationship between changes in fascicle length and changes in sprint performance ( $r = -0.84$ ). They speculated that the increase in fascicle length and the decrease in pennation angle was in response to the high velocity and high rate of force production training they conducted (Nimphius, McGuigan, & Newton, 2012).

## **2.5 Summary**

In this theory section of the thesis we have seen that handball is a sport that contains a lot of different physical aspects. The number of accelerations and other high-intensity actions are not well described in the available literature. However, there seems to be an agreement among researchers that such actions are an important part of the handball game, and thus important in determining performance. It also seems that accelerative qualities are more important than top speed for handball players.

There is now an agreement that speed in sprint and acceleration can be considerably improved by means of training. Coaches and researchers have focused on TST and RST as training methods to improve sprint and acceleration speed, and found both methods to be effective. However, there are some conflicting results regarding RST and its effect on accelerative performance.

In addition, we have seen that the muscles architectural components are of importance when determining a whole muscles contractile properties. The cross-sectional area, the fiber length and the pennation angle in a muscle will affect the forces and the shortening-velocity in that muscle. A significant negative relationship between fascicle length and sprint performance is found in *m. vastus lateralis*, which indicate that it is beneficial for sprint performance to have longer fascicles. The muscle architecture also displays plasticity in response to training, however, mostly shown by means of resistance training. The effect of sprint training on muscle architecture is not well established.

## 3. Method

### 3.1 *Experimental approach*

To compare the effect of TST and RST the recruited participants completed a 10-week specific sprint-training program. The participants were block randomized into two groups based on their 10-m baseline values, so that the groups were matched for this variable at the start of the intervention. The study commenced in the latter portion of the preseason period (3 weeks before the first official match) and was completed in the in-season period. Before commencing the intervention, the team had been in preparation for the up-coming season for three months, with four to five weekly training sessions. The last four weeks before the study commenced, the team did not have any joint team sessions, however the participants completed a detailed training program individually. Throughout the duration of the study, all of the participants engaged in their normal training scheme (3 sessions per week), handball matches (on average 1 per week) and the intervention program (2 sessions per week). In addition, some of the participants engaged in physical education classes at school and some individual training. The training load throughout the study was monitored with sessional Rating of Perceived Exertion (sRPE) (Foster et al., 2001). The participants gave their written informed consent before the start of the study, in addition to a declaration of health.

The effect of the intervention program was evaluated through pre- and post-tests of linear sprint (10 m and 30 m), agility, long jump, squat jump, counter movement jump, 20-m shuttle run test (20MST) and ultrasound measurements of *m. vastus lateralis*. The linear sprint, agility, long jump and 20MST were performed two times pre intervention. These two testing sessions were conducted in order to determine the typical error of these tests for this specific population, and were undertaken with 6-9 days between sessions. Due to practical limitations, it was not possible to determine the typical error for the ultrasound measurements, squat jump and counter movement jump assessments. A simplified outline of the study is shown in figure 3.1.



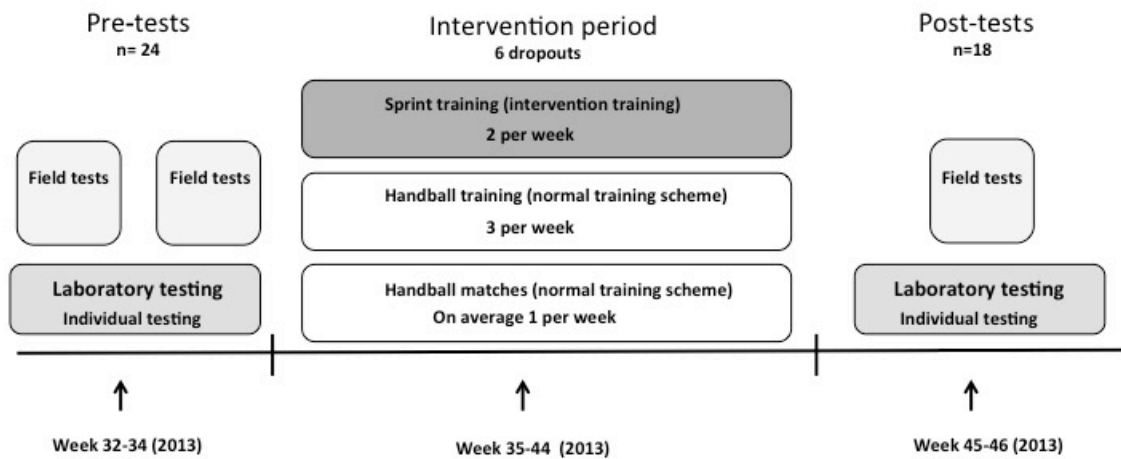


Figure 3.1: Simplified outline of the study.

### 3.2 Subjects

The participants in this study were semi-professional female handball players on a team in a national league in Norway (second highest division in Norway). To ensure a sufficient number of participants, all players in the training group were included (not dependent on experience or number of matches played). A total of 24 subjects were recruited, on the basis that they were healthy, injury free and participated in all of the team's group trainings. To be sure that the data reflected the effect of the intervention, we included a criterion concerning the adherence to the intervention training. The participants had to complete at least 80 % of the intervention trainings, and due to this criterion, six participants were excluded from the analysis. This study thereby is based on 18 participants (Table 1) that completed a minimum of 15 of the 18 total intervention training sessions, and also completed both pre- and post-training testing sessions. The excluded participants reported injuries (3), sickness (2) and school/work (1) as reasons for not adhering to the training intervention program.

*Table 3.1: Participant details at baseline. Numbers are mean  $\pm$  SD. Effect size (ES) of between groups comparison is listed, in addition to the qualitative rating of the ES.*

	TST (n=8)	RST (n=10)	ES	Rating
Age (y)	23.1 $\pm$ 3.9	20.4 $\pm$ 3.1	0.62	Moderate
Stature (cm)	172.0 $\pm$ 6.4	170.3 $\pm$ 5.3	0.22	Small
Body Mass (kg)	69.9 $\pm$ 5.3	74.6 $\pm$ 5.9	0.29	Small
10-m sprint time (s)	2.01 $\pm$ 0.07	2.01 $\pm$ 0.06	0.08	Trivial

\* TST= Traditional sprint training, RST= Resisted sprint training.

### **3.3 Experimental procedures**

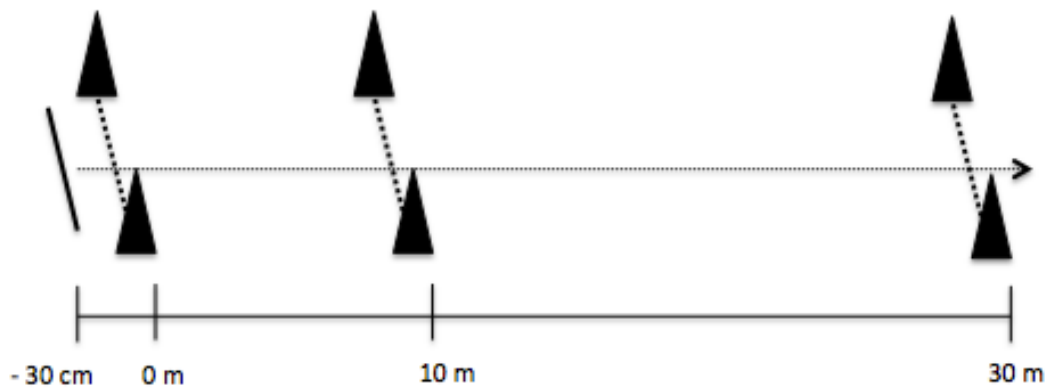
#### **3.3.1 Field testing**

The participants had a light training day (60 min team training with low intensity exercises) before the day of testing. The participants underwent a standardized warm-up drill for each testing session. The warm-up consisted of a general part with 10 min jogging on the same surface as used in the testing session. After the general part, the participants completed a specific warm-up with movement specific drills. The test leader gave continuous instructions of the drills. The specific part of the warm-up lasted for 6 min and included 3 submaximal sprints. After the warm-up, the participants were given time to drink (only water) before commencement of the test session. All testing procedures were replicated for the post-training, testing session.

#### **10-m and 30-m sprint test**

Linear acceleration was measured by a maximal 30-m sprint test. Performance on the 10-m and 30-m test was based on the mean time of the two best trials, to minimize the standard error of measurement. All participants started the test from a standing, stationary start, 30 cm behind the first set of timing gates. The starting position allowed the participants to place one foot right behind the starting line, and the other foot was placed a little further back to allow the participants to bend their knees and hip. The participants were instructed not to have any backwards movement before starting the sprint. Electronic timing gates (Speed Trap II TC Wireless Timing System, Brower) were placed at the start line and also at 10 m and 30 m from the first set of gates (see figure 3.2). The timing gates were placed approximately 1.3 m above the floor. Cones were placed 1-m behind the last set of timing gates, and the participants were instructed

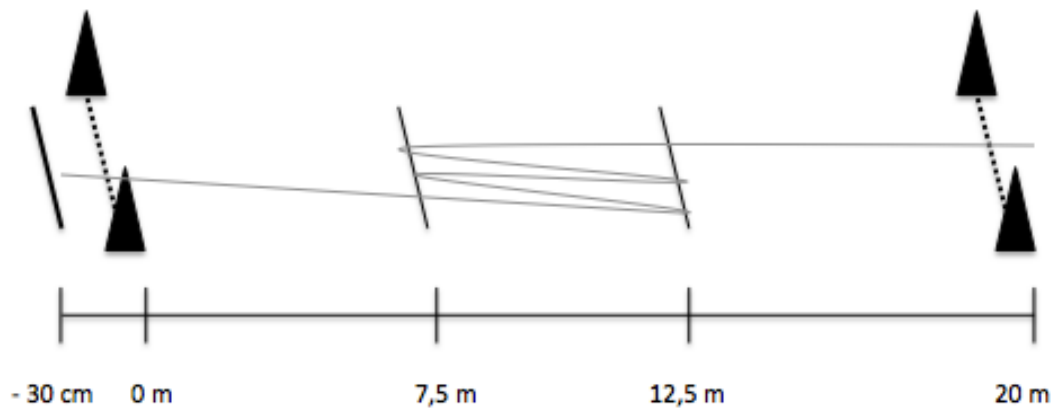
to sprint to the cones, thus to hinder the participants from starting the decelerating too early, and in that way effect the sprint time. All participants completed three trials each, with a 2-min rest between each trial.



*Figure 3.2: Simplified schematic of the setup of the linear sprint test (10-m and 30-m). The black triangles represents timing gates, the heavy black line represents the starting line.*

### **Agility test**

Five minutes after completing the linear sprint test, participants completed an agility test with 180° turns (A180°). The participants started with a stationary start, 30 cm behind the starting line (figure 3.3). They started with a run to the 12.5 m line, and made a 180° turn with either left or right foot, and ran back to the 7.5 m line. Then they made another 180° turn, now with the opposite foot. This was repeated once, before sprinting to the finish line (20 m), so that, in total, the participants completed four 180° turns and 40 m in total distance. Here as well, electronic timing gates were used to measure the time. Time from start (0 m) to finish (20 m) was used as the performance outcome. The starting position for the agility test was the same as for the 30-m linear sprint test, and cones were placed 1-m behind the last pair of timing gates. The participants completed three trials each, with 3 min rest between trials. The mean of the two best trials were used in analysis.



*Figure 3.3: Simplified schematic of the setup of the agility test. The black triangles represents timing gates, the heavy black line represents the starting line. The lines at 7.5 m and 12.5 m represent the lines where 180° turns were made. A line is drawn to present the tests running track.*

### **Horizontal jump test**

After a 5 min rest, the participants also completed a horizontal long jump test (long jump). For this test the participants stood stationary on both legs, with the toes aligned level with the start line and with feet slightly apart. A two-foot take-off and landing was used. Knee bend and arm swing was used (individual chosen amount), before jumping as far forward as possible. The distance from the starting line and rearmost impact point of the back heel was measured, and used as the performance outcome. Elevation platform, to elevate the heels at starting position, was not used in this testing procedure. All participants completed three jumps; rest between trials was 2 min. The mean of the two best trials were used in the analysis.

### **20 meters Shuttle Run Test**

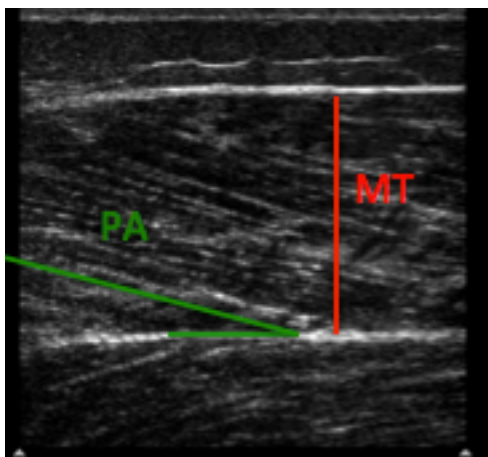
The 20-meter Shuttle Run Test (20-MST) was performed 10 min after the horizontal jump test. Before the start of the test, the participants had 3 min of jogging as additional warm-up. Participants followed the 20-MST protocol by touching the appropriate 20-m line with a foot in tandem with an audio signal (Leger & Gadoury 1989). The speed set by a pre-recorded CD was increased from 8.5 km/h at the rate of 1 km/h every 2 min until termination. The test was terminated when the participant voluntarily dropped out due to exhaustion or could no longer maintain pace with the audio signals. Testers

monitored both 20-m lines closely, to identify when the participants no longer could keep the pace.

### 3.3.2 Laboratory testing

#### Muscle architecture

B-mode ultrasound measurements were performed on *m. vastus lateralis* in the right leg of all participants, using a linear array transducer (50 mm, 5-12 MHz, HD11XE, Phillips, Bothell, Washington, USA). Participants were instructed to restrict from training at the day of muscle architecture measurements, to prevent swelling in the musculature that can effect the measurements. The measurements were performed while the participants were lying supine and instructed to be fully relaxed. Measurements were taken at 60 % of the distance from the greater trochanter to the lateral epicondyle of the femur. Three pictures were taken for muscle thickness and three for pennation angle (figure 3.5), all pictures were analysed (ImageJ, Rasband, W.S, National Institute of Health, Maryland, USA) three times and the mean value was used in further analysis. Fascicle length was calculated with simple trigonometry ( $T/\sin(3.14*\theta/180)$  where  $\theta$  is the pennation angle and T is the muscle thickness).



Figur 3.4: Ultrasound picture of *m. vastus lateralis*, with the deep and superficial aponeuroses (clear white lines). Illustrative lines for measuring muscle thickness (red) and pennation angle (green) are drawn in.

#### Vertical jumps

After ultrasound measurements, the participants had a standardized 5-min warm-up on a stationary cycle before undertaking the vertical jump tests. The participants were

instructed to maintain a 100-watt load during the 5 min of cycling. After the warm-up, the participants had two submaximal attempts of the jumps before stepping onto the force platform. The vertical jump tests were performed on a portable force platform (Hur-Labs, Finland). Two types of jump were performed: the Squat Jump (SJ) and the Countermovement Jump (CMJ). SJ is a jump, starting from a squat position (self-chosen knee angle), with no allowance of countermovement before take-off, while the CMJ is started from an upright position with allowance of a countermovement before the jump (self-chosen knee angle). In both jumps, hands had to be positioned on the waist during the entire length of the jump. Jump height was calculated from take-off velocity, and used as the performance outcome. The participants had three trials for each jump, and the highest jump was used in further analysis.

### **3.4 Training load**

Because of potentially different amounts of training among the participants, the total training load was monitored using session Rating of Perceived Exertion (sRPE) (Foster et al., 2001). Participants submitted a training log each week, containing date of training, duration of training and sRPE of each session. sRPE is used as a marker of training intensity, in a subjective manner, and is based on a scale (figure 3.5), ranging from 0-10, where 0 is rest and 10 is maximal (work intensity). The participants were asked to rate the session within 30 min after the session ended, and that rating should be a reflection of the average load of the whole session. Training load was calculated by multiplying duration of training (min) with sRPE. The participants had a 3-week familiarization period with the training log submission before the start of the study.

<u>Rating</u>	<u>Descriptor</u>
0	Rest
1	Very easy
2	Easy
3	Moderate
4	Somewhat hard
5	Hard
6	-
7	Very Hard
8	-
9	-
10	Maximal

Figure 3.5: Category ratio of rating of perceived exertion scale (Adapted from Foster et al, 2001).

### **3.5 Training**

All training was performed on a flat surface, the same as used in the field-testing sessions. Both training groups completed their respective programmes twice a week for a 10-week period. Training took place on Mondays and Thursdays, late afternoon (from 5-7 pm), for both groups. Before each session the participants completed a standardized warm-up routine that consisted of 5 min jog, 5 min ball play and 5 min movement specific drills (the same as in the testing sessions). Both groups completed the exact same amount of sprints and the same total distance, thus the training sessions were equal between the two groups. The training program for the intervention is specified in table 3.2. The participants were instructed to give maximal effort on all the sprints, and were verbally encouraged during all the training sessions. The RST group performed all the sprints with an additional weight of  $12.4 \pm 0.2$  % of body mass, conducted to a sled (Speed sled: SportLand, Sports-direct, Beijing, China). 12.5 – 13 % of body mass is described in the literature as the optimal load for this type of training, as it does not dramatically alter sprint kinematics during the exercise (Lockie et al., 2003). The TST group performed the exact same sprint training without any additional weight.

*Table 3.2: Summary of training content in the intervention sessions. Training is listed as: number of sets x number of sprints in one set x distance of each sprint. R=rest between each sprint, AR=active recovery between sets. Total time per session is excluding warm-up.*

Week	Training	Total distance (per session)	Total time (per session)
1-4	4x3x20 m  R: 2 min  AR: 5 min	240 m	35 min
5-9	3x3x20 m    2x5x10m  R: 2 min    R: 1.5 min  AR: 5 min    AR: 5 min	280 m	44 min
10	4x3x20 m  R: 2 min  AR: 5 min	240 m	35 min

### **3.6 Validity and reliability**

It is of great importance to be concerned with issues of validity and reliability when collecting data for research purposes. Validity concerns whether the test(s) actually measures the trait it is supposed to measure (Thomas, Nelson, & Silverman, 2011). The tests validity will in this context be justified with the training intervention's main purpose: to develop accelerative qualities. Current recommendations regarding testing of team-sport athletes suggest that speed testing should be focus on acceleration over 5-40 m (Duthie, Pyne, Ross, Livingstone, & Hooper, 2006). Both 10-m and 30-m measurements are thereby in line with the recommended sprint test for accelerative qualities. In addition, agility is a part of the speed qualities important in handball, and thereby this is also tested. Agility can be measured by many different tests, however tests containing 180° turns have been shown to be most valid and reliable (Sporis, Jukic,



Milanovic, & Vucetic, 2010). Even though the A180° may be considered a valid test, we have to acknowledge the fact that the cognitive aspect of agility is not included in this test. The jump tests are integrated in this study to give a simple method to evaluate the strength of leg musculature. Jump height or length has been shown to have a good correlation with an athletes maximal strength (Enoksen & Tønnessen, 2007; Wisløff, Castagna, Helgerud, Jones, & Hoff, 2004), and is thereby used in this study to measure the jump ability and strength of the participants. The 20MST is a specific team sport conditioning test, and there is strong evidence indicating that the 20MST is a valid test to estimate cardiorespiratory fitness (Castro-Piñero et al., 2010) in team sport athletes. Evidence of the validity of ultrasound-based measurements of fascicle lengths and pennation angles are limited. However, in large limb muscles that are measured in a relaxed stated, the validity of measurements is reported to be high to very high (Kwah, Pinto, Diong, & Herbert, 2013).

A test cannot be valid, if its not reliable. The reliability of a test concerns the trustworthiness and accuracy of the results of a test. To quantify the reliability of a test, it is common to take a test re-test and identify the typical error of measurement (Thomas et al., 2011), which has been undertaken in this study for some of the tests. The typical error is used to determine whether a change in results between two testing sessions is due to an actual change in performance or a technical error by the tester or testing equipment (Woolford, Polglaze, Rowsell, & Spencer, 2013). For the field test, the measurements from the two pre-tests were used to calculate the typical error in this study, using a excel spreadsheet from Hopkins (Hopkins, 2000).

Typical error of the ultrasound measurement was obtained by taking repeated measurements of 11 different moderately trained subjects, who were not involved in the study. The reliability of the testing procedure used in this study is presented in table 3.3.

The target typical error of 10-m and 30-m sprint has previously been reported as 0.03-0.04 s (Duthie et al., 2006; Woolford et al., 2013), with use of timing gates. The typical error of this study is in line with the target typical error. However, the typical error must be considered in the context of the magnitude of change that can be of practical importance. In both 10-m sprint and 20-m sprint, the smallest worthwhile change in performance is estimated to be 0.01 s (Duthie et al., 2006), thus smaller than the typical

error for the tests. Therefore, a requirement of relatively large changes in performance is necessary to state a performance change was likely. A systematic review concerning the reliability of ultrasound measurements found that measures of both fascicle length and pennation angles are reliable, both in relaxed and contracted state (Kwah et al., 2013). Only a small number of the included studies involved experienced radiologists/sonographers, suggesting that it is possible to obtain reliable measurements without formal training in ultrasound imaging (Kwah et al., 2013). For the agility-test used in this study, there is to my knowledge a lack of reliability measurements. One unpublished study (Braastad & Nyländen, 2011) showed a CV of 1.3 %, which represents a good reproducibility. Also for the CMJ there is reported a good reproducibility, with a typical error of 0.023 m (Cormack, Newton, McGuigan, & Doyle, 2008).

Table 3.3: Typical error (TE) data for the field tests and muscle architecture of this study. TE is shown as raw and percentage (%) differences, with lower and upper 90 % confidence limits (CL).

		Raw data			%		
		TE	Lower 90 %	Upper 90 % CL	TE	Lower 90 %	Upper 90 % CL
Field tests	(n=19)						
	10 m (s)	0.03	0.03	0.05	1.6	1.2	2.2
	30 m (s)	0.05	0.04	0.07	1.0	0.8	1.5
	Agility (s)	0.11	0.09	0.16	1.2	0.9	1.7
	LJ (cm)	3.0	3.0	5.0	1.7	1.3	1.7
Muscle architecture	(n=11)						
	Muscle thickness (cm)	0.05	0.01	0.06	2.0	-0.6	2.8
	Pennation angle (°)	0.13	-1.0	0.1	1.0	0.9	1.0
	Fasicle length (cm)	0.16	-1.0	0.2	2.7	0.9	1.0

\*LJ= Long jump

### 3.7 Statistical analyses

Data for pre- and post-tests are presented as mean  $\pm$  SD. Data for changes are presented as mean  $\pm$  90 % CL, both for raw data and percentage data. The percentage data shown are log transformed. Differences between pre- and post-test for both groups, and differences between the two groups were analysed using Cohen's effect size (ES) statistic and 90 % confidence limits (CL). ESs of <0.2, 0.2 to 0.6, 0.6 to 1.2, 1.2 to 2.0 and >2.0 were considered trivial, small, moderate, large and very large, respectively (Hopkins, Marshall, Batterham, & Hanin, 2009). Cohen's effect size is calculated using the following equation:

$$d = \frac{\overline{X}_1 - \overline{X}_2}{s}$$

Where  $\overline{X}_1$  is the mean for one population,  $\overline{X}_2$  is the mean of the other population, and s is the standard deviation of the pre-test (for both populations, when calculating

differences between groups). The percentage likelihood of a difference between groups was calculated and considered almost certainly not (<0.5 %), very unlikely (>0.5-25 %), unlikely (<25 %), possibly (25-75 %), likely (>75 %), very likely (>95 %), or almost certainly (>99.5 %). Threshold chances of 5 % for substantial magnitudes were used, meaning if a likelihood of >5 % in both a positive and negative direction was observed, it was considered an unclear difference. Correlations were assessed by Pearson product-moment correlation coefficient. Magnitude of effect for the correlations were based on the following scale: <0.10 trivial, 0.10-1.29 small, 0.30-0.49 moderate, 0.50-0.69 large, 0.70-0.89 very large, and >0.89 nearly perfect (Hopkins et al., 2009). All calculations were performed in Microsoft® Excel for Mac® (2001). For calculations of ES, 90 % CL, log transformation and calculations of likelihood, pre-made excel spreadsheets (Hopkins, 2006, 2007) was used.

## **4. Results**

All participants (n=18) completed the sprint, long jump, and 20MST tests. Due to logistical reasons, only 14 participants completed both pre- and post-test measurements for the muscle architecture and vertical jump tests. The results of the field test are presented in table 4.1.

Table 4.1: Pre-and post-test results (mean  $\pm$  SD), changes in performance in raw data (mean  $\pm$  90 % confidence limits), and magnitude of differences in effect size and rating, for all field tests.

	Performance		Change in performance		Magnitude of differences	
	Pre-test	Post-test	Raw data	Effect size	Rating	
10 m (s)						
TST (n=8)	2.01 $\pm$ 0.07	1.97 $\pm$ 0.07	-0.04 $\pm$ 0.04	0.51	Small	
RST (n=10)	2.01 $\pm$ 0.06	2.01 $\pm$ 0.06	-0.01 $\pm$ 0.02	0.08	Trivial	
30 m (s)						
TST (n=8)	4.77 $\pm$ 0.18	4.46 $\pm$ 0.26	-0.31 $\pm$ 0.19	1.56	Large	
RST (n=10)	4.81 $\pm$ 0.17	4.65 $\pm$ 0.31	-0.16 $\pm$ 0.13	0.93	Moderate	
Agility (s)						
TST (n=7)	9.80 $\pm$ 0.32	9.64 $\pm$ 0.32	-0.17 $\pm$ 0.18	0.46	Small	
RST (n=10)	10.03 $\pm$ 0.40	9.91 $\pm$ 0.33	-0.12 $\pm$ 0.08	0.28	Small	
LJ (cm)						
TST (n=8)	218.2 $\pm$ 26.9	222.1 $\pm$ 15.3	3.9 $\pm$ 13.6	0.17	Trivial	
RST (n=10)	205.7 $\pm$ 13.8	209.9 $\pm$ 11.2	4.2 $\pm$ 3.8	0.29	Small	
SJ (cm)						
TST (n=6)	27.7 $\pm$ 4.0	29.1 $\pm$ 2.5	1.4 $\pm$ 1.2	0.27	Small	
RST (n=8)	26.4 $\pm$ 2.8	28.8 $\pm$ 2.8	2.4 $\pm$ 1.4	0.72	Moderate	
CMJ (cm)						
TST (n=6)	29.8 $\pm$ 4.8	31.1 $\pm$ 3.5	1.4 $\pm$ 2.5	0.23	Small	
RST (n=8)	29.2 $\pm$ 3.4	30.9 $\pm$ 3.2	1.7 $\pm$ 0.8	0.42	Small	
20MST						
TST (n=8)	10.03 $\pm$ 1.15	10.04 $\pm$ 0.82	0.01 $\pm$ 0.58	0.03	Trivial	
RST (n=10)	9.74 $\pm$ 1.63	9.74 $\pm$ 1.58	0.01 $\pm$ 0.26	0.01	Trivial	

\* L.J= long jump, S.J= squat jump, CMJ= counter movement jump, 20MST= 20-m shuttle run test, TST= traditional sprint training, RST= resisted sprint training

#### 4.1 10-m and 30-m sprint test

For 10-m sprint time, the RST group only had a trivial change, while the TST group had a small change in performance. Only the TST group was outside the typical error of measurement for the 10-m sprint time. The ES of the between group comparison was 0.60, thus a moderate and likely (85 %) difference between the two groups. Both training groups had a positive change in performance for 30-m time, although with different magnitudes. The ES of compared groups was 0.85, a moderate, but unclear difference. Only 1/8 (TST) and 1/10 (RST) did not have a beneficial effect on 30-m sprint time. Relative change in for 10-m and 30-m sprint time is shown in figure 4.1.

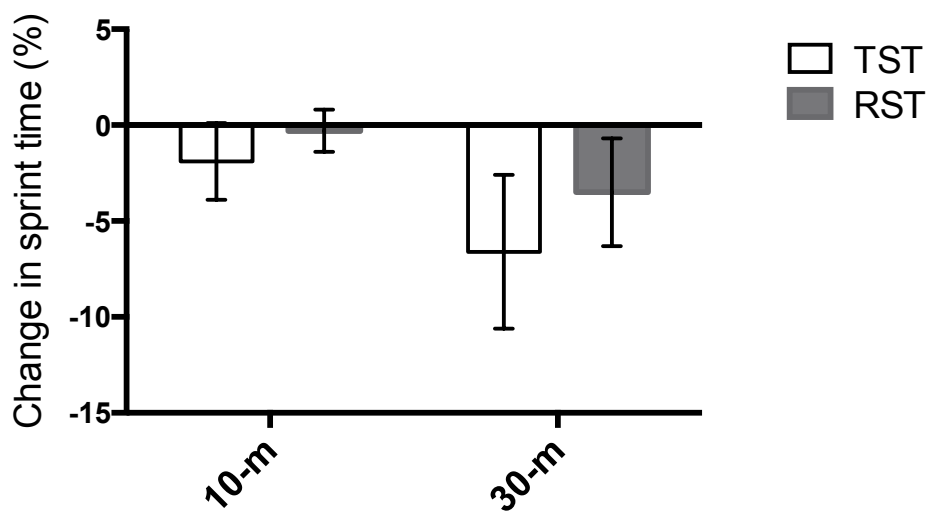


Figure 4.1: Relative (%) change  $\pm$  90 % confidence limits for traditional sprint training (white) and resisted sprint training (grey) in 10-m and 30-m sprint performance.

#### 4.2 Agility, jumps and 20MST

The relative change in the agility test, jump tests and 20MST is shown in figure 4.2. Small changes were found for both groups on the agility performance test, with unclear differences between groups. Correlation of change in performance in agility and 10-m sprint was  $r=0.27$  (small). Trivial, small and moderate effects of the intervention were also found on the jump tests (figure 4.2). Both groups had the largest relative effect in the squat jump. No clear differences were found between the two groups. The 20MST showed a trivial effect of the intervention for both groups.

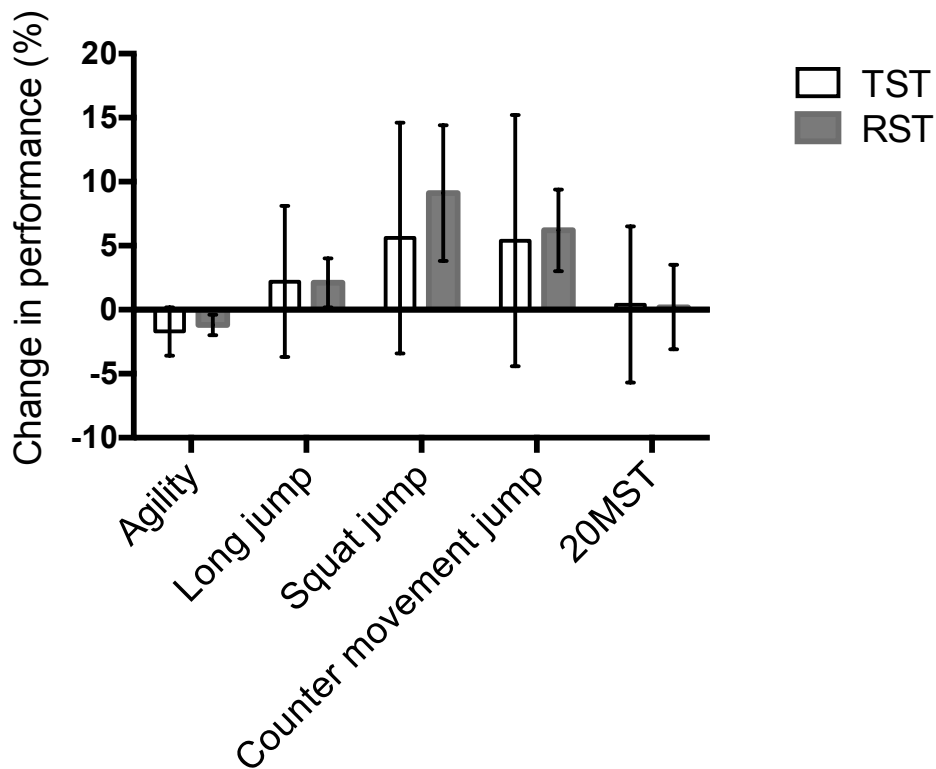


Figure 4.2: Relative (%) change  $\pm$  90 % confidence limits for traditional sprint training (white) and resisted sprint training (grey) in agility, long jump, squat jump, countermovement jump, and 20MST.

### 4.3 Muscle architecture

The pre- and post-measurements of muscle architectural characteristics, changes in raw data, and effect sizes with a qualitative rating are presented in table 4.2, and the relative changes are shown in figure 4.3. Changes for muscle thickness were possibly different between the two groups (49 %), with an increase for RST and a decrease for TST, although, the changes were not outside of the typical error of measurement. Also the changes in pennation angle were possibly different between the two groups (60 %), with a small ES (ES=0.25). The difference in fascicle length between the two groups was unclear. Percentage changes in pennation angle had an almost perfect correlation with percentage changes in 10-m sprint time ( $r=0.92$ ; figure 4.4), however, a similar correlation was not found for pennation angle and 30-m sprint time ( $r=0.07$ ). Percentage changes in fascicle length had a correlation of  $r=-0.51$  and  $r=-0.21$  for percentage change in performance in 10-m and 30-m sprint, respectively.



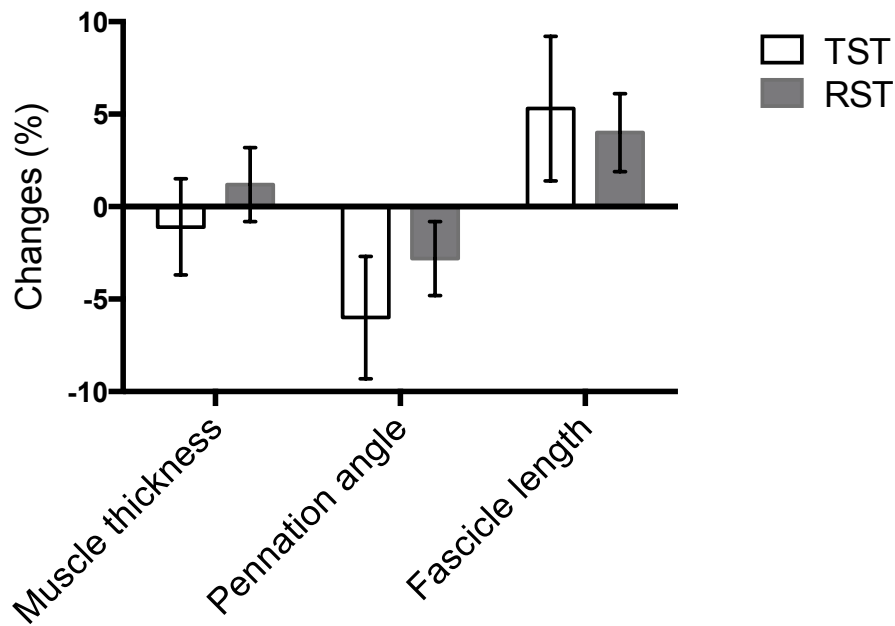


Figure 4.3: Relative (%) change  $\pm$  90 % confidence limits for traditional sprint training (white) and resisted sprint training (grey) in muscle thickness, pennation angle and fascicle length.

Table 4.2: Pre- and post-test (mean  $\pm$  SD) changes in raw data (mean  $\pm$  90 % confidence limits), and magnitude of differences in effect size and rating for the muscle thickness, pennation angle and fascicle length.

		Muscle architecture		Change	Magnitude of differences	
		Pre	Post	Raw data	Effect	Rating
Thickness (cm)						
TST	(n=6)	2.39 $\pm$ 0.30	2.37 $\pm$ 0.31	-0.03 $\pm$ 0.06	0.07	Trivial
RST	(n=8)	2.34 $\pm$ 0.24	2.37 $\pm$ 0.26	0.03 $\pm$ 0.05	0.10	Trivial
Angle ( $^{\circ}$ )						
TST	(n=6)	18.3 $\pm$ 2.5	17.3 $\pm$ 3.0	-1.0 $\pm$ 0.6	0.38	Small
RST	(n=8)	17.8 $\pm$ 2.5	17.3 $\pm$ 2.1	-0.5 $\pm$ 0.4	0.19	Trivial
Fascicle length (cm)						
TST	(n=6)	7.7 $\pm$ 1.3	8.1 $\pm$ 1.3	0.4 $\pm$ 0.3	0.26	Small
RST	(n=8)	7.7 $\pm$ 0.6	8.0 $\pm$ 0.5	0.3 $\pm$ 0.1	0.46	Small

\* TST= traditional sprint training, RST= resisted sprint training

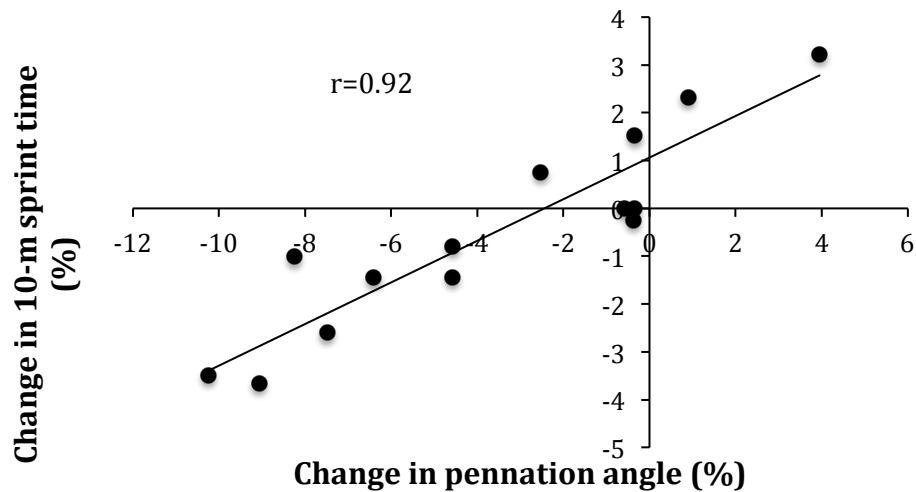
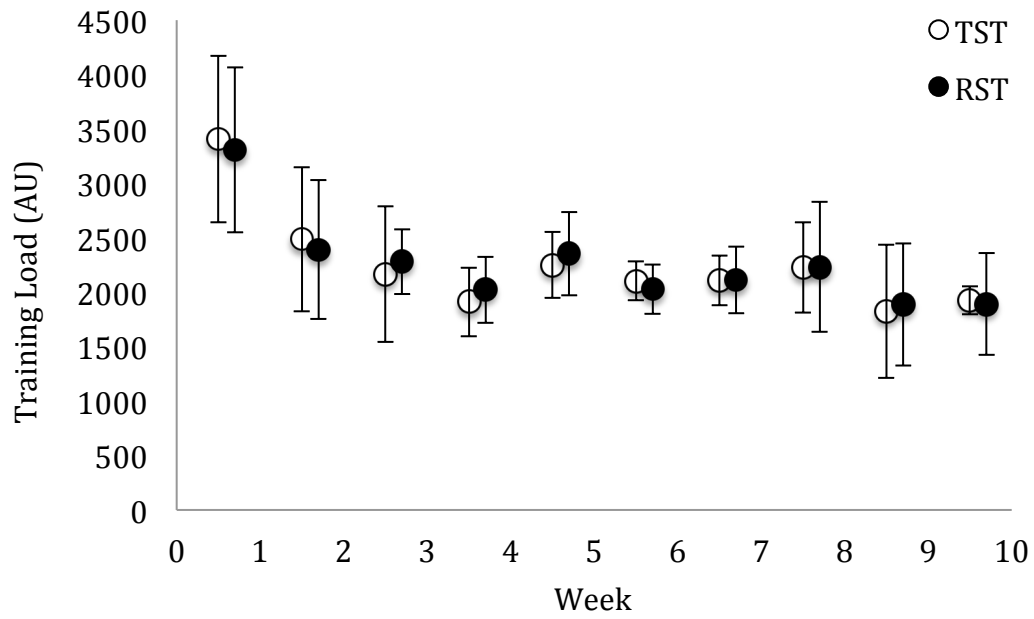


Figure 4.4: Relationship between percentage changes in 10-m sprint time and percentage changes in pennation angle.

#### 4.4 Training load

The results from the sRPE training load monitoring show only trivial to small differences between the groups during the training intervention for each week (figure 4.5). Combined training load for the whole period shows trivial differences between the two groups. Mean data  $\pm$  SD for all 10 weeks for both groups are displayed in figure 2. The first week of the training intervention had the highest training load for both groups ( $3407 \pm 764$  for TST and  $3310 \pm 759$  for RST). The average weekly training load throughout the intervention period was  $2242 \pm 423$  (AU) for the TST group and  $2251 \pm 454$  (AU) for the RST group.



*Figure 4.5: A presentation of the weekly training load (calculated by multiplying duration of training (min) with sRPE) for traditional sprint training (white) and resisted sprint training (black). Values are mean (dots) and SD (lines).*

## 5. Discussion

The aim of this study was to investigate the effect of 10 weeks sprint training in highly trained female handball players, in terms of accelerative qualities, agility, vertical and horizontal jumps, handball specific endurance, and muscle architectural qualities. The possible different effect of TST versus RST was a main focus of this study.

The main findings of this study were that there was an unclear difference between the groups for 30-m sprint time, with both groups having a beneficial effect of the intervention. For 10-m sprint time there was found a likely difference between the groups, with a beneficial effect for TST and no effect for RST. In addition, both TST and RST had a small effect on muscle fascicle length in the *m. vastus lateralis*. The changes found in pennation angle were highly correlated with changes in 10-m sprint time.

I do acknowledge the possible contribution of other training factors, as the participants' concurrently trained for handball specific training during the intervention period. However, all training factors (e.g. training mode, training load, specific exercises and intensities) were consistent for both groups in this study, and should thereby, not influence the differences between the two groups.

### 5.1 Changes in performance

#### 5.1.1 Sprint performance

Acceleration is an important performance factor in team sports and the results demonstrate that 10 weeks of training (two sessions per week) with either RST or TST can improve acceleration over 30 m in highly trained female handball players. The improvements in performance, in this study, are in practical terms very likely to benefit sprint performance in match play. According to Hopkins et al (2009) the smallest worthwhile performance enhancement, or change, in team sports is 0.2 of the between-subjects standard deviation. Based on the data in the present study, this corresponds to ~0.02 s over a 30-m sprint. In practical settings, a change of 0.02 s can be translated to a ~13 cm advantage. The 0.16 to 0.31-s improvement in sprint time found in this study will give a 1-2 m difference, if the sprint distance is executed in same amount of time. The beneficial effect for TST on 10-m sprint time corresponded to a 20-cm difference in

distance. 20 cm might be enough to be decisive in 1-on 1 duels in handball match play, by having the body or shoulder/hand in front of the opposing player.

The 0.31-s improvement of the TST group is in comparison to other studies, large in magnitude. Studies of sprint training in handball are lacking, however previous research in soccer and rugby has shown improvements of 0.06 - 0.13 s in sprint training over 30-40 m (Shalfawi, Young, Tønnessen, Haugen, & Enoksen, 2013; Upton, 2011; West et al., 2013). Less experience with physical conditioning provides more potential for stimulating positive effects (Haugen, Tønnessen, Hisdal, & Seiler, 2014). Even though the participants in this study were well-trained semi-professional handball players, it is proposed by others that well-trained team-sport athletes can be considered untrained in terms of sprint training (Haugen et al., 2014), because the nature of the daily training may not include sprint training as a major focus. It is also observed that team-sport athletes can improve their sprint time in 40-m sprint by 0.2-0.3 s, with one training session per week over 10 weeks (Tønnesen, Alnes, & Aasen, 2013). This indicates that handball players can highly benefit from this kind of training.

These improvements in performance indicate that both interventions had a beneficial impact on acceleration, with a moderate to large effect. Therefore, the results are in line with previous research suggesting that both methods may improve sprint times (West et al., 2013; Zafeiridis et al., 2005). However, the results also demonstrate a difference in effect between the two training methods. The improvement was greater in the TST group than in the RST group. In addition to the improvement in the 30-m sprint, the TST group had a small improvement in 10-m sprint time, which is in contrast to the RST group. All changes of sprint times were outside of the typical of measurement, with exception of the 10-m sprint time for RST. The results are thereby conflicting with previous studies that suggest sled towing may provide a superior training stimulus for sprints over shorter distances (Harrison & Bourke, 2009; Hrysomallis, 2012; West et al., 2013). West et al. found, as previously mentioned, RST to have a more pronounced effect than TST. Furthermore, the authors suggested that others, who have not found RST to be more effective, used a load corresponding to lower percentage of body mass, and thereby was too low (e.g. Clark et al. who used 10 % of body mass). An applied load is thought to increase the demands of the involved musculature, and thereby to have a greater effect on the muscle. Even low loads is reported to have hypertrophic

effects in the musculature (Moss, Refsnes, Abildgaard, Nicolaysen, & Jensen, 1997), and can thereby be beneficial for force output. However, there were no changes in the muscle thickness, and thereby no extra effect on the musculature of the sled training in this study.

This study used the same relative load as reported in West et al. 2013 (12,6 % vs 12,4 % in this study). At least, the load used in RST is not the only factor in explaining varying results regarding this outcome. The recommendation of loading in RST is based on kinematic measurements of male subjects (Lockie et al., 2003). It may be that female subjects do not have the same optimal load, due to sex differences, in such as, muscle mass and maximal muscle strength. It is also possible that optimal load for RST should not be described dependent on body mass alone. Measures of strength, muscle mass or other variables might be more applicable when determining the optimal load of RST.

If in fact, the load used in this study was not optimal, this could in turn affect the results of the RST group. It is previously suggested that resistance training with low load and high velocity may be superior to high load and low velocity in terms of power-output and velocity (Mohamad, Cronin, & Nosaka, 2012). The horizontal speed in RST is shown to be reduced with an increase in load (Lockie et al., 2003), and thereby influence the velocity of muscle contractions. High load and lower velocity might not be specific enough to develop acceleration skills in sprints, as they may affect the power output in a negative manner, and may account for some of the observed effects in this study. Heavy loads could therefore hinder specific high-speed adaptations in the musculature (Atha, 1981). Thus, the decrease in horizontal speed may be of such a degree that the training no longer is applicable for acceleration training. Also, sled towing may alter disruption to sprint kinematics such as stride length, stride frequency, hip flexion and shoulder and elbow flexion (Lockie et al., 2003), which is affected more by higher loading. It is possible that the applied additionally weight in this study affected the participants sprinting technique, to such extent that the possible positive effects of RST were not reflected in the sprint tests. As this study was not designed to assess sprinting technique, this is purely speculative.

### **5.1.2 Agility performance**

Both TST and RST obtained a beneficial effect on agility performance, however the effect was small in magnitude for both groups. Agility performance is dependent on many factors; timing, balance, and coordination of the task at hand are crucial for agility performance. The agility test A180° contains four 180° turns. Since this means an about-face of the body, very fast players can have trouble to decelerate at the right time as the speed into the turn is high (Jones et al., 2009). An important performance factor for agility is thereby learning of timing of the deceleration before the turn. Since the sprint training in this study did not contain decelerating aspects, it is not likely that the technical aspects of agility were affected by the intervention. There seems to be some effect of sprint training on agility performance for trained athletes in this study, however there are no meaningful differences between the two groups, and the displayed correlation between improvements in sprint and agility is small. This may suggest that the improvement is not solely contributed by the intervention, and the concurrent training may account for some of the improvements.

### **5.1.3 Jump performance**

The jumping ability was affected in a trivial to moderate beneficial matter during the training intervention, with unclear differences between the two groups. The fact that both groups had a beneficial effect on jump performance is in line with other researchers that have found similar results of power training on jump performance (Hrysomallis, 2012). It is also a possibility that the concurrent handball training might play a role in this effect, since no clear differences were found between the two groups. The outcome of this is that the jumping ability is at least not negatively affected, and thereby this training intervention did not interfere with this ability. In other terms, the training regime is sufficient to maintain, or increase jumping ability.

### **5.1.4 Conditioning performance**

The intervention was carried out during the latter portion of the pre-season period and for seven weeks in the in-season period, and therefore it is of interest to present its effect on aerobic conditioning. The training intervention did not seem to have a negative nor positive effect on aerobic conditioning, with only trivial changes in the 20-MST for both groups. This indicates that the sprint training intervention, concurrently with

handball training, is sufficient to maintain the conditioning level of female handball players.

## **5.2 Muscle architecture**

The exact mechanism(s) that can account for the different training effects of RST and TST are still unclear. It has previously been suggested that greater elicitation of neuromuscular activation and enhancement of recruitment of fast twitch-fibres might contribute. In addition, there is a significant negative relationship between sprint time and fascicle length, in both male and female athletes (Abe et al., 2001) and research regarding muscle architecture has shown that specific training regimes can evoke changes in muscle thickness, pennation angle and in fascicle length (Alegre, Jiménez, Gonzalo-Orden, Martín-Acero, & Aguado, 2006; Blazevich et al., 2003; Nimphius et al., 2012). The most studied changes are changes due to heavy resistance training, and the most common changes result in an increase in muscle thickness, and an increase in pennation angle. (Alegre et al., 2006) It is also reported that a decrease in pennation angle can occur after a period of sprint training. (Blazevich et al., 2003) This indicates that architectural parameters respond differently according to training modalities.

In this study, both RST and TST had a change in fascicle length, with an increase of 4-5 %, which, for both groups, is outside the typical error of measurement. Thus, 10 weeks of sprint training, resisted and traditional, had an effect on fascicle length in the *m. vastus lateralis*. The decrease in pennation angle was also, for both groups, outside the typical error of measurements, although classified as trivial (RST) and small (TST). In addition, this change showed a nearly perfect correlation with change in 10-m sprint time. These results suggest a velocity-specific adaptation to the sprint training. The force-velocity relationship of muscle fibres can explain the influence of fascicle length on sprint performance. For a given tendon excursion, the shortening velocity of longer fibres (with more sarcomeres in series) is higher than in shorter ones (Kumagai et al., 2000). In addition, longer muscle fibres will exert more force at any given velocity, as they can be at a length closer to their ultimate force-production. As a result, the increase in fascicular length observed in the present study may have enhanced sprint performance by favouring a larger power output of the knee extensor muscles.



Another possibility to explain the present gains in performance lies in the changes in pennation angle. The contraction velocity of pennate muscles can exceed that of its fibres by virtue of their rotation about the muscle line of action (Muhl, 1982). This can affect both the force and the muscle-shortening velocity. The force transmitted by the muscle fibres will decrease with an increasing pennation angle that is present during contractions, however the muscle shortening velocity will increase, due to a larger fibre rotation, and be positive for the power output. The effects of training upon the ratio of fibre- to muscle velocity are unknown and the present study was not designed to measure this parameter. However, the observed decreases in pennation angle suggest that a larger fibre rotation was enabled in the *m. vastus lateralis* of the subjects, favouring a higher contraction velocity. The almost perfect correlation between post-training changes in pennation angle and 10-m sprint performance supports this hypothesis but further research focusing on the above architectural parameters is required. The lack of a meaningful correlation between changes in 30-m sprint and in pennation angle is likely attributable to the relative contribution of knee extensor muscles declining after the first 15 m of a sprint (Delecluse, 1997).

The results suggest a velocity-specific adaption to the sprint training, with a decrease in pennation angle and a lengthening of the fascicles. This might account for some of the beneficial effects of the intervention. However, the fact that there were no differences between the groups on this variable, while there was in the 30-m sprint time, it is not clear if the concurrent handball training also can be influential in these changes

The change in muscle thickness is less than the typical error of measurement, and can thereby not be acknowledged as a true change in either group. A previous study (Abe et al., 2000) found that differences in muscle thickness between sprinters and untrained are more pronounced at 30 % and 50 % of thigh length (measured from great trochanter), with no difference between the groups found at 70 %. In the current study, the participants were measured only at 60 % of thigh length, and thereby this may not reflect the true changes in the whole length of the muscle.

### **5.3 Limitations of the study**

When conducting a study, there are always some limitations that need to be taken into account when reading and evaluating the results. The most obvious limitation of this

study is the low number of participants (n=18 and n=14). With a higher number of participants in each group, the results could provide a stronger statistical outcome. Especially for the muscle architecture data, the number of participants is low, and these data would be interesting to look at with a stronger evidence base. In addition, all the participants were members of the same team, with no control group. This makes it more difficult to generalize the results from this study. If the participants were from a different team, we could say more about the general handball population, while in this case the teams' general training scheme could potentially affect the results.

Also, the specificity of the training intervention to the game of handball is debatable. Specificity is one of the fundamental training principles for speed and acceleration training (Enoksen & Tønnessen, 2007). Possibly, a higher variation of sprint distances, or the addition of changes of direction or decelerations could make the intervention training more specific to the game of handball, and also more attractive for coaches to incorporate in their training programs in the future. The training intervention of this study is specific to the counter-attack phase, especially for wing players. However, other phases of the game have other speed aspects. As the outcome of this study aims to help coaches to efficiently incorporate acceleration training in the teams training program, a more specific approach of the training intervention could be of interest, and should be investigated further in the future. Furthermore, the specificity of the performance tests are debatable, specifically to which extent it is transferrable to the actual demands of handball players in match play situations. However the tests used in this study is the most valid and reliably available at this current time-point.

Familiarization to the test is an important part of obtaining reliable results. Unfortunately, there was no familiarization to the vertical jump test. However, for the other field tests, the participants completed two pre-test sessions, and they showed a variation that is in line with the recommended or targeted typical error. However, this cannot be transferred to the vertical jump test, and the lack of familiarization might be a contributor to the results on this variable.

In addition, the standardization before the test day could have been improved. In this study, we did standardize the training on the day before each testing session. The tests were conducted at the same time of the day for pre- and post-testing, and the subjects

were instructed to eat at same time-points before the testing. However, there was no monitoring of the nutritional intake, which could be of importance for performance. In addition, as the participants were semi-professional, meaning that they had jobs/studies in addition to their handball practices, the total load of the participants might be different from pre- to post-test, even though the training load was standardized.

#### **5.4 *Practical applications***

The current findings have practical implications for athletes in sports that require acceleration abilities. This study shows that female handball players profit from sprint training, with moderate to large beneficial performance outcomes on 30-m sprint time. This indicates that female handball players will have a good effect of this kind of training. When considering this in a practical point of view, it translates to an advantage of 1-2 m. There is no doubt that the magnitude of improvement will benefit handball players in match play. Even though the difference between the two groups was unclear for the 30-m sprint time, TST training seems to be more beneficial than RST, with a beneficial effect on 10-m sprint time as well. This is possibly a more important performance variable than the 30-m, as 10-m sprints are likely to happen more often than 30-m sprints in handball. The focus on sprint training in pre-season and in-season does not seem to be harmful for the jumping ability, agility or conditioning performance, and can thereby be recommended to be implemented in this period.

## **6. Conclusion**

Sprint training appears to be effective in enhancing short distance (10-30-m) sprints in concurrently training handball players, and traditional sprint training appeared to be more effective than resisted sprint training for female handball players. The effect of 10 weeks of sprint training on fascicle length was similar for both groups, yet small in effect size. Changes in pennation angle and changes in 10-m sprint time have a nearly perfect correlation. This possibly suggests a velocity-specific adaption to training, present in concurrently training athletes. The training in pre-season and in-season periods does not seem to have a harmful effect on general conditioning, and can thereby be implemented in training without being at the expense of other important physical factors important for team handball players.

## References

- Abe, T., Fukashiro, S., Harada, Y., & Kawamoto, K. (2001). Relationship between sprint performance and muscle fascicle length in female sprinters. *Journal of Physiological Anthropology and Applied Human Science*, 20(2), 141–147.
- Abe, T., Kumagai, K., & Brechue, W. F. (2000). Fascicle length of leg muscles is greater in sprinters than distance runners. *Medicine and Science in Sports and Exercise*, 32, 1125–1129.
- Abt, G., Siegler, J. C., Akubat, I., & Castagna, C. (2011). The effects of a constant sprint-to-rest ratio and recovery mode on repeated sprint performance. *Journal of Strength and Conditioning Research*, 25, 1695–1702.
- Alcaraz, P. E., Palao, J. M., Elvira, J. L. L., & Linthorne, N. P. (2008). Effects of three types of resisted sprint training devices on the kinematics of sprinting at maximum velocity. *Journal of Strength and Conditioning Research* 22, 890–897.
- Alegre, L. M., Jiménez, F., Gonzalo-Orden, J. M., Martín-Acero, R., & Aguado, X. (2006). Effects of dynamic resistance training on fascicle length and isometric strength. *Journal of Sports Sciences*, 24, 501–508.
- Atha, J. (1981). Strengthening muscle. *Exercise and Sport Sciences Reviews*, 9, 1–73.
- Balsom, P. D., Seger, J. Y., Sjödin, B., & Ekblom, B. (1992). Maximal-intensity intermittent exercise: effect of recovery duration. *International Journal of Sports Medicine*, 13, 528–533.
- Benton, D. (2000). An analysis of sprint running patterns in Australian rules football: The effect of different starting velocities on the velocity profile. Honor thesis, University of Ballarat, Victoria, Australia.
- Blazevich, A. J., Gill, N. D., Bronks, R., & Newton, R. U. (2003). Training-specific muscle architecture adaptation after 5-wk training in athletes. *Medicine and Science in Sports and Exercise*, 35, 2013–2022.
- Blazevich, A. J., & Giorgi, A. (2001). Effect of testosterone administration and weight training on muscle architecture. *Medicine and science in sports and exercise*, 33, 1688–1693.
- Brooke, J., & Knowles, J. (1974). A movement analysis of player behavior in soccer match performance. In *British Society of Sports Psychology Proceedings*, 246–256.
- Braastad, A., & Nyländen, M. (2011). Reliabiliteten til to agilitytester innen fotball. The Norwegian school of sport sciences. Bachelor thesis, The Norwegian School of Sport Sciences, Oslo, Norway.

- Burkholder, T. J., Fingado, B., Baron, S., & Lieber, R. L. (1994). Relationship between muscle fiber types and sizes and muscle architectural properties in the mouse hindlimb. *Journal of Morphology*, 221, 177–190.
- Buttifant, D., Graham, K., & Cross, K. (1995). Agility and speed in soccer players are two different performance parameters. In *Science and Football IV Conference*, Sydney, NSW.
- Buttifant, D., Graham, K., & Cross, K. (1999). Agility and speed of soccer players are two different performance parameters. *Journal of Sports Sciences*, 17, 809.
- Castro-Piñero, J., Artero, E. G., España-Romero, V., Ortega, F. B., Sjöström, M., Suni, J., & Ruiz, J. R. (2010). Criterion-related validity of field-based fitness tests in youth: a systematic review. *British Journal of Sports Medicine*, 44, 934–943.
- Cavagna, G. A., Komarek, L., & Mazzoleni, S. (1971). The mechanics of sprint running. *The Journal of Physiology*, 217, 709–721.
- Clark, K. P., Stearne, D. J., Walts, C. T., & Miller, A. D. (2010). The longitudinal effects of resisted sprint training using weighted sleds vs. weighted vests. *Journal of Strength and Conditioning Research*, 24, 3287–3295.
- Cormack, S. J., Newton, R. U., McGuigan, M. R., & Doyle, T. L. a. (2008). Reliability of measures obtained during single and repeated countermovement jumps. *International Journal of Sports Physiology and Performance*, 3(2), 131–44.
- Cormie, P., McGuigan, M. R., & Newton, R. U. (2011). Developing maximal neuromuscular power: Part 1--biological basis of maximal power production. *Sports Medicine, Sports medicine*, 41(1), 17–38.
- Cronin, J. B., & Hansen, K. T. (2005). Strength and power predictors of sports speed. *Journal of strength and conditioning research*, 19, 349–357.
- Delecluse, C. (1997). Influence of strength training on sprint running performance. Current findings and implications for training. *Sports Medicine (Auckland, N.Z.)*, 24, 147–156.
- Duthie, G. M., Pyne, D. B., Ross, A. A., Livingstone, S. G., & Hooper, S. L. (2006). The reliability of ten-meter sprint time using different starting techniques. *The Journal of Strength & Conditioning Research*, 20, 246–251.
- Enoksen, E., & Tønnessen, E. (2007). Hurtighetstrening. In E. Enoksen, E. Tønnessen, & L. I. Tjelta (Eds.), *Styrketrening i individuelle idretter og ballspill* (1. edition., pp. 156–175). Kristiansand: Høyskoleforlaget.
- Foster, C., Florhaug, J. A., Franklin, J., Gottschall, L., Hrovatin, L. A., Parker, S., Dodge, C. (2001). A new approach to monitoring exercise training. *Journal of Strength and Conditioning Research*, 15, 109–115.

- Gabbet, T. J., & Sheppard, J. (2013). Testing and training agility. In *Physiological test for elite athletes* (2nd. ed., pp. 199–206). Human Kinetics.
- Granados, C., Izquierdo, M., Ibañez, J., Bonnabau, H., & Gorostiaga, E. M. (2007). Differences in physical fitness and throwing velocity among elite and amateur female handball players. *International Journal of Sports Medicine*, 28, 860–867.
- Harrison, A. J., & Bourke, G. (2009). The effect of resisted sprint training on speed and strength performance in male rugby players. *Journal of Strength and Conditioning Research*, 23, 275–283.
- Haugen, T., Tønnessen, E., Hisdal, J., & Seiler, S. (2014). The Role and Development of Sprinting Speed in Soccer. *International Journal of Sports Physiology and Performance*, 9, 432–441.
- Hopkins, W. (2000). Summarizing data: Precision of measurements. [www.sportsci.org](http://www.sportsci.org).
- Hopkins, W. (2006). Spreadsheets for analysis of controlled trials, with adjustment for a subject characteristic. *Sportscience*. 10, 46-50, [www.sportsci.org](http://www.sportsci.org).
- Hopkins, W. (2007). A spreadsheet to compare means of two groups. *Sportscience* 11, 22-23. [www.sportsci.org](http://www.sportsci.org)
- Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise*, 41, 3–13.
- Hrysomallis, C. (2012). The Effectiveness of Resisted Movement Training on Sprinting and Jumping Performance. *Journal of Strength and Conditioning Research*. 26(1), 299-306
- IHF. (2014). IFH-Member federations. <http://www.ihf.info/TheIHF/MemberFederations/tabid/161/Default.aspx>.
- Jones, P., Bampouras, T. M., & Marrin, K. (2009). An investigation into the physical determinants of change of direction speed. *The Journal of Sports Medicine and Physical Fitness*, 49(1), 97–104.
- Karcher, C., & Buchheit, M. (2014). On-court demands of Elite Handball, with special reference to playing positions. *Sports Medicine*, 44(6), 797–814.
- Kawakami, Y., Abe, T., & Fukunaga, T. (1993). Muscle-fiber pennation angles are greater in hypertrophied than in normal muscles. *Journal of Applied Physiology*, 74, 2740–2744.
- Kawakami, Y., Abe, T., Kuno, S. Y., & Fukunaga, T. (1995). Training-induced changes in muscle architecture and specific tension. *European Journal of Applied Physiology and Occupational Physiology*, 72, 37–43.

- Kumagai, K., Abe, T., Brechue, W. F., Ryushi, T., Takano, S., & Mizuno, M. (2000). Sprint performance is related to muscle fascicle length in male 100-m sprinters. *Journal of Applied Physiology*, 88, 811–816. d
- Kwah, L. K., Pinto, R. Z., Diong, J. H., & Herbert, R. D. (2013). Reliability and validity of ultrasound measurements of muscle fascicle length and pennation in humans: a systematic review. *Journal of Applied Physiology*, 114, 761–9.
- Lieber, R. . (2010). Skeletal muscle anatomy. In *Skeletal muscle structure, Function and plasticity - The physiological basis of rehabilitation* (3rd ed., pp. 1–39). Lippincott Williams & Wilkins.
- Lieber, R. L., & Fridén, J. (2000). Functional and clinical significance of skeletal muscle architecture. *Muscle & Nerve*, 23, 1647–1666.
- Lockie, R. G., Murphy, A. J., & Spinks, C. D. (2003). Effects of resisted sled towing on sprint kinematics in field-sport athletes. *Journal of Strength and Conditioning Research*, 17, 760–767.
- MacIntosh, B. ., Gardiner, P. ., & McComas, A. . (2006). Muscle architecture and muscle fiber anatomy. In *Skeletal muscle - Form and function* (2nd ed., pp. 3–22). Human Kinetics.
- Manchado, C., Hoffmann, E., Valdivielso, F. ., & Platen, P. (2007). Physiological demands in female handball - demands and heart rate during matches of the German National Team. *Dt Z Sportmed.*, 58(10), 24–29.
- Manchado, C., Navarro-Valdivielso, F., Pers, J., & Platen, P. (2008). Motion analysis and physiological demands in international women's team handball. Communication to the Annual Congress of the European College of Sport Science, Estoril, Portugal, ECSS Abstract Book, 419.
- Manchado, C., Pers, J., Navarro, F., Han, A., Sung, E., & Platen, P. (2013). Time-motion analysis in women's team handball: importance of aerobic performance. *J. Hum. Sport Exerc.*, 8(2), 376–390.
- Manchado, C., Tortosa, J., Vila, H., Ferragut, C., Platen, P., & Tortosa-Martínez, J. (2013). Performance factors in women's team handball: physical and physiological aspects-a review. *Journal of Strength and Conditioning Research*, 27(6), 1708–19.
- Markovic, G., Jukic, I., Milanovic, D., & Metikos, D. (2007). Effects of Sprint and Plyometric training of muscle function and athletic performance. *Journal of Strength & Conditioning Research*, 21, 543–549.
- Massuça, L. M., Fragoso, I., & Teles, J. (2013). Attributes of top elite team-handball players. *Journal of Strength and Conditioning Research*, 28(1), 178-168
- Michalsik, L. B., Madsen, K., & Aagaard, P. (2013). Match Performance and Physiological Capacity of Female Elite Team Handball Players. *International Journal of Sports Medicine*. In press



- Michalsik, L. B., Aagaard, P., & Madsen, K. (2013). Locomotion characteristics and match-induced impairments in physical performance in male elite team handball players. *International Journal of Sports Medicine*, 34, 590–9.
- Mohamad, N. I., Cronin, J. B., & Nosaka, K. K. (2012). Difference in Kinematics and Kinetics Between High- and Low-Velocity Resistance Loading Equated by Volume: Implications for Hypertrophy Training. *Journal of Strength and Conditioning Research*, 26 (1), 269-275.
- Moss, B. M., Refsnes, P. E., Abildgaard, A., Nicolaysen, K., & Jensen, J. (1997). Effects of maximal effort strength training with different loads on dynamic strength, cross-sectional area, load-power and load-velocity relationships. *European Journal of Applied Physiology and Occupational Physiology*, 75, 193–199.
- Muhl, Z. F. (1982). Active length-tension relation and the effect of muscle pinnation on fiber lengthening. *Journal of Morphology*, 173, 285–292.
- Nimphius, S., McGuigan, M. R., & Newton, R. U. (2012). Changes in Muscle Architecture and Performance During a Competitive Season in Female Softball Players. *Journal of Strength and Conditioning Research*. 26(10), 2655-2666
- Osgnach, C., Poser, S., Bernardini, R., Rinaldo, R., & di Prampero, P. E. (2010). Energy cost and metabolic power in elite soccer: a new match analysis approach. *Medicine and Science in Sports and Exercise*, 42, 170–178.
- Paule, K., Madole, K., Garhammer, J., Lacourse, M., & Rozenek, R. (2000). Reliability and Validity of the T-Test as a Measure of Agility, Leg Power, and Leg Speed in College-Aged Men and Women. *The Journal of Strength and Conditioning Research*, 14(4), 443-450
- Póvoas, S., Ascensao, A., Magalhaes, J., Seabra, A., Krustup, P., Soares, J., & Rebelo, A. (2014). Physiological demands of elite team handball with special reference to playing position. *J Strength Cond Res*, 28(2), 430–442.
- Póvoas, S., Seabra, A., Ascensão, A., Magalhães, J., Soares, J., Rebelo, A., Magalhaes, J. (2012). Physical and physiological demands of elite team handball. *The Journal of Strength & Conditioning Research*, 26(12), 3365–3375.
- Rutherford, O. M., & Jones, D. A. (1992). Measurement of fibre pennation using ultrasound in the human quadriceps in vivo. *European Journal of Applied Physiology and Occupational Physiology*, 65, 433–437.
- Sacks, R. D., & Roy, R. R. (1982). Architecture of the hind limb muscles of cats: functional significance. *Journal of Morphology*, 173, 185–195.
- Sheppard, J. M., & Young, W. B. (2006). Agility literature review: classifications, training and testing. *Journal of Sports Sciences*, 24, 919–932.

- Sporis, G., Jukic, I., Milanovic, L., & Vucetic, V. (2010). Reliability and factorial validity of agility tests for soccer players. *Journal of Strength and Conditioning Research*, 24, 679–686.
- Thomas, J., Nelson, J., & Silverman, S. (2011). *Research methods in physical activity* (6th ed., pp. 193–214). Champaign, USA: Human Kinetics.
- Tønnesen, E., Alnes, L., & Aasen, S. (2013). Hurtighetstrening i fotball. *Olympiatoppen*.
- Upton, D. E. (2011). The Effect of Assisted and Resisted Sprint Training on Acceleration and Velocity in Division IA Female Soccer Athletes. *Journal of Strength and Conditioning Research*, 25(10), 2645-2652
- Varley, M., & Aughey, R. (2013). Acceleration Profiles in Elite Australian Soccer. *International Journal of Sports Medicine*, 34(1), 34-39
- West, D. J., Cunningham, D. J., Bracken, R. M., Bevan, H. R., Crewther, B. T., Cook, C. J., & Kilduff, L. P. (2013). Effects of resisted sprint training on acceleration in professional rugby union players. *Journal of Strength and Conditioning Research*, 27(4), 1014–1018.
- Wickiewicz, T. L., Roy, R. R., Powell, P. L., & Edgerton, V. . (1983). Muscle Architecture of the Human Lower Limb. *Clin Orthop Relat Res*, 179, 275–283.
- Wisløff, U., Castagna, C., Helgerud, J., Jones, R., & Hoff, J. (2004). Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *British Journal of Sports Medicine*, 38, 285–288.
- Woolford, S. ., Polglaze, T., Rowsell, G., & Spencer, M. (2013). Field testing principles and protocols. In *Physiological test for elite athletes* (2nd ed., pp. 231–248). Human Kinetics.
- Young, W. B., McDowell, M. H., & Scarlett, B. J. (2001). Specificity of sprint and agility training methods. *Journal of Strength and Conditioning Research*, 15, 315–319.
- Young, W., Benton, D., Duthie, G., & Pryor, J. (2001). Resistance Training for Short Sprints and Maximum-speed Sprints. *Strength and Conditioning Journal*., 23(2), 7-13
- Young, W., Hawken, M., & McDonald, L. (1996). Relationship between speed, agility and strength qualities in Australian Rules football. *Strength Cond. Coach.*, 4, 3–6.
- Zafeiridis, A., Saraslanidis, P., Manou, V., Ioakimidis, P., Dipla, K., & Kellis, S. (2005). The effects of resisted sled-pulling sprint training on acceleration and maximum speed performance. *The Journal of Sports Medicine and Physical Fitness*, 45, 284–290.

Aagaard, P., Andersen, J., Dyhre-Poulsen, P., Leffers, A., Wagner, A., Magnusson, S., Simonsen, E. (2001). A mechanism for increased contractile strength of human pennate muscle in response to strength training: changes in muscle architecture. *The Journal of Physiology*, 534, 613–623.

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## Abbreviations

A180°	Agility test
CL	Confidence limits
ES	Effect size
HR	Heart rate
LJ	Long jump
Post-test	Test done after the completion of the intervention
Pre-test	Test done before the start of the intervention
RST	Resisted sprint training
SD	Standard deviation
TE	Typical error
TST	Traditional sprint training
20MST	20-m Shuttle run test

# Appendix

- I Information to participants (Norwegian)
- II Health declaration for participants (Norwegian)
- III Training log template (Norwegian)
- IV Permission of image use



## *I Information to participants (Norwegian)*

# **Sprinttrening for håndballspillere**

Vi vil med dette informasjonsskrivet gi et kort innblikk i vårt prosjekt og be om din deltakelse i dette prosjektet. Prosjektet ”Sprinttrening for håndballspillere” er en del av min master-utdanning i idrettsvitenskap med fordypning i idrettsfysiologi, ved Norges idrettshøgskole.

### **Bakgrunn og hensikt**

I dagens håndballspill er det flere fysiske egenskaper som er viktige. Hurtighet og evnen til å akselerere er noen av de ferdighetene som er viktigst for prestasjon på høyt nivå. Det finnes flere måter å trene hurtighet på, og hurtighetstrening med bruk av slede (motstand) er en populær treningsmetode. Forskningen på dette området er ikke konkluderende, det vil si at det ikke er en enighet om slik trening gir noe ulik fremgang sammenlignet med vanlig sprinttrening. Denne studien vil prøve å finne ut om det er noen forskjeller i treningstilpasningene etter 10 uker med sledetrening vs 10 uker med tradisjonell sprinttrening. Dette vil kunne gi innsikt i hvordan trening for håndballspillere bør legges opp i fremtiden for å kunne være mest mulig effektiv og prestasjonsfremmende.

### **Hva innebærer studien?**

De som skal delta i studien må delta på tilvenningstester, pre-tester, 10 ukers hurtighetstrening og post-tester. Treningen vil foregå 2 ganger i uken, i idrettshallen på Norges Idrettshøgskole. Treningene har en varighet på omtrent 60 min og vil inneholde maksimale spurter på omtrent 20 meter. Dere vil bli delt i to ulike grupper (tilfeldig hvilken gruppe man havner i), den ene gruppen vil trene uten motstand og den andre gruppen vil trene med slede som ekstra motstand. Disse treningene inngår som vanlige treninger (i normale treningstider) for dere som forsøkspersoner. Det kreves at dere møter opp til alle treningene. Dersom det skulle være sykdom eller andre ting som forhindrer deg fra trening, er det ønskelig om økten kan gjennomføres en annen dag, sammen med prosjektansvarlig (Live S. Luteberget). Testene som utføres i studien er 10 og 30 m hurtighetstest, spensttester, agility-test, beep-test, 1RM knebøy og ultralyd av

lårmuskulaturen (m. Vastus lateralis). I tillegg vil vi ha en oversikt over all trening du utfører i løpet av perioden. Dette registreres i egne skjema som vil bli delt ut.

### **Mulige ulemper og risiko**

Deltakelse i prosjektet vil kreve en del tid og oppmerksomhet, og det kreves at du som forsøksperson er tilstede på Norges idrettshøgskole for testing på de ulike testdagene i tillegg til treningene.

De fysiske testene som utføres er maksimale og vil oppleves anstrengende. Dette kan medføre noe ubehag, men ikke mer en dere som idrettsutøvere er vant med gjennom deres daglige trening.

Det vil bli gjennomført ultralydmålinger av lårmuskulaturen. Dette gir små doser stråling, men er ikke farlig. Ultralydmålinger er ikke vondt eller ubehagelig.

Om du skulle oppleve ubehag eller andre ting som du tror kan ha sammenheng med forsøkene, kan du når som helst nå meg på telefon.

### **Hva skjer med prøvene og informasjonen om deg?**

Dataene og informasjonen som registreres under testingen skal kun brukes slik som beskrevet i hensikten med studien. Alle opplysninger vil bli behandlet uten direkte gjenkjennende opplysninger, som navn og fødselsnummer. Du vil ved forsøksstart få utdelt et forsøkspersonnummer som skal brukes under studien og det er bare dette nummeret som vil være knyttet til dine data. Det betyr at alle data vil bli behandlet anonymt.

### **Frivillig deltakelse**

Dersom du ønsker å delta, undertegner du samtykkeerklæringen på siste side. Du kan senere når som helst og uten å oppgi noen grunn trekke ditt samtykke til å delta i studien. Dersom du ønsker å trekke deg eller har spørsmål til studien, kan du kontakte:

Live S. Luteberget

Tlf: 400 43 516

# Samtykke til deltagelse i studien

Jeg er villig til å delta i studien

---

(signert av prosjektdeltaker, dato)

Jeg bekrefter å ha gitt informasjon om studien

---

(signert, rolle i studien, dato)

## II Health declaration for participants (Norwegian)

Etternavn:	Fornavn:	Født:
Studentadresse:		
Hjemmeadresse:		
Tlf.:	E-mailadresse:	
Idrettsbakgrunn (angi idrettsgrener og omtrent hvor mange timer du trener pr. uke):		

### EGENERKLÆRING FOR FORSØKSPERSONER

Takk for at du vurderer å delta som forsøksperson ved Norges idrettshøgskole! Før du kan delta, må vi imidlertid kartlegge om din deltakelse kan medføre noen form for helserisiko. Vær snill å lese gjennom alle spørsmålene nøye og svar ærlig ved å krysse av for JA eller NEI. Hvis du er i tvil, bør du be om å få snakke med legen som er ansvarlig for forsøket.

Hvis du krysser av for JA på ett eller flere av disse spørsmålene, må du gjennomgå en legeundersøkelse før forsøksstart. Ved enkelte typer forsøk vil du uansett bli innkalt til legeundersøkelse.

JA	NEI	
<input type="checkbox"/>	<input type="checkbox"/>	1. Kjenner du til at du har en hjertesykdom?
<input type="checkbox"/>	<input type="checkbox"/>	2. Hender det du får brystmerter i hvile eller i forbindelse med fysisk aktivitet?
<input type="checkbox"/>	<input type="checkbox"/>	3. Kjenner du til at du har høyt blodtrykk?
<input type="checkbox"/>	<input type="checkbox"/>	4. Bruker du for tiden medisiner for høyt blodtrykk eller hjertesykdom (f.eks. vanndrivende tablett)?
<input type="checkbox"/>	<input type="checkbox"/>	5. Har noen av dine foreldre, søsken eller barn fått hjerteinfarkt eller død plutselig (før fylte 55 år for menn og 65 for kvinner)?
<input type="checkbox"/>	<input type="checkbox"/>	6. Røyker du?
<input type="checkbox"/>	<input type="checkbox"/>	7. Kjenner du til om du har høyt kolesterolnivå i blodet?
<input type="checkbox"/>	<input type="checkbox"/>	8. Har du besvimt i løpet av de siste 6 måneder?
<input type="checkbox"/>	<input type="checkbox"/>	9. Hender det du mister balansen på grunn av svimmelhet?
<input type="checkbox"/>	<input type="checkbox"/>	10. Har du sukkersyke (diabetes)?
<input type="checkbox"/>	<input type="checkbox"/>	11. Kjenner du til <u>noen annen grunn</u> til at din deltakelse i prosjektet kan medføre helse- eller skaderisiko?

Gi beskjed straks dersom din helsesituasjon forandrer seg fra nå og til undersøkelsen er ferdig, f.eks. ved at du blir forkjølet, får feber, eller blir gravid.

\_\_\_\_\_  
Sted - dato

\_\_\_\_\_  
Underskrift

### *III Training log template (Norwegian)*

#### **Treningsdagbok**

For å kunne overvåke den totale treningsmengden som skjer i løpet av denne perioden med hurtighetstrening er det nødvendig at dere fører en enkel treningsdagbok. Her skal dere notere ned dato for treningen, hvor lenge økten varer, hva økten inneholdt (f,eks, hurtighetstrening eller håndball) og til slutt gi en karakter (på en skala fra 1 til 10) hvor slitsom økten var. Denne karakteren skal være et tall som bestemmer gjennomsnittet av økten, og dere må derfor ta hensyn til både oppvarming og alle øvelser som blir gjort når du setter denne karakteren. Det er derfor høyst usannsynlig at en økt får karakteren 10 (som er det høyeste på slitsomhetsskalaen). Karakteren som dere setter på økten bør du bestemme deg for omtrent 15-30 min etter at økten er avsluttet. Dette er for å sikre at du husker økten, og at tallet ikke bare blir tilfeldig satt.

I eksempelvis styrketrening må du også tenke på at pausene teller inn som en del av økten, og den samlede karakteren fra økten må derfor settes deretter (ikke bare etter arbeidsperiodene). Dere skal loggføre ALT dere gjør av trening, enten det er fellestreninger, egentreninger eller annen trening dere utfører.

Dere fører inn treningene på utlevert ark og leverer til meg en dag i uken. Dere vil da få nytt ark slik at dere kan føre for neste uke. **ALLE** skal levere treningsdagbok **HVER MANDAG**.

Karakterskalaen er beskrevet under:

<u>Rating</u>	<u>Descriptor</u>
0	Rest
1	Very easy
2	Easy
3	Moderate
4	Somewhat hard
5	Hard
6	-
7	Very Hard
8	-
9	-
10	Maximal

Treningsdagbok for: \_\_\_\_\_

<b>Dato</b>	<b>Type aktivitet</b>	<b>Varighet</b>	<b>RPE (karakter 1-10)</b>

## IV *Permission of image use*



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