Effects of Unilateral versus Bilateral Complex Training and High Intensity Interval Training on the Development of Strength, Power and Athletic Performance

-An experimental study on elite male and female handball players during preseason training

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Abstract

Aim: The purpose of the present study is to examine the effects of 6 weeks bilateral (BL) versus unilateral (UL) complex training combined with high intensity interval training (HIIT) on maximal strength, jumping ability, straight sprint (5, 10, 20 and 30 m), change of direction speed (CODS), repeated sprint ability (RSA) and specific endurance in Swedish elite male and female handball players. Another purpose was to examine if a bilateral deficit (BLD) exists in strength and jumping ability (power deficit) and if it changes differently with 6 weeks BL and UL complex training.

Method: 18 male and 12 female elite handball players was selected to either a 6 weeks bilateral (BL, n = 10) or unilateral (UL, n = 20) complex strength training program. In addition both groups trained HIIT. Training volume, intensity and exercise motion was similar between the groups. Tests included maximal (1RM) UL and BL Smith machine squat strength, UL counter movement jump with arm swing (CMJ) and BL (CMJ), squat jump (SJ) jumping ability, modified T-test, straight sprint (5, 10, 20 and 30 m), repeated shuttle sprint ability (RSSA) and Yo-Yo Intermittent Recovery test (Yo-Yo IR) before and after 6 weeks training.

Results: There was no significant difference between BL and UL groups and any of the selected tests. The UL group significantly ($p < 0.05$) increased sprint time pre- to post testing only between 0-10 m and significantly decreased RSA$_{total}$ pre- to post testing ($p < 0.01$). BL group significantly ($p < 0.01$) increased sprint time pre- to post testing only between 0-30 m. When pooling data from both groups significant ($p < 0.01$) improvements were seen in maximal UL and BL strength, UL CMJ dominant leg, CODS and Yo-Yo IR test as well as increasing the BLD and power deficit for elite male and female handball players.

Conclusion: 6 weeks of complex training using only BL or UL exercises combined with HIIT resulted in no significant changes between groups in any of the selected tests. Training unilaterally could possibly be a safer training method since the absolute load is lesser than BL training.

Keywords: bilateral training, unilateral training, handball, bilateral deficit, complex training.
Sammanfattning

**Syfte och frågeställningar:** Syftet med studien är att undersöka effekterna av 6 veckors bilateral (BL) och unilateral (UL) kombinationsträning kombinerad med högintensiv intervall träning (HIIT) på maximal styrka, hoppförmåga, linjär sprint (5, 10, 20 och 30 m), snabbhet med riktningsförändringar (CODS), maximala upprepade sprinter med kort återhämtning (RSA) och specifik uthållighet på manliga och kvinnliga elithandbollsspelare. Ett annat syfte var att undersöka om bilateral deficit (BLD) existerar i styrke- och hoppövningar (power deficit) och huruvida 6 veckors BL och UL kombinationsträning påverkar förhållandet.

**Metod:** 18 manliga och 12 kvinnliga elithandbollsspelare indelades i aningen ett bilateral (BL, n = 10) eller ett unilateral (UL, n = 20) kombinationsträningsprogram. Utöver kombinationsträningen utförde båda grupperna högintensiv intervallträning (HIIT). Träningsvolymen, intensiteten och övningsval var lika mellan grupperna. Testerna inkluderade maximal (1RM) UL och BL knäböjstyrka i Smith maskin, UL counter movement jump med armsving (CMJ) och BL CMJ, squat jump, (SJ), modifierat T-test, linjär sprint (5, 10, 20 och 30 m), upprepade shuttle sprintar (RSSA) och Yo-Yo Intermittent Recovery Test (Yo-Yo IR) före och efter 6 veckors träning.

**Resultat:** Det fanns ingen signifikant skillnad mellan BL eller UL gruppen i någon av de valda testerna. UL gruppen förbättrade signifikant ($p < 0.05$ ) sprint tiden mellan 0-10 m och minskade RSA$_{total}$ ($p < 0.01$) efter träningsperioden. BL gruppen ökade signifikant ($p < 0.01$) sprint tiden mellan 0-30 m. När data från båda grupperna lades samman visade resultatet signifikanta ($p < 0.01$) förbättringar i maximal UL och BL styrka, UL CMJ på det dominanta benet, CODS och Yo-Yo IR test och även en signifikant ökning i BLD och power deficiten för manliga och kvinnliga elithandbollsspelare.

**Slutsats:** 6 veckors kombinationsträning med enbart BL eller UL övningar och HIIT resulterade inte i signifikanta skillnader mellan grupperna på något av de valda testerna. ULträning kan möjligtvis vara en säkrare träningsmetod eftersom den absoluta belastningen är lägre jämfört med BL träning.
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Abbreviations

**Change-of direction speed (CODS)**
CODS is the physical sub-components of agility where no reaction to a stimulus is required and involve pre-planned movements (Sheppard & Young 2006). Agility is defined as change of direction speed in response to a stimulus.

**Repeated sprint ability (RSA)**
The ability to perform repeated short bouts (< 10 s) of maximal efforts with brief (< 60 s) rest periods (Girard, Mendez-Villanueva & Bishop 2011).

**Repeated shuttle sprint ability (RSSA)**
Repeated shuttle sprint ability is a test measuring repeated sprint ability and consists of repeated 15 m shuttle sprints departed every 20 second.

**Bilateral (BL)**
Defined as two legs acting simultaneously.

**Unilateral (UL)**
Defined as one-leg acting alone.

**Bilateral exercises (BLE)**
Exercises where two legs are acting simultaneously.

**Unilateral exercises (ULE)**
Exercises where one leg is acting alone.

**Bilateral Deficit (BLD)**
The state where simultaneous bilateral contractions produce lesser force compared to the summed identical unilateral contractions (Sale 2005)
1 Introduction

Handball is an Olympic team-sport since 1972 and characterized by an intermittent movement pattern across a 40 m court that involve a high level of aerobic energy metabolism interspersed by high-intensity bursts challenging the anaerobic energy system (Chelly, Hermassi, Aouadi et al. 2011; Póvoas, Seabra, Ascensao et al. 2012; Michalsik, Aagaard & Madsen 2013; Ziv & Lidor 2009). Despite the worldwide popularity of the game, scientific data on the physiological demands of handball is limited (Ziv & Lidor 2009). Studies examining the physiological demands of handball have reported that the most essential factors for successful participation in handball is improving anaerobic components as strength, power and athletic abilities e.g. repeated sprint ability (RSA), sprint ability (Gorostiaga, Granados, Ibáñez & Izquierdo 2005; Ziv & Lidor 2009).

Earlier studies have examined if there is a difference in physical fitness between national and international elite female handball players (Granados, Izquierdo, Ibáñez et al. 2013). The results showed similar results for body mass, height, straight sprint, handball throwing velocity and endurance but significant higher values in maximal strength and power of the upper- and lower limb muscles as well as a higher endurance capacity for the international players. High level of muscular strength and power have been suggested to be essential and an advantage for successful participation in elite handball (Marques & Gonzalez-Badillo 2006; Granados et al. 2013; Gorostiaga, Granados, Ibáñez et al. 2006; Gorostiaga, Granados, Ibáñez et al. 2005). It has been suggested that the ability to perform high intensity work together with a high level of muscle strength could be the most important factors that separate better teams and lesser good teams (Michalsik, Aagaard & Madsen 2013). Thus a combination of speed and explosive resistance training should be used to increase sprint velocity and jumping ability (Chelly, Fathloun, Cherif et al. 2009) and high intensity running for improving the maximal anaerobic power and explosive capacity (Buchheit, Laursen, Kuhnle et al. 2009; Buchheit, Millet, Parisy et al. 2008).

The ability to generate a high level of maximum force and to produce work at a rapid rate (power) is essential for intermittent team-sport (Cormie, McCaulley & McBride 2007). As a consequence resistance training has become the regular method for improving sport-specific performance. For elite athletes competing in intermittent team-sports, small alterations could be the difference between winning or losing and therefore the fundamental topic is the
transfer of resistance training to sport-specific activities as sprinting, change of direction speed (CODS) and jumping (Young 2006).

Methods for improving power and furthermore sport-specific activities are a subject of debate in today’s sport science community. Since most resistance training studies typically includes a short training period (6-20 week) gains is mainly attributed to an improved neuromuscular adaptation rather that hypertrophy (Sale 2005; Häkkinen & Komi 1983). The neuromuscular systems ability to produce maximum power output is critical for overall performance in explosive sports that require jumping, sprinting and throwing activities (Izquierdo, Häkkinen, Gonzalez-Badillo et al. 2002) by increasing the activation of prime movers and improving coordination (Sale 2005). Traditional resistance training and plyometric training have been extensively researched methods while more recent studies have focused on optimal load training, combined training and especially complex training which are gaining popularity (Ebben 2002).

Complex training, defined as “Alternates biomechanically similar high load weight training exercises with plyometric exercises, set for set, in the same workout” (Ebben 2002, pp. 42), is not well studied, especially studies on elite athletes are few. A complex training set could for an example consist of a squat followed by a vertical jump. Heavy resistance training and plyometric training alone have been extensively researched but combining the two methods is thought to improve maximal strength and simultaneous power development. Since intermittent team-sports training is complex and multi-dimensional and requires a combination of aerobic, anaerobic, tactical and technical training etc. and complex training have some potential benefits as innovative and time efficient training strategy for power and simultaneous maximal strength development. Earlier reviews on both male (Ziv & Lidor 2009) and female (Manchado, Tortosa, Vila et al. 2013) handball players have made recommendations that future studies need to focus on intervention studies and the effectiveness of different aerobic training regimes and resistance training studies alone or in a combination. The present study is a continuation of an earlier study (Arin, Jansson & Skarphagen 2012) and aim at examining the potential effects of complex training using only unilateral exercises (ULE) or bilateral exercises (BLE) combined with high intensity interval training (HIIT) for Swedish elite male and female handball players.
2 Background and Previous Research

Unilateral (UL) or one-leg training is considered an alternative method for developing lower-body strength and power (Jones, Ambeganokar, Nindl et al. 2012; McCurdy, Langford, Doscher et al. 2005). When unilateral exercises (ULE) is implemented in a resistance training program it most often serves as supplementary exercises to bilateral exercises (BLE) (Jones et al. 2012). However, there is limited research on the potential physiological effects of comparing training using only BLE and ULE. Acute response of standing ULE has been reported to produce a greater sEMG (surface electromyography) activity in the core musculature compared to standing BLE (Behm, Leonard, Young et al. 2005; Saeterbakken & Fimland 2012). This could be explained by the fact that the base of support becomes reduced when altering from BL to UL movements and as a consequence more unstable which means that in order to meet the requirements of stability and balance the core musculature needs to be recruited to a greater extent.

Some differences have also been reported for acute endocrine signaling between UL and BL upper body training (Migiano, Vingren, Volek et al. 2010). BL training induced a significantly greater increase in lactate and iGH (imunoreactive growth hormone) compared to the UL training program. Testosterone and cortisol response was similar between the training programs. A regular problem when comparing BL and UL training is the difference in volume between the intervention groups. In Migiano et al. (2010) the total work for the UL protocol was 52.1 % of the BL protocol and the observed differences could be due to difference in work. However, testosterone response was still similar despite a higher total work load in the bilateral protocol.

Neuromuscular adaptations between training using only ULE or BLE measured with sEMG have shown conflicting results (Jones et al. 2012; McCurdy, O’Kelly, Kutz et al. 2010; Häkkinen, Kallinen, Linnamo et al. 1996). Häkkinen et al. (1996) examined the effects on strength and EMG after a 12 week general resistance training program using BLE or ULE. Principle of specificity was reported where iEMG increased more in the BLE for the BL group (19 %) compared to the UL group (10 %) and a greater increase in the ULE for the UL group (right leg 9 % and left leg, 7 %) compared to the BL group (7 %). Jones et al. (2012) found similar muscle activity and acute testosterone response between BL back squat and UL pitcher squat although the absolute work was lesser in the pitcher squat. Authors concluded
that UL training could provide the same training gains as BL training while also producing sport-specific strength unilaterally. Limitations of the study were the exclusion of EMG on the supporting leg since the exercise is not a true ULE. McCurdy et al. (2010) reported that 14 % of the total weight in a 3 RM modified UL squat was placed on the supporting leg despite that only the toes were in contact with the bench. McCurdy et al. (2010) reported that the modified UL squat produced a greater activation of biceps femoris and gluteus medius in comparison with the BL back squat that produced a greater activation in rectus femoris.

Research focusing on UL training have developed from asymmetries e.g. different maximal strength between the limbs which have been evident in some studies (Newton, Gerber, Nimphius et al. 2006; Hoffman, Ratamess, Klatt, Faigenbaum et al. 2007; Impellizzeri, Rampinini, Maffiuletti & Marcora 2007) while other have not found a asymmetry (McCurdy & Langford 2005; McElveen, Riemann & Davies 2010). Newton et al. (2006) examined strength asymmetries in 14 women collegiate level athletes and reported a significant strength imbalance between 4 % and 16 % between dominant and non-dominant leg when testing isometric dynamometry, laboratory and field tests. In isoinertial (1RM) lower limb strength measured with a modified UL squat exercise, no significant result was reported when examining asymmetries in young men and women (McCurdy & Langford 2005).

Asymmetries (e.g. strength imbalances between limbs) have also been reported in jumping activities, termed power deficit (Hoffman et al. 2007). Hoffman et al. (2007) reported a significant power deficit between dominant and non-dominant leg (9.7 %) when testing 62 American collegiate football athletes UL counter movement jump (CMJ). Some studies have indicated that a strength deficit increase the risk of injury (Crosier, Ganteaume, Binet et al. 2008) while other research have not reported such relationship (Bennell, Wajswelner, Lew et al. 1998).

Research on strength asymmetries are not consistent and probably vary due to methodological differences (e.g. exercise used) and population tested as well as different training regimes adopted by the athlete. Asymmetries and the relationship to sport-specific performance are still lacking and might be a predictor of sprinting activities and change of direction speed (CODS) tests.
2.1 Bilateral Deficit (BLD)

Theory supporting training unilaterally is the bilateral deficit (BLD) phenomenon which simply states that simultaneous BL contractions produces lesser force compared to the summed identical UL contractions (Sale 2005; Jakobi & Chilibeck 2001). If BL contractions produce greater force than the summed identical UL contractions BL facilitation is evident. Since resistance training induces changes in both skeletal muscle system as well as the neuromuscular system (Behm 1995) an increase in strength is due to muscle hypertrophy as well as its activation (Sale 2005). It is more complex for the human body to fully activate the motor units during simultaneous BL contractions than in identical UL contractions (Sale 2005). Thus the force is lesser during BL contractions compared to the summed forces produced by the left and right limb contracting simultaneously (Sale 2005; Jakobi & Chilibeck 2001).

BLD have been a topic of interest in the latest decades and if a true BLD is evident it would suggest a limitation in the neuromuscular system’s activation (Jakobi & Cafarelli 1998). The BLD have been evident in some (Schantz, Moritani, Karlsson & Johansson 1989; Hay, Souza & Fukashiro 2006; Dickin, Sadow & Dolny 2011; Bobbert, Graaf, Jonk & Casius 2006) types of activities but not in others (Jakobi & Cafarelli 1998). BLD have been reported in isometric contractions (Schantz et al. 1989; Kuruganti, Murphy & Pardy 2011; Vandervoort, Sale & Moroz, 1984). Schantz et al. (1989) found a BLD of 10 % lower maximal voluntary isometric force in BL leg extensions compared to the summed UL leg extensions with no difference in quadriceps femoris sEMG activity between the contractions. Kuruganti, Murphy and Pardy (2011) observed similar results, but found a BLD in isometric knee extensions only during 45° contraction and not in 0° and 90° knee angle. BLD in isometric contractions is however, not consistent and Jakobi and Cafarelli (1998) reported no significant BLD and no significant difference in EMG, motor unit firing rates or co-activation in isometric knee extensions when examining 20 untrained youth participants.

BLD have also been reported during dynamic leg press at 100 % (27.7 %) and 200 % (13.0 %) relative body weight loads (Hay, Souza & Fukashiro 2006). The authors also reported a BLD when measuring sEMG in soleus, medial gastrocnemius, biceps femoris, vastus medialis and rectus femoris.
This BLD have similarly been evident in jumping activities, termed power deficit, where the total work is lesser in BL jumps compared to the summed UL jumps (Bobbert et al. 2006; van Soest, Roebroeck, Bobbert, Huijing & Schenau 1985). It has been reported that the total work in the right leg was 20% less in BL jumps compared to the summed UL jumps (Bobbert et al. 2005). The authors reported that the force-velocity relationship is mainly responsible for the power deficit and a less contributor is the reduction in neural drive. Despite a large body of previous research on BLD, the mechanisms responsible is still unknown and various possibilities have been suggested such as a reduced neural drive to the agonist muscles and a lack of synchronization of agonist muscle activation.

If maximal BL power and strength production presents a problem for the neuromuscular system, one might expect UL training to be a more efficient method of training. The hypothesis behind UL training is the assumption that when training bilaterally the muscles is not working effectively enough which is evident when less force is generated. For acyclic sports as handball where power and force development e.g. sprinting and jumping often is performed unilaterally it is an appealing strategy to also train in a similar manner. However the research on BLD is often performed during isometric contractions (Kuruganti, Murphy & Pardy 2011; Jakobi & Cafarelli 1998), untrained populations (Jakobi & Cafarelli 1998) and involve isolated exercises (Dickin, Sandow & Dolny 2011).

The variability among previous studies could be due to methodological differences, for example testing orders needs to be considered in which randomization is essential. If UL testing is performed before BL testing, fatigue may be evident or post-activation potentiation may affect the results showing a false improvement not actually due to differences between BL and UL contractions (Jakobi & Chillibeck 2001). Research is needed to investigate if BLD is evident in more explosive exercises and complex sport-specific exercises as well as longitudinal research studies. The BLD have also been reported to decrease during a BL training period (Kuruganti, Parker, Rickards et al. 2005; Taniguchi 1997) suggesting that well trained athletes should have a minimal BLD if regular resistance training is implemented.

2.2 Determinants of Motor Performance (cross-sectional studies)

Cross-sectional research is a method that theoretically could give some insight if BL or UL movements differentiate in the relationship to different measures of motor performance (e.g. straight sprint, CODS, RSA).
A large body of research have demonstrated that BL maximal back squat strength have a strong relationship with straight sprint speed at different distances (Wisloff, Castagna, Helgerud, Jones & Hoff 2004; Chaouachi, Brughelli, Chamari et al. 2009; McBride, Blow, Kirby et al. 2009; Chelly et al. 2009; Chelly, Cherif, Amar et al. 2010 a). For example, Wisloff et al. (2004) reported a significantly strong correlation between maximal (1RM) BL half squat strength (90° between femur and tibia) and 10 m and 30 m straight sprint performance (r = 0.94 and r = 0.71, respectively) when examining 17 elite soccer players. However, if the complexity of the sprinting incorporates change of directions (COD), BL strength seems to be a poor predictor (Markovic 2007; Young, James & Montgomery 2002). Markovic (2007) examined the BL isoinertial squat and isometric squat and found low correlations to different CODS tests in 76 young physical education students. Young et al. (2002) also found no significant correlation between BL leg extensor power measured with an isokinetic squat and a CODS test. For elite handball players, UL horizontal jump have been reported to be significantly more related to sprinting ability (5, 10 and 30 m) compared to BL horizontal jump which shared no significant relationship to straight sprinting (Chaouachi et al. 2009).

Some studies have indicated that ULE might be a better predictor of CODS but the relationship is generally low to moderate (Young, James & Montgomery 2002; Hoffman et al. 2007; Arin, Jansson & Skarphagen 2012). Young, James & Montgomery (2002) reported some moderately strong correlation between reactive strength measured with a UL drop jump and CODS performance where participants who turned faster to one side tended to have reactive strength dominance in the leg responsible for the push off action. Hoffman et al. (2007) reported a significant correlation between UL power measured with a vertical jump test in the non-dominant leg and CODS. The authors also examined the power deficit and the relationship to CODS and found no significant relationship. Our earlier unpublished research reported a significant moderate relationship between CODS and UL squat and leg press strength (1RM/BM) in youth ice hockey and soccer players (Arin, Jansson & Skarphagen 2012).

Research have demonstrated that leg strength (Wisloff et al. 2004; Ronnestad, Kvamme, Sunde & Raastad 2008; Chaouachi et al. 2009; McBride et al. 2009; Chelly et al. 2009; Chelly et al. 2010 a) and power (Chaouachi et al. 2009; Chelly, Ghenem, Abid 2010) are
important factors of straight sprint speed. Leg strength and power is also considered to be an important ability for CODS (Young, James & Montgomery 2002). CODS activities are more complex than straight sprint and results from earlier studies are not obvious and more longitudinal research are required to further examine the effects.

Repeated sprint ability (RSA), the ability to perform repeated short bouts (< 10 s) of maximal efforts with brief (< 60 s) rest periods (Girard, Mendez-Villanueva & Bishop 2011) is also a topic that have received more interest recently although correlation studies examining prediction factors are few (Newman, Tarpenning & Marino 2004). Newman, Tarpenning and Marino (2004) examined the relationship between isokinetic knee strength, straight sprinting and RSA in 38 intermittent sports players. The results showed a significant relationship between knee strength and straight sprinting but no significant relationship between knee strength and RSA. This could be argued to be related to specificity, where sport performance is complex multi-joint, multi-plane and closed kinetic chain movements, but it is probably more related to energetics. RSA is a multi-dimensional phenomenon depending on both high initial sprint speed or power output and also the ability to resist fatigue (Glaister, Howatson, Pattison & McInnes 2008; Glaister 2008). Thus, isokinetic knee strength is mainly an anaerobic ability where RSA is not only depending on the ATP-PCr system (Gaitanos, Williams, Boobis & Brooks 1993) but also anaerobic glycolysis (Balsoom, Gaitanos, Söderlund & Ekblom 1999) as well as aerobic metabolism (Thébault, Léger & Passelegue 2011) and thus a more complex skill. For improving RSA, training two main components should be addressed including some form of anaerobic training e.g. resistance training and also aerobic training e.g. interval training.

2.3 Training and Effects on Strength and Power (training studies)

Research using ULE and BLE are common, although, studies actually examining the effects of BL and UL resistance training are few (Jones et al. 2012; McCurdy et al. 2005, McCurdy et al. 2010; Häkkinen et al. 1996). Methodological considerations when training using only BLE or ULE is the volume issue where it often is standardized as equal intensity (e.g. % of 1RM) and volume (set x reps). Another special consideration for these studies is taking body mass into consideration if it involves standing exercises.

The earliest study (table 1) found during the research review, examining effects on strength between UL and BL resistance training was Häkkinen et al. (1996). The study examined
neuromuscular adaptations in middle-aged and elderly men and women when training unilaterally or bilaterally. After 12 week resistance training including knee extension and knee flexion, there was a significantly greater increase in BL 1RM strength for the BL trained group compared to the UL trained group (19 % and 13 %, respectively). Principle of specificity was also demonstrated in UL 1RM strength for right and left leg where UL trained group increased (17 % and 14 %) significantly more than the BL trained group (10 % and 11 %). Similar results were found for iEMG measures and recorded CSA (cross sectional area) did not differentiate significantly between training unilaterally or bilaterally. Taniguchi (1997) reported similar results where principle of specificity was reported after UL or BL training. The author reported some exceptions, UL leg extension power was not significantly enhanced for the UL trained group but a significant increase was reported for the BL trained group. This might be explained by a greater trainability in the BL trained group, according to the author. The BLD was also reported to shift in a positive direction, decreasing the BLD for the BL trained group while the UL trained group reported the opposite development.

McCurdy et al. (2005) examined a more complex multi-joint resistance training program and effects of UL and BL resistance training. The results supported earlier studies (Häkkinen et al. 1996; Taniguchi 1997) with the exception for UL CMJ which improved significantly more for the UL trained group.

Previous studies examining BL versus UL training are few (Häkkinen et al. 1996; Taniguchi 1997; McCurdy et al. 2005) but it seems as principle of specificity is supported. Training bilaterally results in greater improvements for BL strength and power compared to UL training and the opposite for UL strength and power. Studies on well-trained athletes are needed but the effects on UL and BL training should be similar, although one might expect UL training to more important in sports requiring higher frequency of powerful UL movements as handball where UL jumping and changes of direction constantly is executed. Still research are lacking on the effects on motor performance (e.g. RSA, CODS and straight sprint). BL resistance training have been shown to increase straight sprint (Harris, Cronin, Hopkins & Hansen 2008; Chelly et al. 2010 b), CODS (McBride, Triplett-McBride, Davie & Newton 2002; Keiner, Sander, Wirth & Schmidtbleicher 2014) as well as RSA (Bogdanis, Papaspyrou, Souglis et al. 2011; Edge, Hill-Haas, Goodman & Bishop 2006; Hill-Haas, Bishop, Dawson, Goodman & Edge 2007) but effects of UL training are not studied.
Table 1. Summary of training studies comparing bilateral and unilateral training

<table>
<thead>
<tr>
<th>Reference</th>
<th>Sample size</th>
<th>Unilateral training</th>
<th>Bilateral training</th>
<th>Duration (wks.)</th>
<th>Major findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Häkkinen et al.</td>
<td>48 (24 middle-aged men and women and 24 elderly</td>
<td>2 sessions/wk. UL knee flexion and extension +assistance exercises</td>
<td>2 session/wk. BL knee flexion and extension +assistance exercises</td>
<td>12</td>
<td>Demonstrated specificity, UL group ↑ more in UL strength. BL group ↑ more in BL strength. CSA was similar pre-post for both groups. iEMG ↑ more in BL for BL group.</td>
</tr>
<tr>
<td>(1996)</td>
<td>men and women)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2005)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>38 (untrained men and women)</td>
<td>2 sessions/wk. UL squat, lunges, step-up +plyo: pogo jumps, countermovement vertical</td>
<td>2 sessions/wk. UL squat, front squat, countermovement vertical jumps</td>
<td>8</td>
<td>Both groups ↑ UL and BL squat. Similar results for men and women. UL group ↑ significantly more in UL CMJ.</td>
</tr>
<tr>
<td>Taniguchi</td>
<td>21 (4 female, 14 male)</td>
<td>3 sessions/wk. 6 maximal isokinetic leg extensions 3 set/day</td>
<td>3 sessions/wk. 6 maximal isokinetic leg extensions 3 set/day</td>
<td>6</td>
<td>BL group ↑BL strength significantly more, UL group ↑ significantly more in UL strength. BLD decreased for BL group but increased for UL group.</td>
</tr>
<tr>
<td>(1997)</td>
<td></td>
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</tr>
<tr>
<td>McCurdy et al.</td>
<td></td>
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</tr>
</tbody>
</table>

UL = Unilateral, BL = Bilateral, BLD = Bilateral deficit, CMJ = Counter movement jump, CSA = Cross sectional area, iEMG = Intramuscular electromyogram.
2.4 Complex Training and PAP

The effectiveness of training strategies as plyometric training and high-resistance training for improving sport-specific activities (e.g. jumping ability and sprint) is well researched and complex training is gaining popularity (Ebben 2002). The definition of complex training adopted from Ebben (2002, pp. 42), “alternates biomechanically similar high load weight training exercises with plyometric exercises, set for set, in the same workout”. A complex pair can consist of a set of maximal back squat followed by a vertical jump. Complex training have been suggested to increase the training effect by using a high-resistance exercise followed by a plyometric exercise and therefore increasing the excitation of motor neurons and optimizing the neuromuscular response (Tillin & Bishop 2009). Theory supporting complex training is post-activation potentiation (PAP) of the neuromuscular system (Tillin & Bishop 2009) which states that jumping performance is enhanced when preceded by a maximal voluntary contraction (MVC). The mechanisms of PAP (Tillin & Bishop 2009) have been argued to be caused by myosin regulatory light chains causing enhanced sensitivity of myofilaments to calcium ions and thus increasing contractions. Another explanation is an increased recruitment of high-threshold motor units.

Studies examining PAP have found an acute effect (Matthews, Comfort & Crebin 2010; Miyamoto, Kaneshisa, Fukunaga & Kawakami 2011; Mitchell & Sale 2011) while other studies have not reported such effect (Gossen & Sale 2000). The study by Gossen and Sale (2000) not reporting an acute effect, used a long pre-activation of 10 s MVC which resulted in no potentiation effect in dynamic knee extensions, and is probably explained by fatigue. For PAP to be beneficial it seems as a short pre-activation is most beneficial.

Complex training is long-term training using the PAP effect and some studies have reported positive changes in sprint and muscle power (Alves, Rebele, Abrantes & Sampaio 2010) while other studies have not found effects on sprint, agility and endurance but only jumping ability and strength (Faude, Roth, Giovine et al. 2013). Adding complex and contrast training to either one or two training sessions per week compared to a control group for youth elite male soccer players showed a significant improvement in muscle power measured with squat jump and straight sprint at 5 and 15 m but not in CODS for the experimental groups (Alves et al. 2010). Another study examined 6 weeks training using complex training, resistance training or plyometric training and effects on strength and anthropometry (MacDonald,
Lamont & Garner 2012). The results showed a significant increase in strength for all experimental groups and no significant difference between the training modalities.

Heavy resistance training and power training are effective methods for improving strength, power and athletic performance abilities. The literature has more recently directed more focus on complex training but it seems to induce similar improvements as other training methods. The advantage of complex training might be related to more intense training regime as well as time-efficient which could be both practical and useful for team-sport athletes. Studies on elite participants are still lacking and complex training might be more relevant for high level athletes to further increase their level of strength and power. The hypothesis was that unilateral training more closely mimic demands in the sports and should induce greater improvements in sport specific variables as speed especially while changing directions.

3 Aim and Research Questions

The aim of the study is to examine physiological effects of 6 weeks unilateral and bilateral complex training combined with HIIT on maximal strength, power, specific endurance and athletic performance (e.g. straight sprint, CODS and RSA) for Swedish elite male and female handball players during pre-season. Also, to investigate if the bilateral deficit of the lower limbs during maximal strength and jumping testing is evident and if it changes with training performed unilaterally or bilaterally.

1. Examine if complex training performed unilaterally or bilaterally results in different effect on maximal bilateral and unilateral strength and jumping ability, running speed, repeated sprint ability and specific endurance.
2. Examine if a bilateral deficit exists in strength and jumping activities for elite male and female handball players and if it changes with unilateral and bilateral complex training.
3. Examine the effects of complex training twice a week and HIIT twice a week on specific endurance ability for elite male and female handball players.

4 Methods

An experimental approach was adopted in the study to investigate if differences existed in bilateral and unilateral complex training combined with HIIT during the latter part of pre-season for elite male and female handball players. Participants were selected through a selective geographic sampling in the Stockholm area for elite male and female teams.
The study consisted of a familiarization session, pre-test and post-test. Teams were selected to either a 6 weeks bilateral (BL) or unilateral (UL) complex training protocol. In addition both groups trained HIIT twice per week during their regular team handball training. The participants also received a training program designed to prevent injuries in hamstrings, knees, shoulders and ankles. The injury prevention training program was optional and a complement program to use in addition to regular team handball training or in the gym training facilities.

**4.1 Participants**

Two male (n = 18, age: 22 ± 3.8 years; body weight: 84.6 ±10.7 kg; height: 182.7 ± 7.4 cm) and two female (n = 12, age: 23 ± 4.4 years; body weight: 79 ± 9.5 kg; height: 178 ± 6.9 cm) elite Swedish handball teams in the two highest divisions (n = 30, age: 22 ± 3.8 years; body weight: 84 ± 10.3 kg; height: 181.7 ± 8.0 cm) volunteered to participate, after having signed an informed consent form and received an information document (appendix 2 & 3) of the study. The informed consent formed explained the purpose of the study, inclusion criterions and data confidentiality in handling personal data. Participation in the study was voluntary and the participants could choose to cancel their involvement in the study at any time. The information document explained the background, purpose, risks and the procedure of the study. The inclusion criteria for the teams to participate in the study were to be an elite male or female handball team and to have experience of regular resistance training at an advanced level. The exclusion criteria were absence of injury or sickness during the testing days. Participants had to complete about > 85 % of the training sessions to be included in the final analysis. Coaches of each team were consulted to determine which players fulfilled the requirements.

**Table 2.** Descriptive statistics for the bilateral (BL) and unilateral (UL) groups physical characteristics. Values are presented as mean (±SD).

<table>
<thead>
<tr>
<th></th>
<th>UL Group (n = 20)</th>
<th>BL Group (n = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>21.1 ±3.1</td>
<td>22.3 ±5.2</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>83.9 ±11.1</td>
<td>82.8 ±8.9</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>182.9 ±8.0</td>
<td>179.4 ±7.9</td>
</tr>
</tbody>
</table>

*P < 0.05, Statistical significances between groups.
4.2 Familiarization

The participants attended two familiarization sessions one week before the pre-test session. This was done to eliminate learning effects. The familiarization sessions included exercises in the testing protocol that the participants were thought to be unfamiliar with. The exercises included in the familiarization session were maximal (1 RM) UL and BL squat in a standard Smith machine, UL and BL Counter Movement Jump (CMJ) and modified T-test. Test leaders documented the approximate 1 RM strength results, that was used to reduce the numbers of 1 RM trials during the actual strength tests. Participants received standardized technique instructions during each exercises.

4.3 Testing Procedure

To determine if training with UL complex training induce different improvements compared to BL complex training on strength, power and specific athletic abilities a testing battery consisting of nine tests were chosen. The tests were designed to be completed during the time span of regular team handball training. The following tests were included: maximal (1 RM) UL and BL squat in a Smith machine, UL and BL CMJ, Squat Jump (SJ) modified T-test, straight sprint (5, 10, 20 and 30 m), 15 m repeated shuttle sprints and Yo-Yo Intermittent Recovery Test Level 2 (YYIRL2) for male and YYIRL1 for female players. Strength was measured in an applied sport science lab and running tests was measured on a full sized wooden indoor floor. Participants completed the tests wearing their own training shorts, t-shirts and indoor shoes. The sequence of the tests was organized in blocks starting with 1) maximal strength followed by 2) block consisting of jumping, and straight sprint and modified T-test, 3) repeated shuttle sprints and 4) YYIR test. The sequence of testing order was the same during pre- to post testing for each team and person. The participants was instructed not to conduct any strenuous leg training the day before the testing procedures and to train in a similar manners pre- to post testing

The tests started with a 15 min non standardized match specific warm up including running and dynamic stretching. Verbal encouragement was given to the participants. Before the tests were performed, the participants was weighed and measured; wearing shorts, t-shirts, but no shoes.
4.3.1 Maximal Strength

Maximal strength, one repetition maximum (1 RM) in lower limb was measured both bilaterally and unilaterally in a standard Smith machine squat exercises. Additional weights used were standard training discs (Eleiko, Halmstad, Sweden). UL strength was measured in the dominant and non-dominant leg. Dominant leg was defined as the preferred leg kicking a football. BL squat has been used as the standard exercise for measuring complex strength in maximal lower limb isoinertial strength in earlier studies (Wisloff et al. 2004; Ronnestad et al. 2008; Chaouachi et al. 2009; McBride et al. 2009; Chelly et al. 2009; Chelly et al. 2010 a). UL squat is a lesser frequent exercise and have been validated by Tagesson and Kvist (2007).

Depth and foot placement was the same in BL and UL squat and pre- to post-testing. Depth of the squat was standardized to parallel thigh to the ground (half squats). To standardize the foot placement, the participants was instructed to place the middle of the foot right under the bar to mimic a free barbell squat. This was thought to improve both validity and reliability of the test. When starting the test the participants was instructed to lower the center of their body slowly to a position where the depth was achieved (90°) and test leaders gave the signal to start the concentric motion back to full extension in the knee joint (180°). The UL squat was performed standing on a box to reduce the risk of touching the ground in mistake. The test started with 1 RM BL squat followed by UL squat on one leg at the time with about three minutes rest period before the next trial. The weights were increased with 2.5-10 kg until failure. The test aimed at a maximal of five trials until 1 RM was achieved to avoid muscular fatigue.

4.3.2 Jumping Ability

Maximal BL lower limb power test was measured with a counter movement jump with arm swing (CMJ) and squat jump (SJ) tests. Maximal UL power was measured with CMJ on dominant and non-dominant leg. Participants started with a BL CMJ followed by BL squat jump and UL CMJ. Participants had two trials of each jump where the best height was used for analysis. An OptoJump system (OptoJump Next v. 1.3.9.0, Italy) was used to measure the height by the time between take-off and landing with infrared transmitter and reflectors. Infrared transmitter and the reflector were placed in parallel with about 1.5 m distance between. Earlier studies (Petsching, Baron & Albrecht 1998; Sassi, Dardouri, Yahmed et al. 2009) have showed a good test-retest reliability for UL vertical jump (r =0.89) and BL vertical jump (r = 0.95) (Bosco, Luhtanen & Komi 1983). The participants were instructed to perform a fast eccentric-concentric cycle in CMJ with the intention to jump as high as
possible. CMJ with free arm swing was used were the participants was allowed to use their arms to produce power in the take-off phase. Two trials in each exercise where the best trial was documented.

SJ test started with participants in a standing position where they were instructed to lower the center of their body to a self-chosen depth. They were instructed to completely stop the motion before beginning the take-off. The hands were placed on the hips during the complete jump cycle with the thumbs pointing downwards. Participants were instructed to land on their toes followed by a jump immediately after landing. Failed test occurred if the participant used a countermovement motion which resulted in a pre-stretching of the legs or if the position of the hands was not maintained.

4.3.3 Change of Direction Speed (CODS)

A modified T-test adopted from Sassi et al. (2009) was used to measure CODS performance. The test is similar to a regular T-test but with a shorter total distance (20 m) than the regular T-test (36.56 m). Reliability have been reported to be good for both male (r =0.90) and female (r =0.97) athletes (Sassi et al. 2009) The modified T-test place greater demands on the explosive abilities to move while changing the direction and is more specific to the game of handball. This test requires acceleration, deceleration and changing the direction of the participants laterally. The course started with 5 m sprint from cone A to B, touching the cone followed by changing the direction laterally and side shuffling to cone C, touching the cone and changing direction and side shuffling to cone D, touching the cone and side shuffling back to cone B, touching the cone and finishing with backward running to cone A. The test was conducted with a standing start, 50 cm behind the starting gates. Participants started the test at free will. The start was marked with coach tape. Microgate electronic timing gates systems (Globus, Microgate; SARL, Italy) was placed in line with the start/finish line and measuring the time completing the test. The electronic timing system consisted of an infrared transmitter and a reflector placed about 1.5 m between each other with 1.25 m height. The participant had two trials with about 3 minutes rest period between the two trials. The best time were documented. The participants were instructed to run the course as fast as possible and verbal encouragement was given. Failed test occurred if the participants crossed the legs during the side shuffling or broke any of the previously mentioned criterions.
4.3.4 Straight Sprint (5, 10, 20 and 30 m)

Acceleration and top-speed was measured using a 30 m straight sprint test (5, 10, 20 and 30 m). Timing gates (IVAR Measuring systems, Estonia) was used and placed at the starting line, at 5, 10, 20 and 30 m. Height of the timing gates was about 1.25 m with approximately 1.5 m distance between. The test started from a standing start, 50 cm behind the start/finish gates and was marked with coach tape. Two trials were given for each participant with about three minutes rest period. The best time recorded was documented. The participants were instructed to run the course as fast as possible.

4.3.5 Repeated Shuttle Sprint Ability (RSSA)

RSA was measured using 8 repetitions of a 2 x 15 m maximal shuttle runs departed every 20 seconds with passive recovery between the sprints (Buchheit, Millet, Parisy et al. 2008; Buchheit, Mendez-Villanueva, Quod, Quesnel & Ahmaidi 2010). Microgate and IVAR timing systems was both used to measure the time taking to complete the shuttle run. Same timing equipment was used pre- to post testing for each participant. The participants were instructed to line up at the starting position when there was five seconds left of the recovery period. Participants started on free will. The RSSA test is adopted from an earlier study (Spencer, Fitzsimons, Dawson, Bishop & Goodman 2006) which have reported reliable and valid measures of RSA. Four different scores were calculated for the RSA test: best sprint time ($RSA_{best}$; s), mean sprint time ($RSA_{mean}$; s), total time ($RSA_{total}$; s) and percent sprint decrement score ($RSA_{dec}$; %).
**4.3.6 Specific Endurance**

To measure specific endurance for handball players’ ability to recover from high intensity repeated sprints a Yo-Yo Intermittent Recovery Test Level 2 (YYIRL2) was used for males and YYIRL1 for females. The test consisted of repeated 2 x 20 m shuttle run interspersed by 10 seconds active recovery. The speed of the test was progressively increased by an audio signal from a CD-player and the test was completed when the participants was not able to keep up the pace. The goal was to cover the greatest possible total distance. Failing to reach the 20 m shuttle run in time resulted in a warning. Two warnings and the test was complete and the final total distance was documented. The test have been reported to be both valid and reliable for intermittent sports as soccer (Krstrup, Mohr, Amstrup et al. 2003) and handball (Souhail, Castagna, Mohamed, Younes & Chamari 2010).

\[ RSA_{dec} \% = 100 - \left[ \frac{RSA_m}{RSA_b} \right] \times 100 \]

Theoretical VO$_2$ max was estimated from Yo-Yo IRL1 for female players and Yo-Yo IRL2 for male players (Bangsbo, Iaia & Krstrup 2008) following the equations listed below:

\[ YYIRL1 : VO_2 \text{ max} \left( \frac{mL}{min\ kg} \right) = IRL1 \text{ distance} (m) \times 0.0084 + 36.4 \]
4.4 Training Procedure

Before the intervention, the participants attended a training session to learn proper technique of the complex training program. Participants also completed a 3 RM testing in each maximal strength exercise to ensure the correct intensity was used during training. The training program lasted 6 weeks with mid-test completed after 3 weeks to adjust the training load after individual improvements. Training consisted of complex training (2 sessions/week, total duration 45 min/session) and HIIT (2 sessions/week, total duration 12.5 min/session). In addition, the teams were given an injury prevention program to prevent injuries in knees, hamstrings, shoulders, and ankles. The injury prevention program was a complement to the complex training program that could be used during regular team handball training or during the resistance training.

4.4.1 Complex Training

The complex training program was performed with only ULE for the UL group and only BLE for the BL group. Complex training was performed as a resistance training session not in connection to regular handball training. At least 48 hours separated the complex training sessions. The exercises were designed to be performed both unilaterally and bilaterally. Training program was designed to implement similar biomechanical motions in both training groups. When comparing BL and UL training, it was thought that the biomechanical motion should be similar as well as volume and intensity between the groups.

The volume of the training program based on reps, sets and each participant 3 RM were equal between the groups (table 2 and 3). When training and testing UL and BL maximal strength, body weight needs to be considered. During UL training, weights need to be lesser since the higher relative load lifted is higher than during BL training. Plyometric training on the other hand involve the same mass during BL and UL exercises and therefore the volume was standardized to the same contact times for the groups (table 2). The heights of the box during depth jumps was therefore lower in the UL group (0.3 m) compared to the BL group (0.5 m) in line with earlier studies (Stephens, Lawson, Devoe & Reiser 2007; Thomas, Lochbaum, Landers & He 1997; Van Soest et al. 1985).

\[
YYIRL2 : VO_2 \max \left( \frac{mL}{min \ kg} \right) = IRL2 \ distance \ (m) \times 0.0136 + 45.3
\]
4.4.2 High Intensity Interval Training (HIIT)

Both the BL and UL group performed an additional HIIT protocol twice a week (Fig. 3). HIIT consisted of 30 seconds x 5 repetitions all-out running with 2.5 minutes recovery between the intervals in an eight-figured pattern. The HIIT was conducted during regular team handball training on a standard sports hall floor. The goal of the HIIT was to reach the same distance during each interval and progressively increase according to individual progress.

![HIIT Diagram](image)

**Fig. 3** HIIT training performed in an eight-shaped movement pattern starting in one of the corners consisting of 5 repetitions of 30 sec all-out running followed by 2.5 min recovery between the intervals.
4.4.3 Injury Prevention Program

A complementary resistance training program was given to the participants focusing on preventing injuries in typical handball specific locations (knees, hamstrings, shoulders and ankles). Training program consisted of low-intensity exercises using body-weight only, balance disk and cable-cross machine. Part of the program for preventing hamstring injuries was based on Askling, Tengvar and Thorstensson (2013) L-protocol.

4.5 Statistical Analysis

Test scores were initially analyzed using Microsoft Excel (Microsoft, Redmond, WA). The final statistical analysis was completed using Statistica (StatSoft, version 11).

The BLD was calculated as previously reported (Howard & Enoka 1991; Hay, Souza & Fukashiro 2006):

\[ BLD\% = \left( \frac{Bilateral}{Dominant + non - dominant leg} \right) - 100 \]

A positive (BLD > 0%) value indicated a bilateral facilitation and opposite, a negative value (BLD < 0%) indicated a bilateral deficit. Since BLD was measured with a standing squat in a Smith machine body weight was added to the total load excluding the estimated shank and feet weight. Standard weight deductions for the feet (women 1.29%, male 1.29%) and shank (women 4.81 %, male 4.33%) were 5.7 % for male and 6.1 % for female athletes for one leg (Leva 1996).

Distribution of normality was proved with the Shapiro-Wilk W test and parametric statistics were applied. Values were expressed as means ±SD or change (%) pre- to post testing. Level of significance was set at \( p \leq 0.05 \). A general linear model with repeated measures analysis of variance was used with 1 between factor (training type; UL vs. BL) and 1 within factor (period; pre- vs. post-testing). Significant results were further examined with a post-hoc test.

5 Results

Only players who completed pre- and post-testing were included in the final analysis. Two players were excluded from the final analysis due to missing values. There were no significant differences between the UL and BL group before the training intervention period.
in any of the measured variables (body mass, height, maximal UL and BL maximal strength, UL and BL jumping ability, straight sprint, modified T-test, RSSA and endurance).

5.1 Maximal strength

Tests before and after the intervention presented as mean (±SD) maximal BL squat, BL squat expressed relative to body mass (kg/BM), UL dominant squat and UL non-dominant squat in table 5 for both groups.

Table 5. Maximal strength variables (mean ± SD) measured before (PRE) and after (POST) the 6-week training program in the unilateral (UL) and bilateral (BL) groups.

<table>
<thead>
<tr>
<th></th>
<th>UL Group (n=20)</th>
<th>BL Group (n=10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PRE (SD)</td>
<td>POST (SD)</td>
</tr>
<tr>
<td>BL squat (kg)</td>
<td>119.4 ± 35.8</td>
<td>128.5 ± 39.4</td>
</tr>
<tr>
<td>BL squat (kg/BM)</td>
<td>1.41 ± 0.34</td>
<td>1.51 ± 0.37</td>
</tr>
<tr>
<td>UL dom squat (kg)</td>
<td>34.6 ± 22.3</td>
<td>44.3 ± 22.0</td>
</tr>
<tr>
<td>UL non-dom squat (kg)</td>
<td>35.6 ± 21.2</td>
<td>46.3 ± 19.5</td>
</tr>
</tbody>
</table>

BL Squat = Bilateral squat, UL dom squat = Unilateral dominant leg squat, UL non-dom squat = Unilateral non-dominant squat. * Significant pre- to post testing within groups at $p < 0.05$ level. ᵻ Significant pre- to post testing between groups at $p < 0.05$ level.

There was no significant interaction for BL squat strength, UL dominant and non-dominant squat strength * period * training type ($p = 0.41$). After training, all strength performance was significantly improved when pooling data from both groups (all: $p < 0.01$).

5.2 Bilateral deficit (BLD)

There was no significant interaction between pre- and post-testing * training * BLD ($p = 0.14$). BLD significantly increased pre- to post testing when pooling data from both groups (all, $p < 0.01$). UL group increased the BLD with 28.3% (±186.7) while BL group increased the BLD with 5.8% (±51.7) after the intervention, although not significantly. After training both groups showed greater improvements in the unilateral strength tests compared to the bilateral strength test and thus increasing the BLD.

Table 6. Maximal strength variables (mean ± SD) measured before (PRE) and after (POST) the 6-week training program in the unilateral (UL) and bilateral (BL) groups.

<table>
<thead>
<tr>
<th></th>
<th>UL Group (n=20)</th>
<th>BL Group (n=10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PRE (SD)</td>
<td>POST (SD)</td>
</tr>
<tr>
<td>BLD (%)</td>
<td>-14.4 ± 10.1</td>
<td>-18.4 ± 7.1</td>
</tr>
</tbody>
</table>

BLD = Bilateral deficit. * Significant pre- to post testing within groups at $p < 0.05$ level. ᵻ Significant pre- to post testing between groups at $p < 0.05$ level.
5.3 Jumping Ability

After training, there was no significant interaction for CMJ, UL CMJ dominant and non-dominant jumping \( \times \) period \( \times \) training type (\( p = 0.87 \)). There was no significant interaction when pooling data from both groups for CMJ and UL CMJ non-dominant leg and pre- and post-testing (all, \( p = 0.11 \) and \( p = 0.49 \)) but a significance for UL CMJ dominant leg (all, \( p < 0.01 \)). No significant interaction between SJ \( \times \) period \( \times \) training type (\( p = 0.16 \)) and SJ pre- and post-testing (all, \( p = 0.83 \)). Pooled group significantly improved UL CMJ on dominant leg (all, \( p < 0.01 \)). After the training intervention, similar results was seen between training groups and both groups maintaining jumping ability except for UL CMJ on dominant leg which improved.

Table 7. Jumping variables (mean ± SD) measured before (PRE) and after (POST) the 6-week training program in the unilateral (UL) and bilateral (BL) groups.

<table>
<thead>
<tr>
<th></th>
<th>UL Group (n= 20)</th>
<th>BL Group (n=10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PRE (SD)</td>
<td>POST (SD)</td>
</tr>
<tr>
<td>CMJ (cm)</td>
<td>43.5 ± 9.9</td>
<td>42.4 ± 9.0</td>
</tr>
<tr>
<td>SJ (cm)</td>
<td>31.1 ± 6.9</td>
<td>31.8 ± 7.1</td>
</tr>
<tr>
<td>UL dom CMJ (cm)</td>
<td>22.5 ± 4.5</td>
<td>24.3 ± 5.0</td>
</tr>
<tr>
<td>UL non-dom CMJ (cm)</td>
<td>24.1 ± 6.0</td>
<td>25.0 ± 6.2</td>
</tr>
<tr>
<td>Power deficit (%)</td>
<td>-6.6 ± 9.5</td>
<td>-13.7 ± 8.0</td>
</tr>
</tbody>
</table>

CMJ = Counter Movement Jump arm swing, SJ = Squat Jump, UL dom CMJ = Unilateral dominant leg Counter Movement Jump arm swing, UL non-dom CMJ = Unilateral non-dominant leg Counter Movement Jump arm swing. * Significant pre- to post testing within groups at \( p < 0.05 \) level. † Significant pre- to post testing between groups at \( p < 0.05 \) level.

For the power deficit there was no significant interaction power deficit \( \times \) period \( \times \) training type (\( p > 0.05 \)). Pooled data showed that the power deficit significantly increased after the training period (all, \( p < 0.01 \)). After training, both groups showed larger improvements in the summed UL CMJ on dominant and non-dominant leg compared to CMJ which increased the power deficit and thus jumping higher unilaterally compared to bilaterally.
5.4 Running Speed

Table 8. Speed variables (mean ± SD) measured before (PRE) and after (POST) the 6-week training program in the unilateral (UL) and bilateral (BL) groups.

<table>
<thead>
<tr>
<th>Speed variable</th>
<th>UL Group (n=20)</th>
<th>BL Group (n=10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PRE (SD)</td>
<td>POST (SD)</td>
</tr>
<tr>
<td>Sprint 0-5 m (s)</td>
<td>1.10 ± 0.07</td>
<td>1.09 ± 0.08</td>
</tr>
<tr>
<td>Sprint 0-10 m (s)</td>
<td>1.84 ± 0.12</td>
<td>1.87 ± 0.13*</td>
</tr>
<tr>
<td>Sprint 0-20 m (s)</td>
<td>3.22 ± 0.23</td>
<td>3.21 ± 0.25</td>
</tr>
<tr>
<td>Sprint 0-30 m (s)</td>
<td>4.50 ± 0.34</td>
<td>4.49 ± 0.37</td>
</tr>
<tr>
<td>Mod. T-test (s)</td>
<td>5.67 ± 0.42</td>
<td>5.58 ± 0.34</td>
</tr>
</tbody>
</table>

Mod. T-test = Modified T-test. * Significant pre- to post within groups at p < 0.05 level. † Significant pre- to post testing between groups at p < 0.05 level.

For straight sprint there was a significant interaction sprint (5, 10, 20 and 30 m) × period × training type (p < 0.01) but no significant results between groups. UL group significantly decreased velocity pre- to post testing, within group, only between 0-10 m (p < 0.05). BL group significantly increased sprint time pre- to post testing, within group, only between 0-30 m (p < 0.01).

![Sprint (% change)](image)

Fig. 8 Mean % change (SD) sprint time at 5, 10, 20 and 30 m before (PRE) and after (POST) a 6-week intervention for the bilateral (BL) and unilateral (UL) groups. * Significant pre- to post within groups at p < 0.05 level. † Significant pre- to post testing between groups at p < 0.05 level.

There was no significant interaction for CODS between period × training type (p = 0.08). UL group decreased CODS time with -1.6 (±2.7) % and BL group decreased CODS time with -3.9 (±4.2) %, but not significantly. Pooling data from both groups showed a significant (p < 0.01) improvements in CODS pre to post-testing.
Fig. 9 Mean % change (SD) CODS time before (PRE) and after (POST) a 6-week intervention for the bilateral (BL) and unilateral (UL) groups. * Significant pre- to post testing within groups at $p < 0.05$ level.

5.5 Repeated Shuttle Sprint Ability (RSSA)

There was no significant interaction for period $\times$ training type for $\text{RSA}_{\text{dec}}$ ($p = 0.96$) or $\text{RSA}_{\text{total}}$, $\text{RSA}_{\text{best}}$ and $\text{RSA}_{\text{mean}}$ ($p = 0.08$). Pooled data showed significant improvements in $\text{RSA}_{\text{total}}$ pre- to post testing ($p < 0.01$) and no significance for $\text{RSA}_{\text{best}}$ ($p = 0.10$) and $\text{RSA}_{\text{mean}}$ ($p = 0.10$).

UL group improved, but not significantly, $\text{RSA}_{\text{dec}}$ with -6.2 (±2.5) % and BL group improved with -5.9 (±1.2) %. UL group improved $\text{RSA}_{\text{mean}}$ with -1.5 (±2.2) %, $\text{RSA}_{\text{total}}$ -1.5 (±2.2) % and $\text{RSA}_{\text{best}}$ 1.25 (±2.24). BL group improved $\text{RSA}_{\text{mean}}$ with -0.2 (±1.4) %, $\text{RSA}_{\text{total}}$ -0.2 (±1.4) % and $\text{RSA}_{\text{best}}$ 0.05 (±1.81) %.

Table 9. RSA (mean ± SD) measured before (PRE) and after (POST) the 6-week training program in the unilateral (UL) and bilateral (BL) groups.

<table>
<thead>
<tr>
<th></th>
<th>UL Group (n=20)</th>
<th>BL Group (n=10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PRE (SD) POST (SD)</td>
<td>PRE (SD) POST (SD)</td>
</tr>
<tr>
<td>$\text{RSA}_{\text{total}}$ (s)</td>
<td>50.92 ± 3.80 50.16 ± 4.23</td>
<td>51.16 ± 3.38 51.06 ± 3.54</td>
</tr>
<tr>
<td>$\text{RSA}_{\text{mean}}$ (s)</td>
<td>6.36 ± 0.47 6.27 ± 0.53</td>
<td>6.40 ± 0.42 6.38 ± 0.44</td>
</tr>
<tr>
<td>$\text{RSA}_{\text{best}}$ (s)</td>
<td>6.08 ± 0.38 6.00 ± 0.43</td>
<td>6.14 ± 0.39 6.14 ± 0.43</td>
</tr>
<tr>
<td>$\text{RSA}_{\text{dec}}$ (%)</td>
<td>-4.65 ± 3.20 -4.36 ± 2.03</td>
<td>-4.22 ± 1.05 -3.97 ± 1.47</td>
</tr>
</tbody>
</table>

$\text{RSA}_{\text{dec}} = $ Repeated Sprint Ability decrement * Significant pre- to post within groups at $p < 0.05$ level. † Significant pre- to post between groups at $p < 0.05$ level.

5.6 Specific Endurance

There was no significant interaction for period $\times$ training type for Yo-Yo IR total distance ($p = 0.62$) and theoretical $\text{Vo}_2 \text{ max}$ ($p = 0.93$). Pooled data showed significant improvements in
specific endurance in Yo-Yo IR test (all, \( p < 0.01 \)). UL group improved Yo-Yo IR total distance with 9.6 (±17.7) % and BL group 13.0 (±21.8) %, although not significantly. Pooled data showed significant (all, \( p < 0.01 \)) improvements in calculated VO\(_2\) max with 1.9 (±2.7) % and 2.0 (±2.4) % respectively.

**Table 10.** Specific endurance (mean ± SD) measured before (PRE) and after (POST) the 6-week training program in the unilateral (UL), bilateral (BL) groups and total (All).

<table>
<thead>
<tr>
<th></th>
<th>UL Group (n = 19)</th>
<th>BL Group (n = 9)</th>
<th>All (n = 28)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Yo-Yo IR total distance (m)</strong></td>
<td>PRE (SD)</td>
<td>POST (SD)</td>
<td>PRE (SD)</td>
</tr>
<tr>
<td></td>
<td>661.1 ±249.6</td>
<td>724.2 ± 211.6</td>
<td>664.4 ± 202.9</td>
</tr>
<tr>
<td><strong>Yo-Yo IR VO2max (ml/l/min)</strong></td>
<td>49.5 ± 5.5</td>
<td>50.4 ± 6.4</td>
<td>48.5 ± 5.2</td>
</tr>
</tbody>
</table>

Yo-Yo IR = Yo-Yo Intermittent Recovery test. * Significant pre- to post within groups at \( p < 0.05 \) level. † Significant pre- to post between groups at \( p < 0.05 \) level.

**Fig. 10** Mean % change (SD) Yo-Yo IR total distance before (PRE) and after (POST) a 6-week intervention for the bilateral (BL), unilateral (UL) groups and all (total). * Significant pre- to post testing within groups at \( p < 0.05 \) level.

**6 Discussion**

The main purpose with the study was to examine if BL or UL complex training combined with HIIT results in different effects on maximal UL and BL strength, UL and BL jumping ability, straight sprint speed, CODS, RSA and specific endurance. The hypothesis was that UL complex training should have greater effects on speed, especially CODS since UL training more closely mimic the demands in the movement’s compared to BL training. Another purpose was to evaluate the effects of relatively low and time efficient dose of endurance training, HIIT, on specific endurance. Finally, the study examined if a BLD is
evident in maximal strength and jumping activities for elite male and female handball players and if it changes with training.

The main results of the study showed no significant difference between 6 weeks UL or BL complex training and HIIT on any of the selected tests and both training interventions induce similar gains in short-term training effects.

When pooling data from both groups the results showed that an addition of 6-weeks complex training and HIIT training resulted in significant improvements in maximal BL and UL strength, UL CMJ on dominant leg, CODS, RSSA and specific endurance for elite male and female handball players. The addition of heavy resistance training and plyometric training (complex training) to handball training resulted in gains in maximal strength, but it may have compromised gains in the production of explosive abilities as sprint and some of the jumping abilities.

Training complex training bilaterally or unilaterally and HIIT twice a week resulted in similar results on specific endurance and both improving endurance. The same was evident for the BLD and power deficit where no significant changes were found between groups. Both groups increased the BLD and the power deficit pre- to post-testing which is explained by greater improvements in the summed UL strength compared to BL strength, after the intervention program.

### 6.1 Maximal Strength

Training complex training bilaterally or unilaterally significantly \((p < 0.01)\) improved maximal strength both unilaterally and bilaterally with no significant difference between training groups. The large variance in strength was due to difference in strength between men and female but don’t affect the results because the study examined effects pre vs. post testing. The results suggest that training bilaterally or unilaterally improves both UL and BL strength which is in line with earlier studies (McCurdy et al. 2005). Other studies have reported specificity where BL resistance training increases BL strength more than UL resistance training and the opposite (Taniguchi, 1997; Häkkinen et al. 1996). This could possibly be explained by the exercise selection and it seems as the more isolated exercises that require less neuromuscular adaptations is chosen the greater difference between UL and BL resistance training. For the athletes in this study BL resistance training was used as standard training regimes while UL resistance training was an unfamiliar procedure in regular
resistance training. The UL groups struggled more with balance, stability and coordination with movements and a longer training period might have shown greater differences between the groups.

The training program consisted of three basic and often used exercises as squat, deadlift and leg press and associated with some risk of injury if the technique is not executed correctly. Training unilaterally could be argued not to be as effective as BL training since the load is greater in BL training but the results in this study suggests that both interventions results in similar effects. UL training is not as time efficient training as BL training but could possibly be a safer training method that induce similar effects at least in short-term training programs.

6.2 Bilateral deficit (BLD)

For Swedish elite handball players a BLD of about -15% was evident before the training period which is in line with previous studies on dynamic exercises (Hay, Souza & Fukashiro 2006). After the intervention there was no significant difference between training group and BLD although the UL group increased the BLD more than the BL group (28.3% and 5.78%, respectively). Earlier training studies have reported that the BLD decrease during a BL training period (Kuruganti et al. 2005; Taniguchi 1997). This could be due to the fact that the training history for the athletes in this study used mainly BL resistance training as standard, and therefore UL squat was easier to improve and as a result the BLD increased.

6.3 Jumping Ability

Training bilaterally or unilaterally resulted in no significant changes between groups in any jumping test. The only significance for all the jumping tests was for UL CMJ on dominant leg \( (p = 0.01) \) which increased for both groups. McCurdy et al. (2005) showed that bilateral and unilateral resistance and plyometric training induced similar effects on bilateral vertical jump but with a significant higher unilateral jump for the UL group. Similar results were shown in this study but with no significant results. UL complex training seems to induce positive effects on jumping ability although it might need a larger training group to see significant results. Although a large increase in maximal strength both unilaterally and bilaterally was seen in both groups it resulted in few significant improvements in jumping ability after the training intervention. Combining unilateral strength with bilateral jumping training might be a better training program for increasing power since the mass during unilateral jump is too large for optimal power development.
Combined resistance training and plyometric training have also been reported to significantly increase maximal lower limb strength and SJ height but with no significant improvements in CMJ height (Ronnestad et al. 2008). Increasing maximal strength does not automatically increase exercises that include stretch-shortening cycle. The reason for not increasing CMJ is not obvious and could be due to the program design, overtraining, short training period or low statistical power.

Both the UL and BL group showed a power deficit before the training period which has been evident in earlier studies (Bobbert et al. 2006; van Soest et al. 1985). The power deficit doubled after the training intervention for both groups with no significant changes between the groups. The main reason for doubling the power deficit is probably because of the decrease in CMJ for both groups while the UL CMJ increased after the training intervention. When examining the power deficit it is important to take the training history into consideration since it changes depending on to specific training program adopted by the athlete. Training bilaterally or unilaterally seems to result in similar effects on the power deficit.

6.4 Running Speed

For straight sprint, the UL group significantly ($p < 0.05$) increased sprint time pre- to post testing between 0-10 m. BL group significantly ($p < 0.01$) increased sprint time pre- to post testing between 0-30 m. No earlier studies were found investigating BLE and ULE effects on speed. There was no consistent difference between the groups and it seems as UL and BL short term complex training results in similar training effects. Complex training twice a week seems to maintain rather than improve straight sprint time at least during a short training period for elite male and female handball players. Earlier research have reported similar results for handball players during an entire season where maximal strength increasing with no significant changes in sprint time (Granados, Izquierdo, Ibanez et al. 2008). Complex contrast training using a combination of jumping, strength and sprinting has been reported to increase sprint performance in junior soccer players (Alves et al. 2010). Preseason training often includes a high training volume and it has probably affected the results on the explosive abilities as sprinting and jumping ability negatively. The variance in sprint time is probably due to gender being pooled but also individual differences in training effects during a
demanding training period. A decrease in training volume before the post testing might have shown more positive results.

For CODS there was no significant difference between group and pre- and post-testing in modified T-test ($p > 0.05$). Pooling data from both groups showed a significant ($p < 0.01$) improvements in CODS. Some earlier studies have shown that heavy resistance training improve CODS in short-term (McBride et al. 2002) and long-term (Keiner et al. 2014) while other have not reported improvements following complex training (Faude et al. 2013). The results was unexpected, and it was thought that unilateral training should be more specific to CODS performance since it require force production performed unilaterally and a high level of balance and stability on one leg at a time. Standing unilateral training is a greater challenge for the neuromuscular system since the base of support is reduced which require more balance and stability and therefore a longer familiarization compared to the bilateral training program. Possibly it might require a longer training period to see any differences.

### 6.5 Repeated Shuttle Sprint Ability (RSSA)

Training intervention was designed to improve the aerobic fitness determinant of RSA by reducing the fatigue over repeated sprints with HIIT and to increase the power and maximal strength factor by increasing the initial sprint speed (e.g. the first sprints, acceleration) with complex training. RSA was measured using a RSSA test consisting of repeated 15 m shuttle runs and the results was presented as RSA$_{\text{mean}}$, RSA$_{\text{total}}$, RSA$_{\text{best}}$ and RSA$_{\text{dec\%}}$. There was no significant differences between training group and pre- and post-testing for RSA$_{\text{dec\%}}$, RSA$_{\text{mean}}$, RSA$_{\text{total}}$, RSA$_{\text{best}}$ ($p = 0.08$).

Earlier studies have shown that BL resistance training with high loads (90% of 1RM) is superior compared to moderate loads (70% of 1RM) for improving RSA in soccer players (Bogdanis et al. 2011). Other studies have showed improvements in RSA for moderately trained female students with high repetition (15-20), short rest period (20 s) moderate to low intensity loads resistance training (Edge et al. 2006; Hill-Haas et al. 2006). There was no earlier studies found researching effects of complex training and HIIT on RSA and the results shows some minor advantages for unilateral training to be more effective for improving RSA$_{\text{total}}$. All RSA variables showed larger improvements in the UL group compared to the BL group although the UL group had a higher, but not significantly, initial RSA test value pre testing. This is the first study showing that unilateral complex training have some importance
for developing RSA. A control group only training handball training had been an advantage but since handball players at elite level often include some type of resistance training it would have been difficult to include. A longer training period or a larger sample seize might be required to see significant results. It seems as different types of resistance training and HIIT is effective for developing RSA but probably depends on the population tested.

6.6 Specific Endurance

There was no significant change pre- to post-testing between groups but a significant improvement in both YYIR total distance (all, $p < 0.01$) and theoretical $VO_2$ max (all, $p < 0.01$) when pooling data from both groups. The results suggest that with relatively low volume HIIT improves specific endurance during a 6 week training period.

Earlier studies support the use of 30 seconds HIIT for improving endurance in well-trained handball players (Buchheit et al. 2010). Although the lack of a control group, other studies have examined the effects of an entire handball season at elite level and not found any significant changes in endurance during pre-season or in-season in both male (Gorostiaga et al. 2006) and female players (Granados et al. 2008). For well-trained handball players HIIT twice a week could be used to improve specific endurance during the latter part of preseason.

6.7 Limitations

The results of the study is difficult to compare with other studies since few studies have compared bilateral versus unilateral training in well-trained athletes and no study were found examining its effect on running speed and RSA. The main purpose was to examine if there is a difference between complex training performed unilaterally or bilaterally and the results suggests that the two training modalities result in similar effects, at least in short-term training. A control group only training regular handball training was lacking in the present study design because strength and endurance training in some form was considered to be an essential part of handball preparation, and therefore not practically or ethically reasonable for the players to be excluded from.

Another purpose with the study was to examine an addition of HIIT twice a week on endurance performance and although YYIR total distance improved with 10.7% it is not possible to determine if this increase was due to regular team handball training or HIIT training since no control group was included.
Another limitation of the study was the unequal participants in the BL and UL groups and a short training period. It would be interesting to see a longer periodized training period since 6 weeks intervention might be too short to see any differences. At least the unilateral training would require a longer period before heavy loads could be lifted. Also a larger sample groups is required since this type of complex training probably have varied effect on different individuals. Both male and female participants were pooled in the analysis as a result of too few participants and comparing gender differences was not possible. This was not considered a limitation since the study measured the difference between before and after a 6 week training period.

All testing was performed on the same day for practical purposes which could have resulted in fatigue in the players especially for the explosive abilities. Greater improvements would probably have been seen if strength and power, speed and endurance was tested at separate days. Testing battery and test order was the same pre- to post testing which made it possible to compare effects of the training intervention. All players except four was tested during preseason with the pre-test in the beginning of the preseason and the post-test close to the starting of the season. Training volume during preseason is often large and most of the players were fatigued at the post-test which probably caused the compromise in the explosive abilities. The results would probably been different if the post-test was preceded by a week of low-volume training.

7 Conclusion

Six weeks of complex training using HIIT in combination with BLE or ULE resulted in similar improvements in strength, jumping ability, CODS, straight sprint, RSA and specific endurance for elite male and female handball players. Pooling data from the UL and BL group showed significant improvements in BL and UL maximal strength, UL dominant leg jumping ability, CODS, RSA_total, RSA_mean, YYIR total distance and theoretical VO2max. Training unilaterally could possibly be a safer training method since the absolute load is lower than BL training and results in similar improvements in strength, jumping ability and athletic performance factors. Short-term complex training using BLE or ULE increased both the BLD and power deficit. HIIT training twice a week and complex training twice a week significantly improved specific endurance in elite male and female handball players.
Future studies examining BL versus UL resistance training should focus on longer periodized training programs that could possibly conclude if UL and BL training results in similar effects on long-term training.
References


Appendix 1 - Source- and literature search

Aims and research questions: The main aim of the study is to examine effects of UL versus BL complex training combined with HIIT on the effects on maximal UL and BL strength, UL and BL jumping ability, straight sprint, CODS, RSA and endurance ability. Another purpose is to examine if a BLD exists in maximal strength and jumping ability and if it changes with 6 weeks UL and BL complex training. Finally, to examine effects of 6 weeks HIIT on endurance capacity for elite male and female handball players.

1. Examine if complex training performed unilaterally or bilaterally results in different effect on maximal bilateral and unilateral strength and jumping ability, straight speed, change of direction speed, repeated sprint ability and specific endurance.

2. Examine if a bilateral deficit exists in strength and jumping activities for elite male and female handball players and if it changes with unilateral and bilateral complex training.

3. Examine effects of adding HIIT twice a week on specific endurance ability for elite male and female handball players.

Which search word did you use?

<table>
<thead>
<tr>
<th>Bilateral training</th>
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</thead>
<tbody>
<tr>
<td>Unilateral training</td>
</tr>
<tr>
<td>Complex training</td>
</tr>
<tr>
<td>Bilateral deficit</td>
</tr>
<tr>
<td>Handball</td>
</tr>
<tr>
<td>Power deficit</td>
</tr>
<tr>
<td>Change of direction speed</td>
</tr>
<tr>
<td>Agility</td>
</tr>
<tr>
<td>Combined resistance and power training</td>
</tr>
</tbody>
</table>

Where have you searched?

PubMed, Ebsco, GIH:s biblotekskatalog, Google Scholar, Sports Discus,

Which searches gave relevant results?
Comments

Most of the articles were found from Pubmed.
Appendix 2 - Informed consent form 1(1)

Informerat dokumenterat samtycke
Du inbjuds härmed delta i en studie genomförts på Gymnastik och Idrottshögskolan. Syftet med studien är att se eventuella skillnader mellan kombinerat styrke- och plyometrisk träning utfört på ett eller två ben. Testerna inkluderar snabbhet i riktningsförändringar, linjär sprint (5, 10, 20 och 30 m), spänst och styrka på ett och två ben, specifik kondition (Yo- Yo IRL) och upprepade sprinter.

Det som förväntas av dig som testperson är att genomföra en invänjningsperiod, två testtillfällen samt 6 veckors träning av complex training. Testerna kommer att bestå av linjär snabbhet och i riktningsförändringar, repeated sprints, Yo-Yo IRL2, spänst på ett och två ben samt maximal styrka i smithmaskin utfört på ett och två ben.

Familjäriseringsperioden kommer att ske vid 2 tillfällen en vecka innan pre-tester. Testerna kommer att utföras vid Gymnastik och Idrottshögskolan. Samtliga tester instrueras och övervakas noggrant av tre testledare. Träningen kommer lagen att få bedriva i sina egna träningslokaler.
Inklusionskriterierna för deltagande är att vara aktiv handbollsspelare på elitnivå. Deltagarna får inte ha någon nuvarande skada eller lida av någon pågående infektionssjukdom som kan påverka testresultaten. För att säkerställa att du är vid full hälsa kommer vi att be dig fylla i en hälsodeklaration.


Datum och underskrift________________________ Namnfördyvigande________________________

Tack för ditt deltagande!
Daniel Jansson
Tel: 0730568128, mail: danne_889@hotmail.com
Appendix 3 - Information to participants 1(2)

Idrottsvetenskap – Mastersprogrammet vid Gymnastik- och Idrottshögskolan (GIH)

Information till deltagare i studien:

Bilateral och unilateral styrketräning och effekter på atletisk prestation

Bakgrund
Tidigare forskning har hittat ett samband mellan styrka i benmuskulaturen och linjär sprint på distanser mellan 0-20 m. Man har även försökt hitta ett samband mellan snabbhet i riktningförändringar och styrka i benmuskulaturen, men misslyckats. Tidigare forskning har framförallt fokuserat på träning på två ben, i isokinetiska maskiner och oftast isolerade övningar. Lite forskning har utförts på styrka på korrelationer mellan styrka på ett ben, agility och linjär sprint samt träningsstudier. Med tanke på att de flesta lagidrotter utförs i huvudsak på ett ben i taget är det av intresse att jämföra vilka effekter complex training har utfört på ett eller två ben på idrottsspecifika tester.

Syfte
Syftet med studien är att se eventuella skillnader mellan complex training utfört på ett eller två ben på idrottsspecifika test som linjär sprint, snabbhet i riktningförändringar upprepade sprints, spänst och uthållighetsförmåga.

Projektets upplägg
Testerna sker genom ett samarbete mellan GIH och Bosön under ledning av erfarna testledare i styrketräning och styrkemätning. Du som deltar i detta program kommer att genomgå ett träningsprogram under 6 veckor där kommer att träna complex training utfört på alltingen ett eller två ben. Före och efter träningsperioden kommer tester att utföras. Testerna kommer att bestå av 1 RM styrka i knäböj i smithmaskin både på ett och på två ben, linjär sprint, snabbhet i riktningsförändringar, CMJ, Yo-Yo, IRL2 samt upprepade sprinter (repeated sprints). Studiens tester sker vid Gymnastik och Idrottshögskolan.

Betydelse
Resultaten av denna studie ska ligga till grund för ökad kunskap om träningstillverkning för idrottsspecifika rörelsemönster.

Vad innebär medverkan i projektet?
All testning är kostnadsfri. Du kommer att kallas till sammanlagt två testtillfällen (beräknad tidsåtgång är ca 2.5 timmar per lag och tillfälle). Tag med träningskläder (shorts och t-shirt) samt inomhusskor.
Du kommer att få tillfälle att genomföra tester som är relevanta för din idrott. Du får inte genomföra någon mycket ansträngande fysisk träning som involverar benmuskulaturen dagen innan testtillfället.

Information to participants 2(2)

**Fördelar och risker med att delta i studien**

**Risken**

Att delta i studien kräver lite tid och uppmärksamhet från din sida, det krävs att du är tillgänglig vid två tillfällen. Testprotokollet som genomförs är maximala tester som kan medföra muskelsmärta (träningsvärd) dagarna efteråt. Testerna kan också uppfattas som ansträngande.

**Fördelar**

Du har möjlighet att delta i ett spännande och nytänkande forskningsprojekt som kan utmynna i ny kunskap om idrotts- och specifik träning. Som deltagare har du möjlighet att ta del av information samt praktiskt utöva de senaste inom forskningen angående styrketräningsmetoder med hjälp av högteknologisk utrustning som annars skulle vara väldigt kostsamma att genomföra. Alla som deltar i studien kommer att vara anonyma i arbetet. Alla som deltar i studien kommer vid projektets slut få resultat av studien presenterat i form av ett utskrivet exemplar av examensarbetet. Dessutom är man välkommen att lyssna på vår presentation av projektet.

**Rätten att avbryta medverkan i projektet**

Deltagandet i projektet är helt frivilligt.

**Om Du undrar över något är Du välkommen att ringa någon av oss i projektgruppen.**

Daniel Jansson, tel: 0730-56 81 28
Mail: danne_889@hotmail.com

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Med. dr. i fysiologi Gymnastik och Idrottshögskolan