HALMSTAD UNIVERSITY

EXERCISE BIOMEDICINE - HUMAN PERFORMANCE 60 ECTS

MASTER THESIS

Effects of 16 Weeks of Unilateral or Bilateral Resistance Training with Varying Movement Velocity on Measures of Power and Performance in Elite Women's Hanball Players

Marie Elliott

Biomedicine with Exercise Physiology application, 30 credits

Halmstad 2016-06-05

Effects of 16 weeks of Unilateral or Bilateral Resistance Training with Varying Movement Velocity on Measures of Power and Performance in Elite Women's Handball Players

Marie Elliott

2016-05-24

Master Thesis 30 credits in Exercise Biomedicine- Human Performance Halmstad University

School of Business, Engineering and Science

Thesis Supervisor: Charlotte Olsson

Thesis Examiner: Ann Bremander

Abstract

Background. Handball is a fast paced sport, with high velocity movements performed in a predominantly unilateral plane. In order to make training as specific as possible to on court movements, resistance training programmes should involve exercises that reflect the speed and stance of how they will be performed during gameplay however, working velocities are rarely prescribed due to the lack of research in the area. **Aim.** The aim of this study was (1) to determine the effect of three different training modes; unilateral high velocity (UHV), bilateral high velocity (BHV) and bilateral slow velocity (BSV) on vertical loaded and unloaded jumps, sprint, agility and balance. (2) To determine if any of these interventions had more of an effect when compared to each other. **Methods.** 29 women from four teams in the Swedish Elitserien participated in a 16-week intervention study. Teams were assigned to either UHV, who performed unilateral exercises with a high intended movement velocity, BHV, bilateral exercises at a high intended movement velocity, or BSV, who continued their regular bilateral slow velocity training. Power was assessed pre- and post-intervention by loaded vertical squat jump and countermovement jump (CMJ) both unilaterally and bilaterally. Performance assessments were conducted through 20m Sprints, agility T-test and Y-balance test. Effect sizes were calculated to determine the magnitude of differences from pre- to post-intervention in three training modes. One-way ANOVA determined if the group interactions were significant. **Results.** All three training modes increased their power output to varying levels and effect sizes. The UHV group demonstrated large effect sizes for all improvements in power output, whilst the BHV and BSV groups ranged from trivial to large. UHV got significantly faster at reaching time to peak velocity in unilateral and bilateral measures compared to both BHV and BSV (p=<0.05). **Conclusion.** The results suggest that a 16-week resistance training intervention regardless of stance improves power however to varying magnitudes. The high velocity groups showed greater improvements in measures of power and performance. This study suggests that resistance training at a high intended movement velocity may be beneficial for improving power and performance in elite women's handball players.

Table of Contents

Introduction

Team handball (hereby referred to as handball) is an increasingly popular, fast paced sport. Elite handball players need to demonstrate excellent proficiency in speed, functional strength and agility (Hermassi et al., 2010), skills which can be improved by increasing power output. To improve power through resistance training focus should be on its individual components; force and velocity. There is a consensus that an increase in force through maximal strength, increases measures of sports performance, as seen in the sprint (McBride et al., 2009) and in jumps (Comfort et al., 2014). Along with agility and balance these sporting movements are central to handball (McCurdy et al., 2005). When aiming to improve power in sporting movements specificity is key, as the majority of the movements take place unilaterally (one leg at a time), some aspect of training should be unilaterally focussed. Despite this the majority of handball teams and players conduct their resistance training using traditional exercises performed slowly and bilaterally on two legs (Nijem & Galpin., 2014).

The speed at which resistance exercises are performed correlates with sports specific movements (Pereira & Gomes., 2003), meaning traditional resistance training with slow movement velocity may not be entirely applicable, however, no real consensus exist in regards to which movement velocity should be used for best improvements in power (Pereira & Gomes., 2003). Theoretically and through gained experience however, some aspects of the resistance training programme ought to be more sports specifically designed, which for handball players could mean a unilaterally focussed resistance training programme performed with a focus on increasing movement velocity to better simulate the stance and velocity most commonly used in the game. Therefore, the purpose of this study was to study the effect of, and the difference between the three resistance training interventions varying in stance and movement velocity on elite women handball players.

Background

Handball

Handball is an Olympic team sport that is increasing in professionalism, particularly in Europe. Handball consists of high impact intermittent exercise with a great degree of lateral movements, jumps and throws (Hermassi et al., 2010). Handball players require proficiency in a wide range of skills including strength, power and speed (González-Ravé et al. 2014). The size of a handball court (40m by 20m), duration (2 x 30mins) and pace of the game means handball poses a unique situation in terms of team sports and generic training plans. In relation to other sports handball players are, for example, more powerful than footballers but less than basketballers (Karcher & Buchheit 2014). During gameplay the longest unbroken interval a player can be on the court for is 30 minutes, however, very few players play an entire period. The rules allow for unlimited substitutions allowing both offensive and defensive players frequent rest. A study analysing gameplay dynamics found that defence and attack phases rotate on average every 22 to 36 seconds with an average recovery time of 60 seconds (Karcher & Buchheit 2014). Therefore, aerobic endurance is not the highest priority for a training programme, although it should not be entirely disregarded (Chaouachi et al., 2009). They also found that performance characteristics didn't significantly differ between positions. This may be due to the size of the court and the nature of the game meaning that players tend to be able to perform in most outfield positions during the course of the game (Chaouachi et al., 2009).

Power is a crucial skill for handball players. Being able to generate a high power output, not only aids in the standard sporting movements previously mentioned, but is also a key component of handball specific movements such as jumping and throwing velocity. In a review of the gameplay and its aspects during a handball game Karcher et al (2014) stated that throwing velocity was one of the most vital skills in handball and all players need to demonstrate a high proficiency for the skill. In order to improve throwing velocity, athletes need to be able to produce a high amount of power, starting from the lower body. In order to compete successfully, coaches need to give specific considerations to the development of power.

Resistance Training and Power

Anaerobic muscle power can be defined as: "The ability to rapidly generate and apply a large amount of force and thereby impart a high velocity to the body, its segments and/or external objects" (Shetty et al., 2002) The application of power is limited to posture, contraction type and movement pattern, implying that power is specific to its functional context and should be assessed accordingly (Maulder et al., 2005).

Power is the product of force and velocity and individual focus needs to be given to each aspect in order to improve power output. The strong relationship between maximal strength and power dictates that one cannot be powerful without a degree of strength. An athlete's strength will determine their ability to generate power (Wilson et al., 1997). This relationship has been shown by the differences between untrained, sub-elite and elite athletes in their abilities to generate power. In studies using untrained participants, as their maximal strength increased so did their power output, this phenomenon has been shown in both upper body (Moss et al., 1997) and lower body (Cormie et al., 2010). The ability to produce large amounts of power is highly beneficial for sports performers as the relationship between power output and common sporting movements has been shown numerous times. In a study determining the relationship between power and sprint performance Cormie et al (2010) found that after 8-weeks of ballistic training, trained men increased their 40m sprint performance. Vertical jump, both loaded (McBride et al., 2002) and unloaded (Hawkins et al., 2009) have been shown to improve after a training intervention focussed on improving maximal strength.

However, increases in strength only aid the production of power to a finite point. As athletes increase their strength their physical capabilities to further improve diminish (Cormie et al., 2011). Due to these diminishing adaptations highly trained athletes are expected to experience either a slower increase or a plateau in maximal power gains if they continue the same training regime. Therefore, to continue to increase maximal power changes to the training programme need to be made. One such adaptation is through changing the stance of the movement from the commonly used bilateral stance to the more sport specific unilateral stance.

Bilateral and Unilateral Resistance Training for Power

Bilateral exercises are the most commonly used variations of resistance exercise (Spiers et al., 2016). It is more commonplace in training programmes to start with bilateral movements and progress to unilateral as the performer becomes more skilled (McCurdy et al., 2005). However, when the basic movements in many sports are considered the majority are performed unilaterally or activate one leg at a time, such as running, jumping and change of direction (Nijem & Galpin., 2014). The lack of inclusion of unilateral exercises in many resistance training programmes could partly depend on resistance training performed unilaterally requires a higher degree of skill and balance. Also, partly due to the lack of research showing conclusively if unilateral is superior to bilateral resistance training.

One of the main benefits of unilateral training is the destabilising effect of working on one leg forces the deeper muscles of the hip and trunk to activate, and thus strengthen. (Ekstrom et al., 2007; McCurdy et al., 2010). A study by McCurdy et al, (2010) found that moderate instability affects the force that can be produced, so by performing movements in an unstable position, as experienced in unilateral stance, the performer can improve motor recruitment. The study also found that in order to maximally activate the hip abductors squats should be performed with higher loads and at high intensity. This translates into an increased force production as strength gains are made up of both neuromuscular development and an increase in muscle cross sectional area.

Unilateral exercises have become more common in strength and conditioning programmes within sub-elite and elite sports teams, but there is a lack of research showing the effects of a training intervention on trained individuals. In a five-week intervention study Speirs et al, (2016) compared the effects of bilateral and unilateral training programmes on measures of lower body strength, sprinting and change of direction speed on academy rugby players. After the intervention there were no significant differences between the bilateral group and the unilateral in back squat 1RM, sprint times and pro-agility times. The short training period coincided with pre-season preparation in which weight gain was a component, possibly affecting the results. This is one of the only papers to perform a comparison study on the effects of a unilateral training programme on elite performers. The results and methodology of which, are useful for both coaches and future researchers. A similar study using untrained women found that the improvements to be found in unilateral training are at their highest for the first six weeks. Beyond this the effects of unilateral training plateau, and after a four week detraining phase both bilateral and unilateral groups showed similar improvements (Makaruk et al. 2011). However, there are no comments on how variation in the training programme affects this plateau.

Although studies into unilateral training have increased over recent years these studies tend to focus on confirming or denying the existence of the bilateral force deficit in varying populations. Very few studies look into how a training intervention affects practical performance and even fewer still that assess trained athletes. More research is needed into the effect of unilateral training on power output and other markers of sports performance in trained athletes to provide coaches with scientific, rather than anecdotal, evidence with which to base their training programmes around.

High Intended Movement Velocity

Velocity is the second half of the power equation. The velocity at which a load is moved is dependent on the intent of the participant to move the load and its magnitude (Pareja-Blanco et al., 2014). Movement velocity is the least understood of the changeable mechanics of resistance training, yet it may be one of the most crucial for adaptation, especially in a resistance training programme. However, due to the lack of controlled studies investigating the effect of movement velocity on strength and power, training plans rarely mention a specific working velocity and when they do it is often vague.

The theory that the intention to move at high velocity is just as important as the actual velocity was first observed by (Behm & Sale 1993) . Their paper has remained one of the most cited pieces in this area. The theory states that the intention to move at a high velocity has a greater effect on the high velocity strength gains regardless of the actual movement velocity.

The available literature surrounding intended movement velocity is extremely varied with regards to the way the protocol is performed. A review by Pereira and Gomes (2003) identified several different modalities used, from isokinetic to hydraulic based. Isokinetic studies are the most popular, and they reach some agreement that training at a high movement velocity improves strength at high velocities and vice versa, however isokinetic movements have very little external validity when applied to sporting movements (Kawamori et al. 2006) . Surprisingly, there are very few papers that focus on isotonic movements, which are the most common form of resistance training and are more specific to team sports

An issue with intended movement velocity is that it relies almost exclusively on the motivation of the participants and it is extremely difficult to tell if the participants are working at their highest possible intensity, without considerable expense or invasive procedures (Pareja-Blanco et al., 2013). It takes a conscious effort to achieve the explosive contractions that are necessary for the development of fast force production that is often observed in aforementioned crucial sporting movements. As motivation is a key factor in the successful implementation of high velocity resistance training it would be more suitable for sub-elite and elite athletes as it has been shown that they tend to be more highly motivated and have the necessary experience in resistance training (Halldorsson et al., 2012).

A study by Young & Bilby (1993) compared how different training velocities improved measures of strength and muscular power in trained male participants. They found there was a trend towards the slow group improving strength and the fast group improving on speed. This agrees with the theory by Behm and Sale (1993) that the intention to move explosively is highly important in a training programme, regardless of the load being moved.

Resistance Training in Handball Players

Several studies have investigated different aspects of resistance training with regards to handball players. The majority of these studies have been primarily focussed on upper body strength and power (Hermassi et al., 2010; Saeterbakken et al., 2011). Some resistance training studies for handball players exist which look at lower body strength and power aspects both from a cross-sectional and longitudinal perspective. Cross-sectional studies on elite men's handball investigating the relationships between different physiological variables found that unilateral movements correlated well with sprint times, whereas bilateral didn't (Chaouachi et al., 2008). In a study using isokinetic strength testing no relationship was found between lower body power and peak torque (González-Ravé et al., 2014).

Longitudinal studies on both men and women in handball have found a positive effect in training response in both men's and women's handball players. After 8-weeks of both upper and lower body heavy resistance training performed during the playing season Hermassi et al (2011) found that men's handball players jump height, muscle volume and peak power all improved in a heavy resistance training group compared to a control. In a season long study Granados et al (2008) assessed changes in physical fitness and anthropometric measures of women's handball players. The study found that there were increases in 1RM measures and fat free mass, along with power output, vertical jumping height and throwing velocity. The results from this study highlight the importance of resistance exercise for women's handball players who wish to improve their power output.

To the author's knowledge, no previous resistance training intervention has investigated the effects of both stance and movement velocity on power output. Therefore, this study will compare both of these variables by using three groups; unilateral stance with high intended movement velocity (UHV), bilateral stance with high intended movement velocity (BHV) and bilateral stance with slow actual movement velocity (BSV). In addition, only a few studies have investigated either of these variables separately in highly trained athletes and none of these interventions have been on elite women athletes.

Aim and Hypotheses

The aim of the current study was two-fold:

1) To determine the effects of a 16-week intervention for three different resistance training modes; UHV, BHV and BSV on vertical loaded jumps, sprint, agility, countermovement jump (CMJ) and balance in elite women's handball players.
2) To determine if any of the three resistance training modes; UHV, BHV or BSV, had more of an effect on vertical loaded jumps, sprint, agility, CMJ and balance compared to the other resistance training modes after 16 weeks of training in elite women's handball players.

It was hypothesised that all three training modes; UHV, BHV and BSV would improve in power (assessed by loaded vertical squat jumps), determined by moderate to large effect sizes. This is due to evidence from previous literature showing that both unilateral and bilateral resistance training programmes of more than 5 weeks have a moderate to large effect on power.

It was hypothesised that the UHV group would show greater improvements in the measures of sprint, agility and balance compared to the BHV and BSV groups due to the training movements more closely relating to the movement patterns of the testing (i.e. being able to produce large amounts of power on one leg.).

It was further hypothesised that the high velocity training intervention groups (UHV and BHV) would significantly improve power output as assessed by loaded vertical squat jump, when compared to the slow velocity training intervention (BSV).

It was also hypothesised that due to the speed of their resistance training intervention the UHV and BHV groups would reach peak velocity quicker in loaded vertical squat jump after 16 weeks of high velocity resistance exercise on one leg (UHV) and two legs (BHV) compared to the BSV, as represented by time to peak velocity.

Methodology

Subjects

Elite women’s handball players from four teams in the Swedish Elitserien, average age 20.3 years (2.3), height 174.0cm (5.8) (for group breakdown see Table 2) participated in the study during their off season. 52 players participated in the pre testing, whereas 29 players completed the full testing protocol and intervention. There were a variety of extenuating circumstances for this dropout rate. Most common reasons were; injuries, player transfers and playing for different national teams (meaning they could not follow the training plan). The original plan was to have four different groups, each one following a different resistance training plan, but due to the lower number of participants from two of the teams they were provided with the same intervention and one intervention group (unilateral resistance training with slow movement velocity) was excluded from the study. The teams were each given a training plan which would place them in one of three groups; unilateral high velocity (UHV) (n=12) including lower body resistance exercises performed exclusively on one leg at a time with high intended movement velocity, bilateral high velocity (BHV) (n=7) with lower body resistance exercises performed solely on two legs with high intended movement velocity, or bilateral slow velocity (BSV) (n=10) where only bilateral strength training was conducted with slow actual movement velocity. All subjects had at least basic experience in resistance training before starting the study.

Training Intervention

The UHV and BHV groups were provided with a detailed training plan, including 32 strength training sessions, over 16 weeks, performed twice a week. Of the 16 weeks, 12 weeks were supervised. The resistance training exercises of the UHV group were the unilateral equivalent of the bilateral exercises prescribed to the BHV group. These exercises included: unilateral or bilateral variations on squats, deadlifts and friction based exercises. The training programme also consisted of identical upper body exercises for a full resistance training programme for all study participants. For the complete training programme see appendix 1. Throughout most of the resistance training intervention participants in the BHV and UHV groups were supervised and told to perform all their exercises as quickly, but safely, as possible in both concentric and eccentric phases. All exercises were done with heavy loads (>80% of 1RM).

The players in the BSV group were asked about their regular resistance training routine and after noting that all of the included athletes performed their exercises bilaterally with a slow movement velocity they were instructed to train their regular traditional bilateral resistance training twice a week, at a controlled, slow movement velocity over the same period of time as the other two groups and keep a training log. Training was unsupervised since the athletes in the BSV group trained at different facilities and not together as a group. None of the athletes had any other scheduled strength training during the intervention, however there was no control over what the athletes did in their off time, and all teams continued the pre-season training with their team coach including handball technique and tactics, endurance training, sprint training and each team followed their own handball training regime.

Pre- and Post-Intervention Performance Testing

During the testing session, the groups were split into two subgroups in order to make assessment more time efficient. Before any testing was conducted participants undertook a 20 minute standardised warm up which included jump and sprint movements. After this, half of the group started assessment on the loaded and unloaded vertical jumps whereas the other half started on other performance measures such as sprint, agility and balance. All testing stations were monitored by trained test leaders familiar with the testing protocol.

Loaded Vertical Squat Jump

To measure power outputs and velocity times loaded vertical squat jumps (LVSJs) were performed. Protocols were conducted in the same way for all groups. To ensure the safety of the participants unilateral LSVJ tests were performed in the Smith machine whilst the bilateral LVSJ tests were performed with free weights and spotters were available to step in if needed. A linear encoder was attached to the bar for measurements of power (MuscleLab 4020, ErgoTest, Norway). Weights were then loaded onto the bar and the participant placed the barbell along the back of their shoulders. For the bilateral LSVJ, the participants bent at the knee until thighs were parallel with the ground before rising and jumping explosively. The bilateral assessments were performed with both legs at the same time for weights of; 20kg, 30kg, 40kg, 50kg and 60kg. Unilateral LVSJ were performed on the left leg and then the right leg with weights of; 20kg, 30kg and 40kg. For both bilateral and unilateral LSVJ each participant did three trials on each weight and the trial with the highest power was saved for later analyses, along with measures for average power eccentric, average power concentric and time to peak velocity in both bilateral and unilateral stances. The use of a linear encoder to determine power output was assessed for validity and reliability by Cronin et al (2011). They determined that linear encoders have a very high relationship with the measures collected from force plates (r=0.67-0.88) and determined it to be a reliable method (ICC=0.88-0.96).

Unloaded Jump Testing

A series of unloaded countermovement jump tests (CMJ) were measured in this study; bilateral and unilateral (left and right). For the bilateral countermovement jumps (CMJb) participant were told to jump as high as possible with their hands on their hips. The unilateral CMJs were performed on the left leg (CMJl) and the right leg (CMJr), again with hands on hips. Participants were instructed to bend at the hip and knee and then immediately jump up as high as they possibly could and land softly in the testing zone. This was assessed by a researcher observing the positioning before it took place, also via infrared beams (MuscleLab, ErgoTest, Norway) which converted the time spent in the air into jump height (cm). The use of CMJs has been deemed a reliable field test (ICC=0.98) to assess lower body power, with a high correlation (r=0.87) with squat jumps (Markovic et al., 2004)

Y-Balance test

In order to assess the balance of the players a Y-balance test was conducted according to Pilsky et al (2009) with some minor adjustments. The test was done on a non-slip surface, with the three legs of the Y marked in mm, with hands on the hips at all times. In more detail, participants stood in the middle of the 'Y' on one leg and with hands on hips. Maintaining a single legged stance participants were required to reach with the non-standing leg in anterior, posteromedial and posterolateral directions. This was repeated for left and right legs in the recommended order of; anterior, posteromedial, and posterolateral. Before measures were recorded each participant had six practice movements, as it has been shown in previous studies that after six trials, length stabilises (Hertel,2006). Participants reached as far as they could and an assessor marked where the tip of their toe touched the ground. This was repeated for three successful turns in each direction. In order to provide a comparable score limb length was measured from the anterior superior iliac spine to the distal portion of the medial malleolus. The equation used for scoring was: sum of all directions/ (3x limb length) x 100 (reported in cm). The Y-balance test was chosen to assess possible differences in balance between groups since unilateral resistance training has previously been shown to affect stability in. The interrater reliability for the Y-Balance test has been investigated and was classed as good (ICC=0.85-0.93) by Shaffer et al (2013).

Sprint-Testing

Data was collected for participants at 5,10 and 20 meters (Infrared gates, MuscleLab, ErgoTest, Norway) on an indoor track. After a brief warm up and trial, each participant had two trials to run through electronic timing gates at a maximal sprint, starting 50 cm from the start and was instructed to continue at maximal speed beyond the final gate. The best time from all distances was chosen for later analyses and all times were recorded to three decimal places.

T-Test

Change of direction, also referred to as agility, was measured using the T-test. Testing was done using the same protocol as Pauole et al., (2000) who, in their study confirmed the validity and reliability of the T-test as a measure of agility and leg speed for both men and women. Participants started at their own will, ran as quickly as possible to the centre cone, side-stepped to the left side cone and then right to the opposite marker, sidestepped back to the middle cone, then ran backwards to the start. Timing was done with timing gates. During the test participants were not allowed to cross their ankles when changing direction, if this happened the test was disallowed and the participant conducted it again.

Ethical and Social Considerations

All subjects were informed of the protocols and purpose of the study and provided their written informed consent. They were told that participation was voluntary and that they were free to leave the study at any time, without explanation. The study was approved by the regional Swedish ethics committee (Lund, Dnr 2013/707)

Available data pertaining to handball players is sparse so new research is welcomed by coaches, especially as the popularity of the sport increases. The results of this study may be applicable both to handball players and other team sports. Data from elite performers is not very common, and being able to implement a training study on elite performers is less common still, therefore, new data regarding the effects of resistance training is beneficial for multiple populations. It also holds relevance to the further general population; the ACSM position stand recommends that all populations take part in at least 2 resistance training sessions a week (ACSM, 2011). The relationship between chronic resistance exercise and general muscle health is widely documented (ACSM, 2011). Therefore, more information about the different types and their benefits for certain populations can be beneficial for exercise prescribers.

Statistical Analysis

All analyses were done using the statistics package (SPSS, v.20, IBM statistics, New York, United States). To assess if there were any significant differences between the participants' anthropometric measures at the start of the resistance training intervention, a one-way analysis of variance (ANOVA) was conducted on age, height, pre- and post-weight. Anthropometric measures were reported as means, whereas for values of weightlifting experience participants provided a score out of 5 (1= no experience- 5= very experienced), therefore, this variable was expressed as a median value and analysed by Median test. In order to determine the magnitude of the effect of the intervention, effect sizes (ES) are reported. These were calculated with the equation (post mean-pre mean)/pre standard deviation provided by Rhea (2004). The scale of magnitude constructed by Rhea (2004) was used to determine the size of the effect (Table 1)

To investigate changes in the variables of interest from pre- to post-intervention percentage change and actual change were calculated from the mean values for loaded vertical squat jumps and for sports performance measures; 20m sprint, T-test agility, CMJ and Y-balance test. New variables were then tested for normality. Actual change data met the assumptions of normality and a one-way ANOVA was conducted to determine if there were any significant differences between the three groups for the intervention. After analysis it was found that there for 5, 10 and 20m sprints the results were the same for all groups, therefore it was decided that only 20m sprints would be reported to avoid repetition of information. In this study we had a rather low number of participants in each group. Therefore, the level of significance was set to $p<0.10$ to >0.05 for determination of trends and $p<0.05$ for statistical significance in order to reduce the possibility of committing a type II error. If significant values were found both at the $p<0.10$ and 0.05 level, then post-hoc analysis was conducted using independent samples t-test to determine which groups differed.

Table 1: Rhea's (2004) Scale for determining the magnitude of effect sizes for highly trained individuals

Magnitude	Highly Trained
Trivial	<0.25
Small	0.25-0.50
Moderate	0.50-1.0
Large	>1.0

Results

To establish if there were any differences between the groups before the intervention a one-way ANOVA was conducted. This confirmed that there were no significant differences between the groups for age, height, weight and weightlifting experience at the start of testing (Table 2). Assessing median values for level of experience showed that the UHV group rated themselves as having resistance training experience as being "somewhat experienced", whereas both the BHV and BSV groups rated their experience as "good". The scale ran from 1-5 and was defined as; 1= no experience, 2= little, 3=somewhat, 4=good, 5=large.

Table 2: Statistical analysis of anthropometric measures and weightlifting experience. Age, height and bodyweight reported as Mean (SD). Weightlifting experience: Median (range).

Characteristic	UHV (n=12)	BHV (n=7)	BSV (n=10)	One-Way ANOVA (*p*)
Age (years)	20.0 (2.3)	19.9 (1.6)	21.0 (2.8)	0.52
Height (cm)	174.0 (5.71)	174.6 (6.99)	175.0 (5.74)	0.93
Bodyweight Pre (kg)	71.6 (7.6)	70.8 (7.81)	70.1 (7.8)	0.90
Weightlifting Experience (Scale 1-5)	3.5 (2.0)	4.0 (2.0)	4.0 (2.0)	0.43

Effect of Training Intervention

To investigate the effects of a 16-week intervention for the three resistance training groups UHV, BHV and BSV on loaded vertical power, CMJ, sprint, agility and balance in elite women's handball, effect sizes were calculated for each variable and per group. Along with this a magnitude value from trivial to large (Table 1) was provided to determine the magnitude of the effect.

Unilateral High Velocity Group

The UHV group showed improvements in the bilateral loaded vertical power assessments (table 3) with large effect sizes seen in; eccentric power (ES= 1.45), concentric power (ES=1.98) and time to peak velocity (ES=1.49). Similarly, large effect sizes were also seen in the unilateral loaded vertical power assessments; eccentric power left (ES=1.59) and right (ES=1.13), concentric power left (ES=3.35) and right (ES=1.37) and time to peak velocity left (ES=1.65) and right (ES=1.27). For the other performance variables only trivial to small effects were seen in either direction.

Bilateral High Velocity Group

There were fewer large effect sizes in the BHV group compared to UHV (Table 3). However, large effect sizes were seen for improvements in concentric measures of power (ES=1.27) in the bilateral assessments (table 3). Again in the unilateral power assessments the larger effect sizes were seen for increases in concentric power, both left (ES=2.70) and right (ES=1.62). There as a trend for BHV to have higher effect sizes than both UHV and BSV for improvements in measures of sports performance with moderate effects seen in the agility T-test (ES=0.56) Y-balance test left (ES=0.62) and right (ES=0.79).

Table3: Pre and Post measures of performance and power assessments and their effect sizes. Effect size magnitude reported as: TRV=Trivial, SML=Small, MOD= Moderate, LRG= Large. +=Increase -=Decrease. Boundaries as described by Rhea (2004). All values presented as mean (SD)

	Unilateral High Velocity M (SD)			**Bilateral High Velocity M (SD)**			**Bilateral Slow Velocity M (SD)**		
	PRE	POST	ES	PRE	POST	ES	PRE	POST	ES
Bodyweight (kg)	71.63 (7.60)	73.66 (8.30)	+0.27 SML	70.84 (7.81)	71.59 (8.31)	+0.09 TRV	70.10 (8.31)	72.42 (7.73)	+0.28 SML
20m Sprint (s)	3.49 (0.18)	3.49 (0.15)	+0.01 TRV	3.42 (0.28)	3.32 (0.17)	-0.37 SML	3.47 (0.17)	3.47 (0.18)	+0.02 TRV
Y-BalanceL (cm)	98.86 (5.78)	98.91 (5.20)	+0.01 TRV	96.50 (6.83)	101.90 (7.46)	+0.62 MOD	98.63 (6.74)	100.90 (5.73)	+0.10 TRV
Y-BalanceR (cm)	96.70 (6.65)	96.82 (9.50)	+0.31 SML	97.12 (7.28)	101.2 (8.3)	+0.79 MOD	99.68 (6.70)	100.96 (5.98)	+0.34 SML
T-Test (s)	11.58 (0.77)	11.34 (0.50)	-0.35 SML	11.51 (0.78)	11.03 (0.41)	-0.56 MOD	11.35 (0.81)	11.44 (0.60)	+0.19 TRV
CMJ (cm)	26.09 (3.14)	25.09 (2.32)	-0.32 SML	31.90 (3.17)	32.80 (3.56)	+0.28 SML	30.13 (5.51)	30.90 (5.16)	+0.14 TRV
CMJl (cm)	14.98 (1.81)	13.73 (1.59)	-0.68 MOD	17.67 (2.12)	18.67 (3.0)	+0.47 SML	17.54 (3.25)	18.23 (3.44)	+0.21 TRV
CMJr (cm)	14.37 (1.94)	13.77 (1.41)	-0.31 SML	17.91 (1.27)	18.39 (2.76)	+0.38 SML	16.26 (4.22)	17.66 (3.38)	+0.33 SML
Eccentric Power BIL (W)	1093.33 (170.0)	1339.40 (174.83)	+1.45 LRG	1312.77 (207.77)	1408.47 (197.02)	+0.01 TRV	1158.5 (158.97)	1197.03 (156.23)	+0.24 TRV
Concentric Power BIL (W)	431.30 (128.32)	684.99 (221.13)	+1.98 LRG	520.12 (111.53)	661.55 (70.03)	+1.27 LRG	492.43 (141.31)	613.71 (184.05)	+0.86 MOD
Time to Peak Velocity BIL (s)	0.37 (0.06)	0.28 (0.03)	-1.49 LRG	0.35 (0.08)	0.32 (0.06)	-0.38 SML	0.41 (0.07)	0.45 (0.11)	+0.66 MOD
Eccentric Power L (W)	660.71 (128.70)	864.85 (111.0)	+1.59 LRG	766.39 (167.55)	859.23 (145.77)	+0.35 SML	638.38 (114.95)	689.81 (120.29)	+0.45 SML
Eccentric Power R (W)	679.91 (166.63)	868.17 (130.24)	+1.13 LRG	776.44 (125.34)	859.23 (139.84)	+0.66 MOD	633.36 (97.85)	708.75 (125.68)	+0.77 MOD
Concentric Power L (W)	234.21 (69.47)	466.91 (131.21)	+3.35 LRG	316.82 (59.68)	477.82 (145.19)	+2.70 LRG	288.87 (80.80)	346.72 (109.84)	+0.72 MOD
Concentric Power R (W)	264.09 (100.46)	402.1 (245.02)	+1.37 LRG	304.81 (92.91)	455.21 (104.60)	+1.62 LRG	290.79 (92.43)	345.65 (116.19)	+0.59 MOD
Time to Peak Velocity L(s)	0.36 (0.08)	0.23 (0.11)	-1.65 LRG	0.37 (0.10)	0.35 (0.07)	-0.15 TRV	0.43 (0.11)	0.46 (0.12)	+0.22 TRV
Time to Peak Velocity R (s)	0.36 (0.09)	0.24 (0.04)	-1.27 LRG	0.36 (0.09)	0.36 (0.08)	-0.03 TRV	0.43 (0.08)	0.47 (0.13)	+0.48 SML

(BIL)= Bilateral, (R)=Right, (L)=Left

Bilateral Slow Velocity

The majority of effects in the BSV group were trivial to small (table 3). There was a detrimental effect on time to peak velocity, resulting in a moderate effect size (ES=0.66). 16 weeks of resistance training for the BSV resulted in some improvements with moderate increases in right sided eccentric power (ES=0.77) and concentric power right (ES= 0.59) and concentric power left (ES=0.72).

Comparison of Training Intervention

To determine if any of the three resistance training interventions; UHV, BHV or BSV, had more of an effect on loaded vertical concentric and eccentric power, sprint, CMJ, agility and balance when compared to one another. Absolute change from pre- to post-intervention measures were calculated for all variables, analysis conducted with one-way ANOVA and, if appropriate, subsequent post-hoc analyses.

Countermovement Jump, Sprint, Agility and Balance

For the measures of sports performance there were trends for differences in the 20m sprints between the groups (p=0.05) where BHV improved their sprint time compared to both UHV (p=0.06) and BSV (p=0.06). For the agility T-test, there was a significant difference between groups (p=0.05) where BHV was significantly faster compared to BSV (p=0.02), but not to UHV (p=0.28). No difference in jump performance was found for either bilateral CMJ (p=0.11) or CMJr (p=0.34), however CMJl showed a trend for being different between groups (p=0.08) with improvements in jump height for both BHV (p=0.10) and BSV (p=0.05) compared to UHV.

Table 4: Percentage change and significance testing. Change reported as Mean (SD). One-way ANOVAs and corresponding post-hoc analyses were made on actual change values.

	UHV	BHV	BSV	ANOVA	UHV VS BHV	UHV Vs BSV	BHV Vs BSV
	%Change	%Change	%Change	*p-value*	*p*	*p*	*p*
Bodyweight (kg)	2.67 (2.39)	0.89 (4.29)	3.24 (4.07)	0.44	-	-	-
20m Sprint (s)	0.2 (2.39)	-2.82 (4.29)	0.12 (1.76)	0.05	0.06	0.97	0.06
Y-Balance L (cm)	1.58 (3.07)	5.66 (4.17)	2.43 (3.69)	0.65	-	-	-
Y-Balance R (cm)	0.49 (5.20)	4.25 (5.06)	1.37 (3.08)	0.71	-	-	-
T-Test (s)	-1.70 (3.86)	-3.99 (4.37)	0.86 (2.89)	0.05	0.28	0.11	0.02
CMJ (cm)	-12.19 (29.01)	3.03 (7.81)	3.17 (9.04)	0.11	-	-	-
CMJl (cm)	-15.53 (27.44)	7.22 (22.88)	5.12 (16.02)	0.08	0.10	0.05	0.85
CMJr (cm)	-20.47 (40.05)	3.36 (0.28)	11.17 (15.29)	0.34	-	-	-
Eccentric Power BIL (W)	24.04 (18.35)	7.58 (3.97)	3.82 (9.29)	0.00	0.03	0.00	0.21
Concentric Power BIL (W)	63.83 (52.38)	30.05 (18.01)	25.35 (26.38)	0.08	0.15	0.06	0.67
Time to Peak Velocity BIL (s)	-22.86 (11.05)	-7.69 (8.84)	11.09 (22.45)	0.00	0.02	0.00	0.05
Eccentric Power L (W)	16.49 (47.20)	11.25 (8.84)	8.72 (12.36)	0.53	-	-	-
Eccentric Power R (W)	22.35 (24.95)	14.33 (15.75)	12.61 (16.06)	0.09	0.08	0.46	0.08
Concentric Power L (W)	67.69 (73.87)	57.33 (51.03)	21.34 (30.27)	0.08	0.65	0.08	0.02
Concentric Power R (W)	52.67 (88.77)	60.57 (43.95)	20.79 (31.56)	0.13	-	-	-
Time to Peak Velocity L (s)	-37.52 (33.36)	-6.09 (12.58)	0.45 (28.89)	0.00	0.03	0.00	0.06
Time to Peak Velocity R (s)	-38.81 (37.92)	-6.18 (12.44)	7.20 (19.63)	0.00	0.02	0.00	0.14

(L)= Left leg, (R)= Right leg, (BIL)= Bilateral

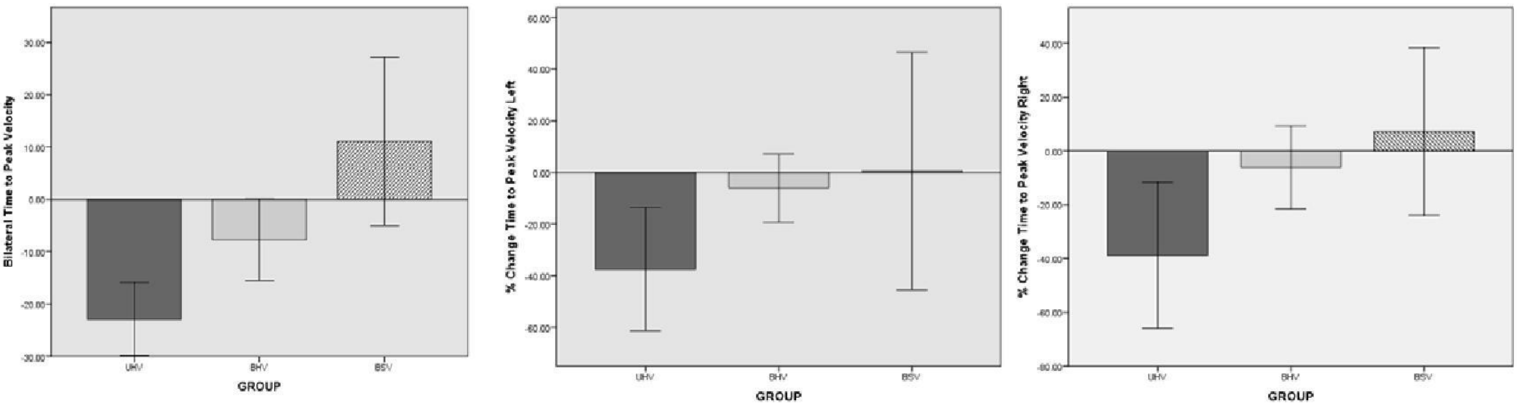
Loaded Vertical Concentric and Eccentric Power

There was a significant effect for bilateral eccentric power between groups (*p*=0.00) where the UHV group produced a higher average power output compared to BHV (*p*=0.03) and BSV (*p*=0.00). Both left (*p*=0.05) and right (*p*=0.04) time to peak velocity significantly improved for the UHV group when compared to BSV (L: *p*=0.05, R: *p*=0.04)

Time to Peak Velocity

To determine the significance of movement velocity the high intended movement velocity groups (UHV and BHV) were compared to the slow movement velocity group (BSV) and to each other.

Bilateral time to peak velocity was significantly different between groups (p=0.00) where both UHV (p=0.00) and BHV (p=0.01) were significantly quicker compared to BSV, and UHV were even quicker than BHV (p=0.01) (Table 4 and figure 1a) Time to peak velocity on the left side was significantly different between groups (p=0.00), only the UHV significantly improved over both BHV (p=0.03) and BSV (p=0.00) (Table 4), improving by 37.52% (33.36) (Table 3 and figure 1b). Time to peak velocity on the right side was, again, significant between groups (p=0.00), with only the UHV being significantly quicker than both BHV (p=0.02) and BSV (p=0.00) (Table 4), an improvement of 38.81% (37.92) (Table 3 and figure 1c) from pre- to post-intervention.



a *b* *c*

Figure 1: Percentage change from pre- to post-measures after velocity based resistance training intervention in: a) Bilateral time to peak velocity. (b) Time to peak velocity left. (c) Time to peak velocity right. Figures shown with 95% confidence interval

Discussion

Results Discussion

The main findings of this study were that for loaded vertical power measures in concentric power, eccentric power and time to peak velocity, the UHV group displayed large ES improvements in all measures and stances (9 out of 9 variables), the BHV group had large ES improvements in concentric power only for all stances (3 out of 9 variables), whereas improvements in loaded vertical power for the BSV group did not reach large ES (0 out of 9 variables) but ranged from trivial to moderate (Table 3).

For assessments of sports performance in sprint, agility and CMJ no large ES improvements were evident. The only improvements seen at a moderate ES degree were in the agility T-test in the BHV only. Similarly, only the BHV group had moderate ES improvements in balance in both left and right side

When the groups were compared to each other for their pre- to post-changes in loaded vertical power the UHV group performed significantly better than both BHV and BSV in measures of bilateral eccentric power and time to peak velocity (bilateral, left and right) and significantly better than BSV for concentric power (bilateral and left). The BHV group significantly improved in time to peak velocity (bilateral and left), eccentric power (right), concentric power (left and right) when compared to BSV.

Results from both bilateral and unilateral time to peak velocity measures showed that the UHV significantly had the highest improvements in time to peak velocity compared to both other groups, the BHV group came next with a significantly faster time to peak velocity compared to the BSV group, who over the course of the resistance training intervention slowed.

Effect of Training Intervention

The data from this study shows that all three training modes improved in measures of power output as assessed by loaded vertical squat jump, albeit to varying degrees. As the hypothesis stated that all three groups would show similar improvements with moderate to large effect sizes the results from this data refute this hypothesis as although the BHV and BSV groups improved in all measures, several of the measures only show trivial to small effect sizes. UHV showed the greatest improvements in both bilateral and unilateral assessments. The effects for training intervention are similar to the ones found by Speirs et al (2016) when they assessed the effects of a 5 week unilateral and bilateral training intervention on lower body power in men's rugby players. They found that all training interventions improved, and there were large effect sizes reported for improvements in lower body strength as assessed by back squats. A similar effect to Speirs' (2016) study was found in untrained men and women after an eight-week resistance training intervention with free weights McCurdy et al., (2005) found that both unilateral and bilateral resistance training improved measures of power as assessed by free-weight squat. This phenomenon has also been shown to be true in young soccer players after six weeks of plyometric training (Ramírez-Campillo et al., 2015) and untrained postmenopausal women after 26 weeks of resistance training (Janzen et al., 2006). There are no current studies, comparable to the current study in which a unilateral intervention group increased performance to this extent. A proposed mechanism as to why the UHV group improved to a larger effect size than the BHV and BSV may be due to the ability to coordinate muscles. During one-legged movements the standing leg takes 75% of the resistance, so although less weight is generally lifted the single leg is working at a higher relative intensity than it would be in a bilateral resistance exercise (Hefzy et al., 1997). The decreased stabilisation increases muscle recruitment from the hip abductors (Neumann et al., 1985), which can be effectively utilised in both the unilateral and bilateral testing. Whereas, the bilateral groups, who have trained in stable positions for the intervention, will not have trained the ability to coordinate supporting muscle groups, such as those in the hip abductors (McCurdy et al., 2005). The relative inexperience of the UHV, along with the training intervention having the UHV group doing twice as much work, compared to the BHV and BSV groups, could also be a factor in their greater improvements.

Measures of Sporting Performance

It was hypothesised that due to the specificity of the movement patterns involved in the UHV training intervention that this group would show the most improvements in sports performance measures. However, the data has shown this not to be true, the sprint times of the UHV group marginally decreased (0.2%), more so than BSV (0.12%) whilst the BHV group increased (2.82%) (Table 4). This is in agreement with data from Speirs et al (2016) who found that unilateral training did not improve 10m, 40m, and change of direction speed. While findings from the present study are in agreement with Speirs et al (2016) the results disagree with the majority of the literature that increases in lower body power output relate to increases in sprint performance (Seitz et al., 2014). In a study involving multiple measures of sports performance after unilateral, bilateral and a unilateral and bilateral combined intervention, Ramírez-Campillo et al (2015), found that the unilateral and combined unilateral and bilateral interventions showed the greatest improvements in sports performance, however in this study resistance exercises were combined with sports specific training. A proposed mechanism for why the UHV group did not increase in the measures of sporting performance may be due to when the teams performed their actual handball skills practice. In a study using untrained participants Cronin et al. (2002) found that netball throwing velocity improved when resistance training with the intention to move explosively was coupled with explosive netball passes. Performing sports specific skills alongside high velocity resistance training takes full advantage of training-induced adaptations to the neuromuscular system (Bobbert et al., 1994). The use of training sports specific skills alongside resistance training in order to improve transfer is a theory that has been echoed by Speirs et al, (2016), who hypothesised that the lack of specificity in the training programme could have been a factor in the lack of improvements in sprint times. The inclusion of sports specific training alongside the resistance training may provide the required stimulus to improve in tests of sporting performance. This lack of specificity could explain the differences in performance, however, as the training programmes of the different teams are unknown this is speculative.

Effect of Movement Velocity

It was hypothesised that the high movement velocity groups (UHV and BHV) would improve to a higher level in measures of power assessments compared to the BSV group due to the speed of training more closely matching the speed of performance. This was shown to be true as in all nine variables of loaded power assessment the UHV and BHV groups improved to a greater degree than the BSV.

The definition of a “high” or “fast” training velocity is open to interpretation, this means that a wide range of velocities and assessment methods are represented in the literature. As this study is the only study to compare the effects of both stance and movement velocity direct comparisons are difficult. Morrissey et al. (1998) found similar results to the current study, after seven weeks of velocity specific squat training the fast training group improved strength in tests that were performed at faster velocities in women athletes. After 16-weeks of either fast or slow lower body resistance exercises at 70% of 1RM Fielding et al, (2002) found that a fast training group increased muscular power significantly more than a slow group even though both groups showed increases in maximum strength, however this study was performed on untrained older women. On the other hand, in assessments of vertical jump height Young and Bilby (1993) found no difference between slow and fast training interventions in vertical jump height.

A proposed mechanism for greater increases in power by high velocity training groups is that high velocity training changes neural activity. These changes occur quicker than hypertrophic adaptations and is commonly referred to as a "learning effect" (Coyle et al., 1981). This may also account for the lack of agreement between studies as this is dependent on the training experience of the performer (Duchateau & Hainaut., 1984).

Time to Peak Velocity

It was hypothesised that due to the UHV and BHV groups training at a high speed they would show greater improvements in reaching their time to peak velocity quicker in the loaded vertical squat jump assessments than the BSV group. The data has shown this to be true, not only for the bilateral measures but for both left and right sides in the unilateral measures. From this it can be inferred that training at a high velocity is beneficial for women's handball players aiming to improve power and sports performance.

The existing literature investigating movement velocity specification in trained individuals is conflicting, mainly due to the wide range of training protocols, exercise types and working speeds used. With regards to studies using similar protocols to the current study Morrissey et al (1998) showed that after a seven-week intervention women who trained squats at a high velocity improved in high velocity assessments than a group who trained at a slower velocity. In a study where 18 trained men performed half squats where eight subjects prioritised moving the weight at high speeds Young and Bilby (1993) found no statistically significant differences between training speeds.

The mechanisms behind training for velocity have produced conflicting results. This is due to the variability of training experience in participants, no set parameters of what constitutes as high speed and the method of providing resistance (Duchateau & Hainaut., 1984). In their review of existing movement velocity studies Kawamori et al (2006) found that the mechanism for adaptations to training for velocity is dependent on the experience of the performer. The untrained participants in Behm & Sale's (1993) study improved performance due to neural adaptations that increased synchronisation and firing frequency of fast motor units. In comparison the trained participants of McBride's (2002) study improved due to physiological adaptations such as hypertrophy and changes to contractile pattern and muscle fibre type. (Kawamori et al., 2006).

Methods Discussion

The main strength of this study lies in being able to implement a long and thorough intervention on elite athletes. Intervention studies of this length are rarely done on elite performers due to their normal training limitations. Using elite athletes does mean there are more considerations to be made, often making it difficult to implement, but not impossible. During this study several considerations needed to be made. The study was conducted during the "off-season" as this was the most practical time, players were not in full season training, but were still taking part in regular preparation phase training. Although pre-season was the most practical time to implement the training interventions it also coincided with the transfer period for handball teams, due to this some athletes only had pre-intervention measures as they had transferred into other teams. During the training sessions weight were self-selected based on the instruction of it being >80% 1RM and therefore, no objective control over how much effort the participants were regularly putting into their workouts was available. However, training sessions were overseen by trained strength coaches and they were able to judge approximately what effort each individual put in. In addition, the participants kept training logs where the weight lifted in each session was noted.

It was also recognised that the UHV group did more total work than the BHV group as they performed the workout for each side; this could go some way to explaining why the UHV group improved so much more. In studies with similar training interventions the unilateral group exercises are normally of a lower intensity (Speirs et al., 2016, Makaruk et al., 2011). It was not possible to randomise who took part in which training session due to training schedules, which led to each team undertaking a training intervention. Problems with this allocation of training arise if the different teams train on court very differently and if the teams had different levels of resistance training experience and the standard of the handball being played. Our results show that the level of experience was slightly lower in the UHV groups and that the teams placed very differently in the previous season. This could provide an explanation for some of the unexpected differences in data.

This is the first study to look at the effects of both stance and velocity in one intervention. An ideal study design would include a 4th group that would train unilaterally and with a slower movement velocity. In the implemented study design the BSV group acted as a control for both the stance and the movement velocity so if the improvements were seen in only UHV and BHV groups then it could be determined that the movement velocity may be a key variable. If the BHV and BSV groups were similar, then stance could have been a main effect. The inclusion of a 4th group would have aided in making clearer determinations, however this was not feasible in the current study. This should be a consideration in future research as it may offer some new insights.

There are several aspects of this study that need to be addressed if future studies are to build on these results; measuring maximal strength in the pre-testing to provide a working weight for the training programme is advised, the allocation of a working weight could be done as a 5RM, as demonstrated by (McCurdy et al., 2005) or a 3RM (Speirs et al., 2016). This will allow for both structure in the programme and will aid to balance the work done by both UHV and BHV groups. In the present study this was not done due to geographical limitations meaning there was only one evening where all study participants could perform all of the tests needed, the inclusion of a maximal strength test would have affected the results for loaded and unloaded jump data. However, we are aware that the inclusion of maximal strength testing conducted both pre- and post-intervention would have been valuable in interpreting the data.

Conclusion

The results from this study show that both unilateral and bilateral resistance training interventions are sufficient at increasing lower body power output in elite women’s handball players as assessed through measures of loaded vertical jumps. However, the magnitude of the effect differs between training modes with the UHV group experiencing larger, more consistent effects for both unilateral and bilateral loaded power assessments. Whilst BHV and BSV did improve the magnitude of their effects it was a lot more varied. High velocity training groups showed greater improvements in all measures compared to the slow velocity group showing that for high velocity training has a place in training programmes for elite women handball players. The unilateral group failed to improve in measures of sports performance as it was hypothesised, with the BHV group showing the greatest improvements in sprint, agility T-test and Y-balance tests. The effect of velocity training was most clearly seen in time to peak velocity measures with the UHV and BHV groups both reaching peak velocity quicker post-intervention whereas the

BSV group slowed. It can be concluded that regardless of stance resistance training can improve power output in elite women's handball players, but in order to see more substantial improvements training at a high intended movement velocity is recommended.

References

Behm, D.G., Abehm, D.G., Anderson, K. and Curnew, R. S. (2002). Muscle Force and Activation Under Stable and Unstable Conditions. Journal of Strength and Conditioning Research. 16 (3), Pp.416–422.

Behm, D.G. and Sale, D.G. (1993). Intended Rather Than Actual Movement Velocity Determines Velocity-Specific Training Response. *Journal of Applied Physiology,* 74 (1), Pp. 359.

Bobbert, M.F. and Van Soest, A.J. (1994). Effects of Muscle Strengthening On Vertical Jump Height: A Simulation Study. *Medicine and Science in Sports and Exercise,* 26 (8), Pp. 1012-1020.

Chaouachi, A., Brughelli, M., Levin, G., Boudhina, N.B.B., Cronin, J. and Chamari, K. (2009). Anthropometric, Physiological and Performance Characteristics of Elite Team-Handball Players. *Journal of Sports Sciences*, 27(2), Pp. 151-157.

Comfort, P., Stewart, A., Bloom, L. and Clarkson, B. (2014) Relationships Between Strength, Sprint, and Jump Performance in Well-Trained Youth Soccer Players. *Journal of Strength and Conditioning Research*. 28(1), Pp. 173-177.

Cormie, P., Mcguigan, M.R. and Newton, R.U. (2010). Adaptations in Athletic Performance After Ballistic Power Versus Strength Training", *Medicine and Science in Sports and Exercise,* 42, (8), Pp. 1582-1598.

Cormie, P., Mcguigan, M.R. and Newton, R.U. (2011). Developing Maximal Neuromuscular Power: Part 2 — Training Considerations for Improving Maximal Power Production. *Sports Medicine,* 41(2), Pp. 125-146.

Coyle, E.F., Feiring, D.C., Rotkis, T.C., Cote, R.W., Roby, F.B., Lee, W. and Wilmore, J.H., (1981). Specificity of power improvements through slow and fast isokinetic training. *Journal of applied physiology*, 51(6), pp.1437-1442.

Cronin, J., Mcnair, P.J. and Marshall, R.N. (2001). Velocity Specificity, Combination Training and Sport Specific Tasks. *Journal of Science and Medicine in Sport*, 4 (2), Pp. 168-178.

Cronin, J.B., Hing, R.D. and Mcnair, P.J. (2004). Reliability and Validity of a Linear Position Transducer for Measuring Jump Performance. *The Journal of Strength and Conditioning Research*. 18(3), Pp. 590.

Duchateau, J. and Hainaut, K. (1984). Isometric or Dynamic Training: Differential Effects On Mechanical Properties of a Human Muscle. *Journal of Applied Physiology: Respiratory, Environmental and Exercise Physiology*. 56 (2), Pp. 296.

Ekstrom, R.A., Donatelli, R.A. and Carp, K.C. (2007). Electromyographic Analysis of Core Trunk, Hip, And Thigh Muscles During 9 Rehabilitation Exercises. *The Journal of Orthopaedic and Sports Physical Therapy.* 37 (12), Pp. 754.

Fielding,- R.A., LeBrasseur, N.K., Cuoco, A., Bean, J., Mizer, K. and Singh, M.A.F., (2002). High velocity resistance training increases skeletal muscle peak power in older women. *Journal of the American Geriatrics Society*, 50(4), pp.655-662.

Garber, C.E., Blissmer, B., Deschenes, M.R., Franklin, B.A., Lamonte, M.J., Lee, I.M., Nieman, D.C. and Swain, D.P., (2011). American College of Sports Medicine Position Stand. Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory, Musculoskeletal, And Neuromotor Fitness in Apparently Healthy Adults: Guidance for Prescribing Exercise. *Medicine and science in sports and exercise*, 43(7), pp.1334-1359.

González-Ravé, J.M., Juárez, D., Rubio-Arias, J.A., Clemente-Suarez, V.J., Martinez-Valencia, M.A. and Abian-Vicen, J. (2014). Isokinetic Leg Strength and Power in Elite Handball Players. *Journal of Human Kinetics,* 41(1), Pp. 227-233.

Granados, C., Izquierdo, M., Ibáñez, J., Ruesta, M. and Gorostiaga, E.M. (2008). Effects of an Entire Season On Physical Fitness in Elite Female Handball Players. *Medicine and Science in Sports and Exercise,* 40 (2), Pp. 351.

Halldorsson, V., Helgason, A. and Thorlindsson, T. (2012). Attitudes, Commitment and Motivation Amongst Icelandic Elite Athletes. *International Journal of Sport Psychology,* 43 (3), Pp. 241

Hawkins, S.B., Doyle, T.L.A. and Mcguigan, M.R. (2009). The Effect of Different Training Programs On Eccentric Energy Utilization in College-Aged Males. *Journal of Strength and Conditioning Research*. 23(7), Pp. 1996-2002.

Hefzy, M.S., Al Khazim, M. and Harrison, L., 1996. Co-Activation of the Hamstrings and Quadriceps During the Lunge Exercise. Biomedical Sciences Instrumentation, 33, Pp.360-365.

Hermassi, S., Chelly, M.S., Tabka, Z., Shephard, R.J. and Chamari, K. (2011) Effects of 8-Week In-Season Upper and Lower Limb Heavy Resistance Training On the Peak Power, Throwing Velocity, And Sprint Performance of Elite Male Handball Players. *Journal of Strength and Conditioning Research,* 25 (9), Pp. 2424-2433

Hermassi, S., Chelly, M.S., Fathloun, M. and Shephard, R.J. (2010). The Effect of Heavy- Vs. Moderate-Load Training On the Development of Strength, Power, And Throwing Ball Velocity in Male Handball Players. *Journal of Strength and Conditioning Research,* 24 (9), Pp. 2408-2418.

Hertel, J., Braham, R.A., Hale, S.A. and Olmsted-Kramer, L.C. (2006). Simplifying The Star Excursion Balance Test: Analyses of Subjects with and Without Chronic Ankle Instability. *The Journal of Orthopaedic and Sports Physical Therapy,* 36 (3), Pp. 131.

Karcher, C. and Buchheit, M. (2014). On-Court Demands of Elite Handball, With Special Reference to Playing Positions. *Sports Medicine,* 44 (6), Pp. 797-814.

Kawamori, N., Naoki, K. and Newton, R.U. (2006). Velocity Specificity of Resistance Training. *Strength and Conditioning Journal,* 28(2), Pp.86–91.

Makaruk, H., Winchester, J.B., Sadowski, J., Czaplicki, A. and Sacewicz, T. (2011). Effects of Unilateral and Bilateral Plyometric Training On Power and Jumping Ability in Women. *Journal of Strength and Conditioning Research,* 25 (12), Pp. 3311-3318.

Markovic, G., Dizdar, D., Jukic, I. and Cardinale, M. (2004). Reliability and Factorial Validity of Squat and Countermovement Jump Tests. *The Journal of Strength and Conditioning Research*, 18(3), Pp. 551.

Maulder, P. and Cronin, J. (2005). Horizontal and Vertical Jump Assessment: Reliability, Symmetry, Discriminative and Predictive Ability. *Physical Therapy in Sport*, 6(2), Pp. 74-82.

McBride, J.M., Triplett-McBride, T., Davie, A. and Newton, R.U. (2002). The Effect of Heavy-Vs. Light-Load Jump Squats On the Development of Strength, Power, and Speed. *Journal of Strength and Conditioning Research,* 16(1), Pp. 75.

McBride, J.M., Blow, D., Kirby, T.J., Haines, T.L., Dayne, A.M. and Triplett, N.T. (2009). Relationship Between Maximal Squat Strength and Five, Ten, And Forty Yard Sprint Times. *Journal of Strength and Conditioning Research,* 23 (6), Pp. 1633-1636.

McCurdy, K., O'Kelley, E., Kutz, M., Langford, G., Ernest, J. and Torres, M. (2010). Comparison of Lower Extremity EMG Between The 2-Leg Squat and Modified Single-Leg Squat in Female Athletes. *Journal of Sport Rehabilitation*, 19(1), Pp. 57.

McCurdy, K.W., Langford, G.A., Doscher, M.W., Wiley, L.P. and Mallard, K.G. (2005). The Effects of Short-Term Unilateral and Bilateral Lower-Body Resistance Training On Measures of Strength and Power. *The Journal of Strength and Conditioning Research*, 19(1), Pp. 9.

Morrissey, M.C., Harman, E.A., Frykman, P.N. and Han, K.H. (1998) Early Phase Differential Effects of Slow and Fast Barbell Squat Training. *The American Journal of Sports Medicine*, 26 (2), Pp. 221.

Moss, B.M., Refsnes, P.E., Abildgaard, A., Nicolaysen, K. and 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(3), Pp. 193-199.

Neumann, D.A. and Cook, T.M., (1985). Effect of Load And Carrying Position On the Electromyographic Activity of the Gluteus Medius Muscle During Walking. *Physical Therapy*, 65(3), Pp.305-311.

Nijem, R.M. and Galpin, A.J., (2014). Unilateral Versus Bilateral Exercise and The Role of the Bilateral Force Deficit. *Strength and Conditioning Journal*, 36(5), Pp.113–118.

Pareja-Blanco, F., Rodríguez-Rosell, D., Sánchez-Medina, L., Gorostiaga, E.M. and González-Badillo, J.J. (2014). Effect of Movement Velocity During Resistance Training On Neuromuscular Performance. *International Journal of Sports Medicine,*35 (11), Pp. 916.

Pauole, K., Madole, K., Garhammer, J., Lacourse, M. and 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 & Conditioning Research*, 14(4), pp.443-450.

Pereira, M.I.R. and Gomes, P.S.C., (2003). Movement Velocity in Resistance Training. *Sports Medicine , 33(6)*, Pp.427–438.

Plisky, P.J., Gorman, P.P., Butler, R.J., Kiesel, K.B., Underwood, F.B. and Elkins, B. (2009). The Reliability of an Instrumented Device for Measuring Components of the Star Excursion Balance Test. *North American Journal of Sports Physical Therapy: NAJSPT,*4(2), Pp. 92.

Ramírez-Campillo, R., Burgos, C.H., Henríquez-Olguín, C., Andrade, D.C., Martínez, C., Álvarez, C., Castro-Sepúlveda, M., Marques, M.C. and Izquierdo, M. (2015). Effect of Unilateral, Bilateral, And Combined Plyometric Training On Explosive and Endurance Performance of Young Soccer Players. *Journal of Strength and Conditioning Research*, 29(5), Pp. 1317-1328.

Rhea, M.R. (2004). Determining The Magnitude of Treatment Effects in Strength Training Research Through the Use of the Effect Size. *The Journal of Strength and Conditioning Research*, 18(4), Pp. 918.

Seitz, L.B., Reyes, A., Tran, T.T., de Villarreal, E.S. and Haff, G.G., (2014). Increases in lower-body strength transfer positively to sprint performance: a systematic review with meta-analysis. *Sports Medicine*, 44(12), pp.1693-1702.

Shetty, A.B. (2002) "Leg Power", *Sports Biomechanics*, 1(2), Pp. 147-155.

Speirs, D.E., Bennett, M.A., Finn, C.V. and Turner, A.P. (2016). Unilateral Vs. Bilateral Squat Training for Strength, Sprints, And Agility in Academy Rugby Players. *Journal of Strength and Conditioning Research*, 30 (2), Pp. 386-392.

Wilson, G., Murphy, AJ. and Walshe AD. (1997). Performance Benefits from Weight and Plyometric Training: Effects of Initial Strength Level. *Coaching Sport Sci J*, 2 (1): 3-8

Young, W.B. and Bilby, G.E. (1993). The Effect of Voluntary Effort to Influence Speed of Contraction On Strength, Muscular Power, And Hypertrophy Development. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, 7(3), Pp.172–178.

Appendices

Appendix 1: Unilateral and Bilateral Training Programmes

Day	Week A	Sets/Reps	Week B	Sets/Reps
1	Programme 1		Programme 3	
	Marklyft Enbens	4/4leg	Enbens benböj djupa FLOWIN	4/5leg
	Enbens benböj	4/ 5leg	Enbens hantelryck rakt upp 2 hantlar	2/4leg
	Enbens benböj knix	2/ 5leg	Hängande drag djupa Ett ben	4/4leg
	Enbens vader	4/10leg	Omvänd bänkdrag hantlar	4/6
	FLOWIN baksida lår ett ben	4/5leg	Statisk mage diagonalt	4/5 side
	En arms bänkpress	4/5 side	Enbens rygglyft	4/5 leg
	FLOWIN knästående sidled 2 underarmar	4/8 side	Stående på ett ben axellyft i sidled 3 grepp	4/3
2	Programme 2		Programme 4	
	Frivändning enbens	4/4 leg	Överstöt enbens fram	2/4 leg
	Enbens hantelryck med rotation	2/4 leg	Stående sidvrid en arms ett ben	4/5 side
	Sidlyft bellyback	4/5 side	Sidlyft raka armar skivstång eller vikt	4/8
	Knästående en armsdrag med rak arm	4/6	Knästående sidvrid	4/5 side
	Stående sidvrid en arms ett ben	4/5 leg	Enbens hantelryck med rotation	2/4 leg
	FLOWIN ett knä två händer rakt fram	4/5 leg	Överstöt enbens bak	2/4 leg
	En arms flyes 3 riktningar	3/3	FLOWIN baksida lår en bens curl	4/6 leg
			FLOWIN knästående sidled 2 underarmar	4/8 side

Day	Week A	Sets/Reps	Week B	Sets/Reps
	Programme 1		Programme 3	
	Marklyft	4/4	Benböj djupa	4/5
	Benböj halva	4/5	Hantelryck 2 hantlar	2/4
	Benböj knix	2/5	Hängande drag djupa	4/4
1	Tåhäv	4/10	Omvänd bänkdrag hantlar	4/6
	FLOWIN baksida lår	4/5	Statisk mage diagonalt	4/5 side
	Bänkpress	4/5	Rygglyft	4/5
	FLOWIN knästående sidled 2 underarmar	4/8 side	Stående på ett ben axellyft i sidled 3 grepp	4/3
	Programme 2		Programme 4	
	Frivändning	4/4	Överstöt fram	2/4 leg
	hantelryck en arms	2/4 arm	Stående sidvrid	4/4
	Sidlyft bellyback	4/5 side	Sidlyft raka armar skivstång eller vikt	4/8
	Drag fram	4/6	Knästående sidvrid	4/5 side
	Stående sidvrid	4/5 side	Hantelryck 1 hantel (5)	2/4
2	FLOWIN ett knä två händer rakt fram	4/8	Överstöt bak	2/4
	Flyes	3/6	FLOWIN baksida lår en bens curl	4/6 leg
			FLOWIN knästående sidled 2 underarmar	4/8 side

Bilateral training programme

Marie Elliott

HALMSTAD UNIVERSITY

PO Box 823, SE-301 18 Halmstad
Phone: +35 46 16 71 00
E-mail: registrator@hh.se
www.hh.se