Optimizing Physical Performance During the Competitive Season for Female Handball Players: A Comparative Study on the Effects of High-Load Strength Training versus Power and Plyometric Training

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Sammendrag

Hensikt: Målet med studien var å sammenligne effekten av maksimal styrketrening mot power- og plyometrisk styrketrening på eksplosive egenskaper for kvinnelige håndballspillere i sesong. **Metode**: Trettien håndballspillere (alder, 20 ± 3 år; høyde, 170 ± 6 cm; vekt, 68 ± 11 kg) ble tilfeldig fordelt til en maksimalstyrketreningsgruppe (maksstyrkegruppe) som utførte øvelser med belastning på ≥80% av 1RM eller en power- og plyometri treningsgruppe (power-plyo gruppe) som utførte ballistiske øvelser på ≤50% av 1RM og hoppøvelser. Treningsperioden varte i tolv uker og bestod av to ukentlige økter hvor utøverne ble fulgt opp en gang i uken. Svikthopp høyde, vertikal hopprekkevidde, stående- og tre-steg kastehastighet, tid på lineær sprint (5-, 10-, 15-, 20-, 30m) og retningsforandringsløp (4x180°retningsforandringer), teoretisk maksimal powerutvikling i under- og overkropp (P_{max}) og maksimal power ved lav til høy belastning (Keiser beinpress, og benkpress) og kraftutviklingshastighet (RFD) ble målt før og etter treningsperioden. Resultatene ble analysert ved bruk av t-tester med signifikansnivå satt til $p < 0.05$. **Resultat**: Ingen signifikante forskjeller mellom gruppene ble observert i noen av de testede variablene. Signifikante endringer ble observert i svikthopp (6,6% og 7,2%), hopprekkevidde (5,6% og 6,1%), P_{max} i beinpress (11,7% og 8,3%) og benkpress (8,1% og 5,5%: tendens; 0.068) for makismalstyrke- og power-plyo gruppen henholdsvis. Kasthastighet og sprintprestasjon forble uendret, men maksstyrke-gruppen forbedret seg signifikant i retningsforandringsløp (2% vs. 1%) og kraftutviklingshastighet (6.7-13.4% vs. -2.2-4.4%). **Konklusjon**: Funnene antyder at kvinnelige håndballspillere kan oppnå samme effekt av begge treningsformer for å opprettholde eller forbedre eksplosive egenskaper i løpet av sesongen.

Nøkkelord: Håndball, styrketrening, i sesong, maksimalstyrke, power, plyometri,

Abstract

Purpose: The present study aimed to compare the effects of high-load strength training and low-load power and plyometric training on explosive performance measures in in-season female handball players. **Methods:** Thirty-one sub-elite handball players (age, 20±3 years; height, 70±6 cm; weight, 68±11 kg) were randomly assigned to a high-load (weekly: 5-20 sets ≥80% of 1RM per muscle group) or low-load power and plyometric training group (power-plyo) (13 sets ≤50% of 1RM and 165 bodyweight jumps). Training sessions were performed biweekly and supervised once per week for 12-weeks. Pre- and post-measurements were countermovement jump (CMJ) height, single-leg vertical jump-and-reach, standing- and 3-step throw velocity, linear sprint (0-30m) and change of direction (CoD) times (4x180°turns), lower- and upper-body theoretical maximal power (Pmax) and power at low to high loads (pneumatic resistance leg-press, and bench press) and rate of force development (RFD). Results were analyzed using t-tests with a significance level set at $p<0.05$. **Results**: No significant between-group differences were observed in any of the variables. Compared to baseline, the high-load and power-plyo group improved CMJ (6.6% and 7.2%) and jump-and-reach height (5.6% and 6.1%), Pmax in leg-press (11.7% and 8.3%) and bench-press (8.1% and 5.5%: tendency; 0.068) respectively. Throwing velocity and linear sprint remained unchanged, but the high-load group significantly improved in CoD (2% vs. 1%) and RFD (6.7-13.4% vs. -2.2-4.4%). **Conclusion:** The findings suggest that female handball players can achieve similar benefits from either a high-load or a low-load power and plyometric oriented strength program in improving or maintaining in-season explosive abilities.

Keywords: Handball, resistance training, in-season, high-load, power, plyometric.

Structure of the Thesis

Part 1 of this thesis consists of four chapters: an introduction providing the rationale for the study, a theoretical framework, a methods chapter outlining how the study was conducted, and a discussion of the methodology.

Part 2 presents a research paper, written according to the guidelines of the Scandinavian Journal of Medicine & Science in Sports.

Appendices are found after the reference list of the research paper, and include an informed consent form, approval by the Norwegian Centre for Research Data (NSD), and an application of ethical approval.

PART 1

STUDY RATIONALE, THEORY AND METHODS

TABLE OF CONTENT

1 Introduction

Team handball has been an Olympic sport since 1976. Since then, its popularity has skyrocketed, with around ~30 million active players from recreational to elite levels (International Handball Federation, 2023). In the past decade the general interest of women's handball has also increased, as can be exemplified by the cumulative audience of the 2018 Women's European championship which increased 83% since the 2012 European championship, reaching 696 million people (Infront News, 2015, 2019).

The sport is one of the fastest and most intense team sports where a regular match can involve more than 800 high-intensity actions (Bragazzi et al., 2020), such as sprints, rapid changes of direction (CoD), jumps and throws. The higher the degree of effort and intensity put into these explosive actions means a correspondingly higher chance of success of feints and duels won, shots blocked, goals scored, and ultimately games won (Póvoas et al., 2012; Ronglan et al., 2006). Performance in these abilities is highly dependent on the athlete's overall strength level and ability to express high power outputs (Haff & Nimphius, 2012; Stone et al., 2002). Accordingly, elite players are often stronger, throws harder, jump higher, and run faster than their sub-elite counterparts, making strength training an essential part of training for increased handball performance (Gorostiaga et al., 2005; Massuça et al., 2014; Póvoas et al., 2012).

Strength training may, however, receive less attention during the competitive period when the players readiness to perform at their best during handball play has the highest priority. This poses a challenge when planning an in-season strength program as the fatigue induced by strength and power training could potentially impede the on-court performance (Karcher & Buchheit, 2014; Ronglan et al., 2006). Nevertheless, strength and power training should likely be included, given that a total absence of this type of training has been observed to decrease in-season sprint, throwing velocity, and jump performance (Hermassi et al., 2017; Marques & González-Badillo, 2006). Another consideration is that handball sessions also cause neuromuscular fatigue, thereby negatively impacting the potential for optimal adaptations following strength training (Bishop et al., 2008; Karcher & Buchheit, 2014; Ronglan et al., 2006). Yet, performing strength training at a time that minimizes interference with handball play and in a state where full recovery is not always achieved, may be a necessary compromise to maintain in-season physical capacities.

High-load, lower-load power, and plyometric training have all been shown to increase or maintain physical performance for handball players during the in-season (Aloui et al., 2019; Chelly et al., 2014; Falch et al., 2022, 2022; Granados et al., 2008; Hammami et al., 2020; Hermassi et al., 2010, 2011, 2014, 2015), which begs the question of which method of training that should be prioritized. However, high-load strength training seems to require a longer recovery time than lower load power and plyometric training (Helland et al., 2020). Considering the time required to reach full recovery, it can be questioned whether prioritizing low-load power and plyometric training during the busy and demanding competitive period may be advantageous as compared to high-load training. Conversely, as handball players regularly perform explosive actions during matches and handball specific training, it is possible that the different training stimulus acquired from heavier loads are more beneficial. Nevertheless, an in-season strength program needs to give sufficient training stimulus to maintain or improve explosive capabilities, while simultaneously avoiding unnecessary fatigue that could lower on-court handball performance (Spieszny & Zubik, 2018).

Based on earlier research on the topic, there is a gap in the existing literature as no studies have directly compared the combination of lower-load power and plyometric training with traditional high-load strength training in in-season handball players. There is also a scarcity of research on female handball players, and due to possible physiological sex differences, more research of this population are needed (Costello et al., 2014; Saavedra et al., 2018; Wik et al., 2017). Therefore, this study aims to fill the obvious gap in the literature and examine the effect of these types of strength training methods on changes in explosive-performance measures in a sample of female players. The results of this study can provide additional information on the effects of different types of strength training, and new information for strength coaches on how to better plan in-season strength training for female handball players.

1.1 Purpose

To examine the effects of high-load strength training compared to low-load power- and plyometric training on power, jump, throwing velocity, and linear and change of direction sprint performance in female handball players during the competitive season.

2 Theoretical Framework

2.1 The Importance of Jump, Throw, Linear and Change of Direction Sprint Performance in Handball

Handball can be considered a power demanding sport, as power output is vital for the success in the execution of all these explosive actions (Haff & Nimphius, 2012; Young, 1993). For instance, the ability to rapidly apply a large amount of force relative to bodyweight onto the floor is important for the ability to quickly change direction while reacting to a counterattack, jump and reach to shoot or block a goal shot, and accelerate and sprint past the opposing players to gain an advantage in an attacking phase. Correspondingly, applying a large amount of force rapidly on the ball increases the velocity of a pass or goal shot, diminishing the window of opportunity for defenders and goalkeepers to intervene the pass or save the shot (Manchado et al., 2013). The relationship between performance in these abilities and success is well established, and several studies have found that elite players are often stronger, throws harder, jump higher and run faster than their sub-elite counterparts (Gorostiaga et al., 2005; Massuça et al., 2014; Póvoas et al., 2012), and the differences between elite and sub-elite in female handball players are observed to be even greater (Granados et al., 2008)

2.2 Factors Determining Jump, Throw, Sprint, and Change of Direction Performance

These actions are all characterized as movements performed at high-speeds against different forms of resistances and are therefore often referred to collectively as explosive actions (or “abilities” depending on the context) (Waller et al., 2023; Young, 1993). The influencing factors determining the performance in these explosive actions are complex and multifactorial, and due to the aim of the study, only physiological factors that may be optimized through strength training will be further explained.

A high maximal and relative strength level are considered general factors determining the performance in these explosive actions. For instance, a greater strength level allows for the production of more force that can be applied during these actions. Additionally, for movements where the athlete is required to change the momentum of their own bodyweight, such as during jumps or CoD actions, a high strength level relative to their bodyweight is especially important (Falch et al., 2021; Keiner et al., 2022). However, these actions also differ in the time available to develop force. For example, ground contact times during sprints are 80-100msec or 170-180msec for high-jumping (Zatsiorsky & Kraemer, 2006). While it takes approximately 300-500ms for muscles to reach peak force production (Aagaard et al., 2002; Thorstensson et al., 1976) (figure 1). Thus, the time constraints of the specific movements signifies the importance of the rate of force development (RFD) rather than maximal strength itself. Higher RFDs have for example been directly associated with better sprint and jumping performances (Laffaye & Wagner, 2013; Slawinski et al., 2010).

Figure 1: Rate of Force Development

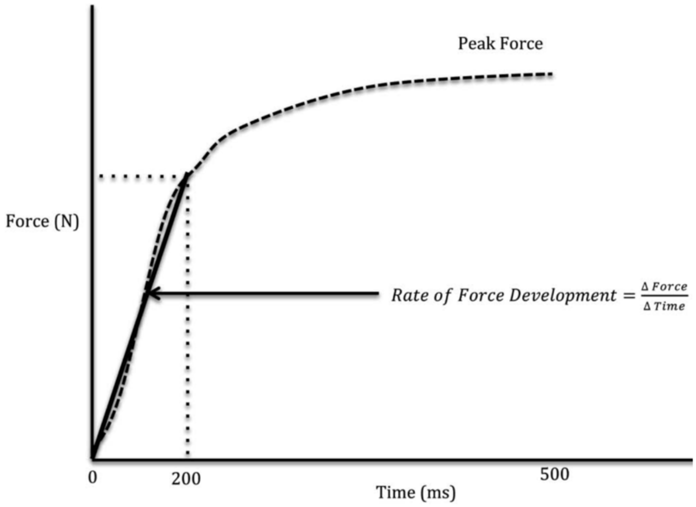

Figure 1: Rate of force development from (Haff & Nimphius, 2012)

While maximal strength is the general ability to produce force, and RFD determines how quickly the force can be produced, these are some factors influencing the ability to develop high levels of muscular power. Considered a key determinant for all these explosive actions (Stone et al., 2002; Young, 1993).

2.3 Muscular Power

The basic definition of power is the rate of doing *work*, which is the product of the force generated and the distance over which it is applied (work=force*distance). Since power is the *rate* of doing work, power can be expressed as work divided by the time taken to do it (Power=work/time). And since the distance component of *work* divided by *time* is the same as *velocity*, power is equal to the force generated times the velocity of the force applied (power =

force*velocity), thus consisting of the two components force and velocity (Haff & Nimphius, 2012).

Muscular power output is therefore the level of power achieved in muscular contractions (Cormie et al., 2011a). And while jumping, throwing, sprinting and CoDs differs in muscles used, forces to overcome and the time available to do so, the ability to develop high levels of muscular power output is considered the most important factor impacting the performance of these explosive actions (Stone et al., 2002; Young, 1993). The ability to develop high levels of muscular power is determined by a variety of different trainable physiological factors influencing either the force or the velocity component of power.

2.3.1 Morphological Factors

The ability to produce power is heavily influenced by the contractile capacity of the involved muscles, which in turn is dictated by a plethora of influencing factors, some far from fully understood. Some of the most relevant and apparent morphological factors are the fiber cross-sectional-area (CSA) and muscle fiber type, fascicle length, pennation angle and tendon properties (Cormie et al., 2011a).

The force producing capabilities of the muscle fiber is proportional to its CSA (Widrick et al., 2002), and due to the fundamental relationship between force and power, an increase in CSA in muscle fibers further increases the maximal power production. The power-producing capability of the muscle is also affected by its fiber composition, as the different fiber types have different contractile properties. The cross-bridge cycle refers to the theory of how a muscle generates force. In short, the sarcomere is the basic contractile unit of a muscle fiber and consists of the two filaments actin and myosin. The myosin filament has side pieces or "myosin heads" that undergo cyclic attachments and detachments on binding sites on the actin filament, forming a cross-bridge when the myosin head attaches to the actin. When the cross-bridge is formed, the myosin head pulls the actin relative to the myosin filament, producing a muscle shortening as this cycle of attachments and detachments continue (Binder et al., 2009; Huxley, 1957). Consequently, as Type II fibers have a significantly shorter cross-bridge cycle time than Type I fibers, a greater percentage of Type II means a higher power producing capacity as force is generated faster (Cormie et al., 2011a). Fascicle length affects power production as the shortening velocity of the muscle fiber is proportional to its length, as a higher number of sarcomeres in a series increases the shortening velocity (Wickiewicz et al., 1983). A longer muscle fiber, can therefore generate more power (Cormie et al., 2011b). The pennation angle, which refers to the angle of the muscle fibers in relation to the direction of the contraction has an important effect on the development of power (Kruse et al., 2021). The reason behind this is as the angle increases, more muscle fiber can be attached to the tendons or aponeurosis, thereby generating more force. Although greater pennation angles has been observed to slower the contraction velocity of the muscle (Eng et al., 2018; Spector et al., 1980), it is theorized that the increase in the force producing capability has a more substantial impact on maximal power than the reduction in contraction velocity (Cormie et al., 2011a).

Finally, the compliance of the muscle-tendon complex can influence the ability to produce power. Muscle and tendon structures (tendons and aponeurosis) have elastic properties, where the stiffness can have a favorable effect on the stretch-shortening cycle (SSC) (Kubo et al., 1999). The SSC can be defined as the sequence of an eccentric muscle action immediately followed by a concentric action, which occurs in any movements when a limb changes direction such as jumping, running, and throwing (Kubo et al., 1999). The SSC is often described as a spring-mechanic, where elastic energy is stored within the muscle-tendon complex and when stretched causes a recoil that increases the force in the following contraction. Ultimately enhancing the power production (Walker, 2016a). Research suggests that lower extremity stiffness is optimal for sprinting and jumping performance, however too much or too little might increase the risk of injury (Brazier et al., 2014). Although a muscle mechanic, the type of muscle actions performed also influences power output, as maximal muscular power can be enhanced in movements involving an SSC (Cormie et al., 2011a).

2.3.2 Muscle Mechanics

Muscle mechanics heavily influence the ability to produce power, with some of the most apparent factors being the length-tension relationship and type of muscle action, and the time available for the muscle to develop force.

The length-tension relationship of a muscle fiber, sarcomere (or whole muscle) is defined as the relationship between muscle length and the force the muscle can produce at that length (Sandercock, 2009). The sliding filament theory can also predict that variations in whole muscle length have an effect on force producing capacity caused by changes in the myofilament overlap (Gordon et al., 1966; Sandercock, 2009). When there is an optimal alignment or "length" between the actin and myosin filaments in a sarcomere, the cross-bridge interaction is at its maximal. At this length, the ability of the muscle to develop the most force is at its peak. Consequently, at shorter sarcomere lengths there is an overlap between the actin filaments from the opposing ends, impairing the force production capacity. Stretched beyond the optimal length, the cross-bridge interaction decreases due to less overlap between the filaments, causing force production to decrease (Cormie et al., 2011a). Thus, the practical applicability for power production is that the ability to exert force is dependent on the muscle length at the time of contraction. Moreover, as ground contact times are often limited during sprinting and jumping, efficient cross-bridging is important for the performance of such abilities. As force cannot be generated instantly due to time constraints in the excitation-contraction coupling, an advantage of SSC movements is that during the eccentric phase, the agonist's muscles have time to develop force before the concentric contraction. This means that the SSC contractions are better at producing power since force is generated over a greater distance than concentric-only movements (Cormie et al., 2011a).

2.3.3 Neural Factors

The neural system activates the muscle fibers, and the most relevant and trainable neural factors relevant for the power production capacity include motor unit recruitment, firing frequency, and inter-muscular coordination.

The ability of the muscle to produce force is determined by the number and the type of recruited motor units (Cormie et al., 2011a). According to the size principle, motor units activate in a hierarchal manner, where the smaller motor units predominantly innervating type I fibers activate prior to larger motor units (capable of activating more muscle fiber) predominantly activating type II fibers, during maximal contractions of increasing force (Henneman et al., 1974). Consequently, it is advantageous to recruit high-threshold units as they innervate the largest amount of fibers capable of producing higher levels of force in a shorter amount of time, thus resulting in a higher power production (Cormie et al., 2011a;

Kraemer & Newton, 2000; Sandercock, 2009). Firing frequency of motoneurons affects the force producing capability of the muscle contraction. With increased firing frequency, the magnitude of force generated increases, and the rate of which force is developed (RFD), thus determining the development of power (Cormie et al., 2011a). Finally, optimal inter-muscular coordination is needed to produce force. As a lot of sport specific actions are complex multi-joint movements, such as jumping, sprinting, and throwing. Appropriate coordination of both timing and magnitude of activation of agonist and synergist, and the relaxation of antagonist muscles are needed to produce power most efficiently in the direction of the movement (Cormie et al., 2011a).

2.4 Training to Develop Power to Optimize Sport Specific Actions

As power is force*velocity, there are no specific adaptions that increase power output independently. To improve power output, different methods that either increase the strength (force component) or speed (velocity component) are needed (figure 1). These components can be trained by applying different strategies to cause adaptions in the aforementioned physiological factors (Cormie et al., 2011a). Some common methods used to improve power are high-load strength training, lower-load power or plyometric training.

Figure 1. Force-Velocity-Power Relationship

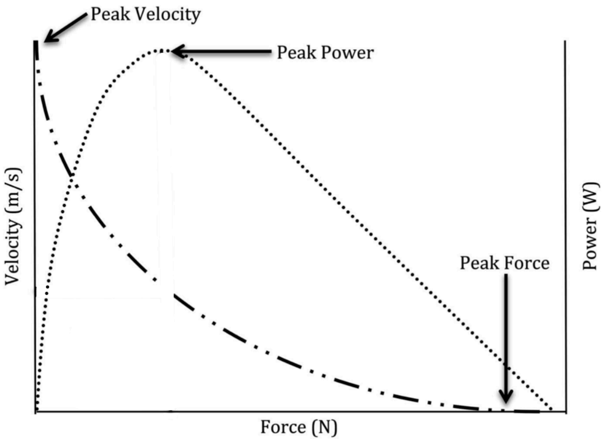

Figure 1: Force-velocity-power relationship Modified from (Haff & Nimphius, 2012)

However, independently of the method used, when aiming to optimize sport specific abilities through resistance training it is also important to consider the characteristics of movement patterns, the direction of force applied, and ground contact times for optimal transference Which ultimately affects how the programs should be designed (Young, 1993, 2006).

2.4.1 High-Load Strength Training

High-load strength training is resistance training that primarily impacts the high-force end of the force-velocity relationship and can be defined as resistance training using heavy-loads of ≥80% of 1RM. This method can increase maximal power output mainly as it is seen as the most efficient method of increasing maximal strength. Additionally, according to the size principle, it is suggested that heavy-load training is more effective than lower-load training in recruiting and developing power-efficient type II muscle fibers (McBride et al., 2002; Wilson et al., 1993), although. The increased power-output after high-load strength training is driven by physiological adaptions, such as an increase in motor unit activation (neural drive), CSA of both Type I and II fibers, greater fascicle length and pennation angle, inter-muscular coordination, and RFD capability (Blazevich et al., 2003; Campos et al., 2002; Cormie et al., 2011b; Kraemer & Newton, 2000; Seynnes et al., 2007; Staron et al., 1994; Widrick et al., 2002).

Due to the fundamental relationship between maximal strength and power output, an increase in relative strength will further enhance the performance in abilities where one must move their own body mass. However, as strength level increases, the window of adaptation for further enhancement decreases (Cormie et al., 2011b). Based on this, much of the literature suggests that once a high-enough strength level is achieved, athletes might benefit more from other forms of "velocity" based adaptions such as lower-load power and plyometrics (Haff & Nimphius, 2012; Stone et al., 2002). However, there exists no standard scale on how high the relative strength level should be, although recommendations have been made based on correlations between squat strength and sprint and jump performance. For example, Wisløff et al. (2004), suggested that those who could squat twice their body mass, were significantly faster and jumped higher than those who could not squat twice their body mass. Additionally, it should be noted that there is limited research on relative strength effects that goes beyond this relative strength level (e.g., 2.5*body mass), and compares their performance with individuals with a squat of 2* body mass. Implying that the knowledge of how much an increased relative strength level can contribute to further enhancement of performance is limited. However, athletes should still emphasize to maintain a high-strength level (Suchomel et al., 2016).

2.4.2 Lower-Load Power, and Plyometric Training

Lower-load power training is characterized by the use ballistic exercises (e.g., medicine ball throw, jump squat) or using loads of 0-60% of 1RM performed with the intent of maximal velocity, while plyometric training are characterized by the use of ballistic exercises with emphasis on fast SSC muscle actions with little to no external load other than bodyweight e.g. drop jumps (Cormie et al., 2011b). These methods are therefore more focused on the velocity component of power by improving the RFD or SSC mechanic. The physiological adaptations contributing to an increase in power from applying these methods, are theorized to be due to improved neural drive, firing frequency, and inter-muscular coordination and increased fascicle length (Alegre et al., 2006; Blazevich et al., 2003; Häkkinen et al., 1985; Kyröläinen et al., 2005). Although debated, it is thought that plyometric training can increase tendon stiffens, thus optimizing the efficiency of the SSC mechanic (Bragazzi et al., 2020; Hirayama et al., 2017; Kubo et al., 1999; McBride et al., 2002).

2.5 In-Season Strength Training for Handball Players

The total volume of matches and training sessions during the in-season varies depending on factors such as league competitiveness, competition schedule and the coach’s area of focus. However, some studies suggest that high-level handball players participate in approximately one weekly competitive match, 3-4 weekly handball-specific sessions, and biweekly strength sessions (Granados et al., 2008; Hermassi et al., 2015; Spieszny & Zubik, 2018).

Biweekly high-load strength sessions performed over the course of 6 – 10 weeks have been observed to cause a significant increases in jump height, throw, CoD, sprint, upper and lower body power performance during the in-season for both sexes (Falch et al., 2022; Hermassi et al., 2010, 2011, 2017; Hoff & Almåsbakk, 1995). Correspondingly, lower-load power and plyometric training have also been shown to cause an increase in the same abilities when performed over the course of 6 – 8 weeks (Chelly et al., 2014; Falch et al., 2021; Hermassi et al., 2014, 2015). Although, in the study of Hermassi et al. (2015) and Hoff & Almåsbakk (1995) on throwing velocity, the programs were performed three times a week.

However, when high-load training are compared to lower-load power and plyometrics, scarce differences are found. For instance, Falch et. al (2022) found no significant between-group differences in CoD, 30m sprint and jump performance between a high-load group and group following plyometric training. However, the study only lasted for 6 weeks, limiting the time available for potential group differences to develop. In a study lasting four months there were observed no major differences in performance between the two training methodologies other than CMJ peak power in favor of the high-load group. Although the plyometric group did improve more in throwing performance, it was not significant (Spieszny & Zubik, 2018) However, both these studies had group sizes of 8-11, thus limiting the statistical power to detect group differences.

2.5.1 Considerations for the Female Handball Player

Physiological differences between genders are apparent and might cause considerations for female handball players. Research suggests that both males and females respond similarly to high-load resistance training (Ramirez-Campillo et al., 2015; Roberts et al., 2020; Zatsiorsky & Kraemer, 2006), although females may achieve lesser gains after plyometric training (De Villarreal et al., 2009). Which might be explained by women typically having less muscle fiber CSA, especially of type II fibers, and often more body fat, thus less relative and maximal strength levels than men (Landen et al., 2023; Nygaard Falch et al., 2019; Zatsiorsky & Kraemer, 2006). Considering this, untrained female handball players might especially benefit from applying high-loads to increase their strength level by recruiting high-threshold motor units and increase the amount and CSA of type II fibers (Zatsiorsky & Kraemer, 2006). However, research on the effects of relative strength level and performance in female athletes are scarce, and the relative strength recommendations commonly referred to in the literature are based on results from male athletes (Suchomel et al., 2016).

3 Methods

3.1 Study Design

A randomized controlled trial (RCT) was chosen for this study. Female handball players from two sub-elite teams were in each team pair-matched based on playing position and randomized into two groups that either followed a strength oriented (high-load) or a power- and plyometric (power-plyo) oriented program for 12 weeks. The stratified randomization was to ensure a balanced on-court workload during the intervention period. Physical performance tests were conducted on and off-court to assess sport-specific abilities and power capacities at baseline and post-intervention. A familiarization session for each test-battery were completed one week prior to baseline testing to reduce a potential learning effect (Figure 1).

Figure 1 *Study Design*

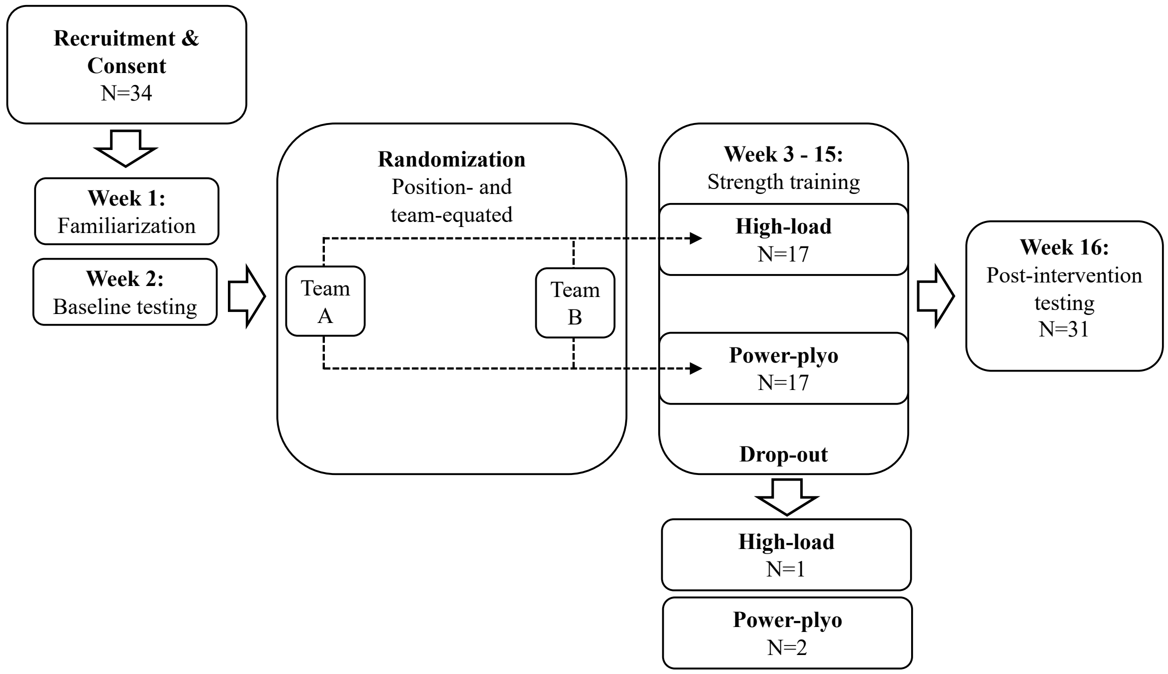

Figure 1: Illustrates the overview of the study design.

3.2 Participants

Thirty-four female handball players from two senior teams playing in the Norwegian 2. division volunteered for the study. Thirty-one of the participants followed the program for 12 weeks and completed both baseline and post-intervention testing (mean ± SD: age: 20±3 years; height: 170 ± 6 cm; weight: 68±11 kg). There were no significant baseline differences in characteristics between the two training groups (Table 1)

Table 1 *Group Characteristics*

Characteristic	High-load	Power-plyo
Age (yrs)	20 ± 3	20 ± 3
Height (cm)	170 ± 6	170 ± 6
Weight (kg)	70 ± 14	66 ± 7
Attendance (%)	90 ± 8	90 ± 9
Keepers (n)	2	2
Backs (n)	7	8
Pivots (n)	4	1
Wings (n)	3	4
Sample size (n)	**16**	**15**

Abbreviations: SD, Standard deviation; Yrs, years; Cm, centimeter; Kg, kilo.

As inclusion criteria the participants had to be in the age range of 16 to 35 and be familiar with strength training. The teams included had to be within proximity of Kristiansand, training equipment fitting our programs, and facilities with equipment capable of supporting two groups training at the same time. The participants were excluded if they got pregnant or injured during the intervention period. Other forms of strength training besides the one prescribed to each participant were prohibited during the entirety of the intervention period. Dietary ergogenic supplements, such as creatine was not allowed during the intervention period. One participant were excluded due to handball related injuries and two dropped out due to lack of motivation.

3.3 Ethics

The study has been approved by the local ethical committee at the University of Agder (Kristiansand, Norway) (Appendix 1), and by the Norwegian Centre for Research Data (Bergen, Norway) (Appendix 2). The principles described in the Declaration of Helsinki and Vancouver recommendations were followed. All participants have been informed of their right to withdraw, the risks involved, and how personal data and results will be treated. All participants signed informed consent before participating (Appendix 3).

3.4 Training Intervention

Both strength programs included two workouts per week. Workout A was supervised by the research personnel and completed on a fixed day during the week, while Workout-B was performed unsupervised on a self-chosen day. A minimum of 48h between the workouts was recommended. In both groups, workout A was considered the higher-volume program, and workout B the lower-volume program. The high-load program consisted mainly of loads of approximately ≥80% of 1RM with 1 repetition in reserve (RIR), as described by Helms et al. (2016) (Table 2). The power-plyo program consisted of low loads at 50% of 1RM as well as a variety of different plyometric bodyweight exercises with the intent of maximal effort and quality in each repetition (Table 3).

To avoid injuries and ensure that the participants were comfortable with the exercises, both programs included a familiarization period where the training intensity was gradually increased. In the high-load program, the RIR gradually decreased from 3RIR in the first workout to 2RIR in their second workout, before beginning with 1RIR through weeks 2-12. The power-plyo program did not increase the weight load. Instead, they were instructed to perform the work sets with submaximal efforts of ~80% during the first workout and ~90% during the second workout, before increasing their efforts to a maximum at week 2-12.

Table 2 *High-Load Program*

High-Load Program

Workout A		**Exercises**	**Load**	**Set x Rep**	**RIR**	**Rest intervals**
Frequency:	1x/week	Parallel squat	≥80% 1RM	3 x 5	1	3 min
		Split squat		3 x 5	1	3 min
When:	Pre-planned day together	*Superset 1* : Hip-thrust		3 x 5	1	3 min
	with the rest of the team	*Superset 1* : Single-leg calf raise		3 x 10	1	2 min
		Romanian deadlift		2 x 5	1	3 min
Supervised:	Yes	*Superset 2* : Bench press	≥80% 1RM	3 x 5	1	2 min
		Superset 2 : Pull ups/lat pulldown		3 x 5	1	2 min
		Shoulder press (dumbbell/barbell)		2 x 5	1	2 min
		Weighted sit-ups		2 x 10	1	2 min
Workout B		**Exercises**	**Load**	**Set x Rep**	**RIR**	**Rest intervals**
Frequency:	1x/week	Parallel squat	≥85 % 1RM	2 x 5	1	3 min
		Superset 1 : Nordic hamstring curl		2 x 5	1	3 min
When:	At a self chosen time	*Superset 1* : Superman (sling/rollout)		2 x 10	1	2 min
		Bulgarian lunge		2 x 5	1	3 min
Supervised:	No	Bench press (dumbbell)		2 x 5	1	3 min
		Superset 2 : Cable row/Bent over dumbbell row		2 x 5	1	2 min
		Superset 2 : Overhead dumbbell tricep extension		2 x 5	1	2 min

Description of the strength oriented high-load program. Abbreviations: RM, repetition maximum; RIR, repetitions in reserve; Min, minutes.

Table 3 *Power and Plyometric-Oriented Program*

Power and Plyometric Program

Workout A		**Exercises**	**Intensity/Load**	**Set x Rep**	**Effort**	**Rest intervals**
Frequency:	1x/week	Parallel squat jumps	≤50% 1RM	4 x 5	Maximal	3 min
		Push Jerk	≥1ms	3 x 5	Maximal	2 min
When:	Pre-planned day together	*Superset 1* : Single leg hip-thrust jumps	Bodyweight	3 x 5	Maximal	2 min
	with the rest of the team	*Superset 1* : Bench press w/Elastic bands	≤50% 1RM	3 x 5	Maximal	2 min
		Drop jumps	>20cm	3 x 10	Maximal	3 min
Supervised:	Yes	*Superset 2* : Kettlebell swing	12kg +	3 x 8	Maximal	2 min
		Superset 2 : Standing medicine ball push throw	2-3kg	3 x 8	Maximal	2 min
		Bulgarian lunge jumps	Bodyweight	3 x 5	Maximal	3 min
		Superset 3: Box jumps	Bodyweight	3 x 10	Maximal	2 min
		Superset 3 : (Week 1- 6) Reverse row (barbell/slings)	Bodyweight	3 x 5	Maximal	2 min
		Superset 3 : (Week 6 - 12) Medicine ball slam	4 - 6kg	3 x 5	Maximal	2 min
Workout B		**Exercises**	**Intensity/Load**	**Set x Rep**	**Effort**	**Rest intervals**
Frequency:	1x/week	Parallel squat jumps	≤50% 1RM	3 x 5	Maximal	3 min
		Superset 1 : Single leg hip-thrust jumps	Bodyweight	2 x 5	Maximal	2 min
When:	At a self chosen time	*Superset 1* : (Week 1 - 6) Standing medicine ball push throw	2-3kg	2 x 5	Maximal	2 min
		Superset 1 : (Week 7 - 12) Lying medicine ball push throw	2-3kg	2 x 5	Maximal	2 min
		Hinder jumps (Week 1 - 6)	Bodyweight	2 x 10	Maximal	2 min
		Frog Jumps (Week 7 - 12)	Bodyweight	4 x 5	Maximal	2 min
Supervised:	No	Split-squat jumps	Bodyweight	3 x 5	Maximal	2 min
		Horizontal jumps (Week 1 - 6)	Bodyweight	2 x 5	Maximal	2 min
		Single-leg horizontal jumps (Week 7 - 12)	Bodyweight	2 x 5	Maximal	2 min
		Superset 2: Box jumps	Bodyweight	2 x 10	Maximal	2 min
		Superset 2: Reverse row (barbell/slings)	Bodyweight	2 x 5	Maximal	2 min

Description of the power- and plyometric-oriented program. Abbreviations: RM, repetition maximum; Ms, meter per second; Cm, centimeter; Kg, kilo; Min, minutes.

3.5 Testing Procedure and Measurements

The physical performance test battery was mainly divided into two testing sessions. An on-court session was completed at each team's home court, while the other session was carried out in a laboratory. The participants were instructed to refrain from any strength straining or strenuous exercise the day prior to the testing sessions. Percieved recovery status (PRS) were obtained from each participant before each testing session on a scale from 1 (very poorly recovered) to 10 (very well recovered) using questionaries. PRS is supposed to give an evaluation of the participants performance status and readiness for the upcoming test session (Laurent et al., 2011).

The baseline laboratory tests relevant for the present thesis consisted of measurements completed in the following order: registration of height, weight and PRS, rate of force development (RFD); leg-press power test, and a bench press power test. For the complete test battery look to Table 4. All participants were given a banana and a protein shake (Yt, Tine, Oslo, Norway) to ensure sufficient energy intake before starting the physical tests (in total: 22g protein and 90g carbohydrates; ~ 247 kcal)

Table 4 *Timeline and Completion Order of the Full Laboratory Test Sessions*

Duration	Familiarization / Baseline	Post intervention day 1	Post intervention day 2
00:00	**Registration**	**Registration***	**Registration**
00:10	Ultrasound	Ultrasound	DXA scan*
00:40	DXA scan / Biopsy: *m.vastus lateralis*	Biopsy: *m.vastus lateralis*	**Warmup: 100W cycling**
	Warmup: light jogging*	**Warmup: 100W cycling**	**Leg-press power test**
01:20	MVC: Isometric knee extension	**CMJ**	1RM Squat
01:30	**RFD: Isometric knee extension**	MVC: Isometric knee extension	**Bench press power test**
01:40	**Leg-press power test**	**RFD: Isometric knee extension**	1RM Bench press
02:00	1RM Squat	Another part of the project with additional biopsies and tests not relevant to this thesis	
02:20	**Bench press power test**		
02:30	1RM Bench press		

The measurements not marked with **bold** text were completed as parts of other research projects but are still presented to illustrate the completion order and total workload. Abbreviations: DXA, Dual-energy X-ray absorptiometry; MVC, Maximal voluntarily contraction; RFD, Rate of force development; RM, Repetition maximum; W, watt; CMJ, Countermovement jump. *Energy intake: 22g protein and 90g carbohydrates; ~ 247 kcal.

The completion order of the post intervention laboratory test battery could not be replicated identical to the baseline test battery. The reason being logistical and recovery related issues due to two muscle biopsies on each participant. This caused the CMJ test to be moved from the court test battery to the laboratory test-battery. However, the CMJ test still remained the first lower-body performance test post-warmup. Additionally, the RFD-test were not completed prior to the leg-press power test, as they were completed on two separate days. The two days of post intervention lab-testing were completed with a minimum of two rest days between.

Upon arrival of the first test day of post-testing the participants ate and drank the same as what they got on baseline testing. As a warmup procedure of the participants underwent 10 minutes of stationary cycling at ∼100W. After the warmup the participants were tested in CMJ, and RFD, respectively (Table 4).

The second day of post-testing consisted of 10 minutes of jogging as warm up. If jogging felt uncomfortable due to the recent biopsy, the participants could choose 10 minutes of light cycling. After the warmup, the participants completed the leg-press power test and bench press power test respectively.

The on-court test battery consisted of tests completed in the following order: handball throwing velocity in two types of throws (standing throw followed by three-step running throw); countermovement jump (CMJ) height; jump-and-reach height; 30-meter linear sprint with split times recorded at 5, 10, 15, 20 and 30 meters; and change of direction (CoD) sprint (Figure 2). During post-intervention testing the test-battery was similar to baseline testing (except CMJ, as mentioned). Prior to all tests, a submaximal familiarization set of the specific test was performed as a warmup. To avoid queueing at the test stations, the participants started the test battery in groups of 5 with a 15-minute interval between groups. After the assessment of their PRS, the participants warmed up with light jogging and throwing drills.

Figure 2 *Overview of The On-Court Test-Battery*

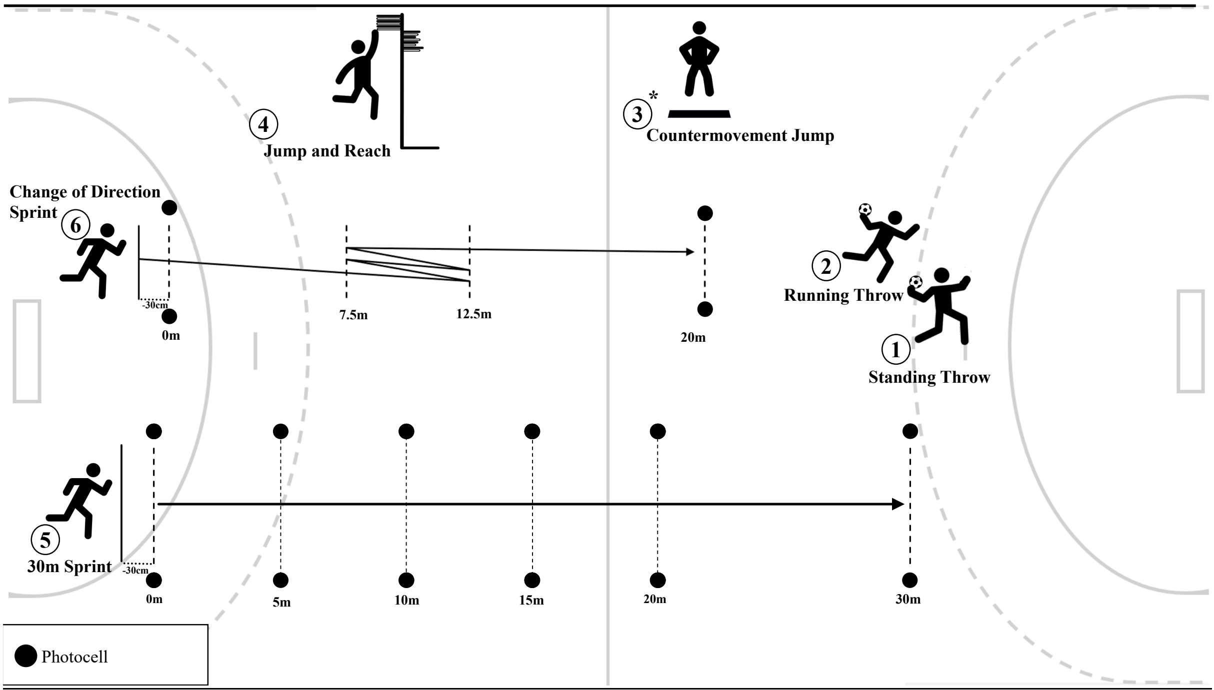

Figure 2: Illustration of the completion order of the test stations and how it was set up on the court.
*At post intervention testing the Countermovement Jump test were completed with the tests performed at day 1 of the laboratory test battery sessions (Table 4).

3.5.1 Throwing Velocity

Throwing velocity was measured using a standard women's handball (size 2) during two different types of throws: the standing throw and the three-step running throw. The standing throw involved throwing from a stationary position at a distance of 7 meters (penalty shot), while the three-step throw allowed for a run-up of three steps before throwing at the same distance (7 m). Ball velocity was measured with a hand-held radar (Bushnell velocity speed gun [101911], Overland Park, Kansas, USA), standing diagonally behind the shooters dominant arm. Participants were instructed to aim for the middle of the goal and were given two sets of three attempts for each type of throw, with a 3-minute rest between sets. If performance improved, participants were given additional attempts, and their best results were used for further analysis.

3.5.2 Countermovement Jump

Jump height was measured by performing a CMJ on a force plate (Advanced Mechanical Technology, Watertown, USA) with a sampling frequency of 2000Hz. The participants stood in their preferred jumping position, which was about a shoulder-width distance between their feet. The participants were instructed to keep their hands fixed on their hips and jump as high as possible, with the depth of the countermovement being self-chosen.

All participants completed a CMJ warm-up session where they got to experiment with different depths in the countermovement. The participants were given two sets of three jumps, with a 3-minute rest interval between sets and a 10-second rest between each attempt. If the jump height increased, another attempt was given. More attempts were also given if the jump was considered invalid (e.g., hand placement or faulty calculations from the platform). Jump height was calculated from the impulse during takeoff using a custom-made MATLAB script (MATLAB, MathWorks, Natick, USA). The average of the two best results was used for further analysis.

3.5.3 Jump and Reach

Jump and reach ability was assessed by performing a three-step run-up with the intent of reaching the highest vane possible on a Vertec vertical jump tester (Vertec [800-556-3198], Sportsimports, Columbus, USA). The participants were instructed to start the lift-off phase from their dominant foot, corresponding to how they would do a jump shot. Standing reach height was measured with both feet together, without lifting their heels, and their dominant arm fully extended using the whole shoulder range of motion. Jump height was calculated by subtracting their standing reach height from the highest vane reached during the jump test. After completing two familiarization attempts, the participants performed three attempts with maximal effort. The participants were given a 3-minute rest interval between each attempt. If jump height increased, or the participants themselves thought they could perform better, more attempts were given. The best attempt in terms of maximal jump height was used for further analysis.

3.5.4 Linear Sprint

Linear sprint ability was assessed by performing a 30-meter sprint, with split times recorded at 5, 10, 15, 20, and 30-meters. Sprint times were measured with single-beam MuscleLab timing gates with infrared photocells (Ergotest Innovation AS, Porsgrunn, Norway). The first photocell was placed 30cm above the ground while the rest were placed at 100cm above the ground. The participants were instructed to stand still before initiating their run. Trials initiated with a countermovement to gain momentum were not approved. The participants initiated their run from 30 cm behind the starting line (Figure 2). All participants were given three attempts, with a minimum of three minutes of rest between the attempts. If the 30-meter time improved, they were given additional attempts. All split times used in the analysis were retrieved from their best 30-meter attempt. The sprint times were extracted using the manufacturer's software (MuscleLab, Ergotest Innovation AS, Porsgrunn, Norway).

3.5.5 Change of Direction Ability

CoD ability was assessed by using the A180° test, the standard CoD test used at the Norwegian Olympic Sports Centre. Sprint times were recorded with single-beamed timing gates with infrared photocells (Brower Timing Systems, Draper, USA). The photocells at the starting line were placed 30 cm above the ground, and 100 cm above ground at the finish line. All participants initiated their run 30 cm behind the starting line. The test consists of four 180° changes of direction between two marked turning lines at 12.5 meters and 7.5 meters, resulting in a total of 40 meters. (Figure 2).

The participants were instructed to stand completely still before initiating their run. If they initiated with extra momentum by swaying or skipping, they were quickly called off and had to redo their run. The participants had the freedom to choose which foot they started the first change of direction with, as long as they alternated between their dominant and non-dominant foot for each direction change, maintaining a consistent pattern throughout all test sessions, and ensuring an equal number of left and right-footed CoDs. The test leader controlled that the correct foot crossed the turning line on all direction changes. If the participants did not manage to step on the turning line, the result was not approved, and they were given another attempt. Further attempts were given if the participants improved their sprint times. The best attempt was used for further analysis.

3.5.6 Leg-Press Power

Lower limb power was assessed using a pneumatic resistance-based Keiser A300 horizontal leg-press device (Keiser sport, Fresno, USA). Power values were retrieved from the manufacturer's software after completing a standardized ~10-repetition test that starts at a low resistance that gradually increases for each repetition until failure is reached. Rest periods increased with gradual increments of 5 to 38 seconds between repetitions. The seating position was adjusted for each participant to the position where the femur was as close to perpendicular to the floor as possible. Seating position was logged for each participant to maintain consistency between baseline and post intervention testing. Warm-up included two sets of three repetitions with gradually increasing efforts completed at 30 and 60kg respectively, before starting the maximal effort 10-step test. The participants were instructed to extend their feet with maximal effort at all increments. The resistance increase of each increment was preprogrammed by the Keiser A420 software, based on the resistance of the 10th repetition, manually set by the test leader before the test started. The estimated resistance of the 10th repetition was set to be 150, 200, 250, or 300kg, depending on which load was deemed closest to the participant's maximal capacity. The resistance increments for each participant were logged and replicated during post intervention testing. Average concentric power output in each repetition was used to determine power-output at different loads and used in the statistical analysis. Using the same results, a power-velocity relationship were established by the Keiser software, and the participant's maximal power output (P_{max}: force*velocity at optimal loads) was calculated as the apex of the power-velocity curve and used for further analyses.

3.5.7 Bench Press Power

Bench press power was assessed with a linear encoder (MuscleLab Linear Encoder; Ergotest Innovation, Porsgrunn, Norway) attached to the bench press barbell by performing five sets with maximal concentric effort with gradually increasing loads, starting at 10kg, and ending at a resistance near 90% of 1RM. The number of repetitions performed decreased from five to one, with fewer repetitions performed as weight increased set by set with constant loads of either 5-, 7.5- or 10kg, until the fifth and last set ended at 30, 37.5 or 50kg (1st-: 10kg, 2nd-; 15/17.5/20kg, 3rd-; 20/22.5/30kg, 4th-; 25/30/40kg, 5th -Set; 30/37,5/50kg). The pause times between the sets increased from 1 minute between the first three sets to 2 minutes between the two last sets. The load increments were determined by the participant's subjective assessment of their own strength level at familiarization and if necessary, adjusted to baseline, and replicated at post-intervention testing. To estimate power, the encoder measured the distance and time of displacement at every given load (200Hz sampling rate). Power measurements, such as P_{max}, and average power values were calculated by the manufacturer's software (Muscle lab; Ergotest AS, Porsgrunn, Norway), using the time of displacement of the concentric phase, and the load lifted during each repetition. The repetitions with the highest average power from each load was used to assess power-output at different loads and used for further analysis. A power-velocity relationship was established, and P_{max} calculated as the apex of the power-velocity curve.

3.5.8 Rate of Force Development

Rate of force development was measured with a dynamometer (MuscleLab, Ergotest AS, Porsgrunn, Norway) while performing a maximal voluntary isometric contraction (MVC). The participants sat on a custom-made bench with their knee pits against the edge, and their dominant-leg ankle fixed tightly to a dynamometer at a 90° knee-joint angle (Figure 3). Following a brief three-repetition warmup with gradually increasing efforts, the participants were encouraged to extend their leg as fast and hard as possible for 1-second. All participants were given at least three attempts, with a 15-second rest between each attempt. More attempts were given if performance improved. The RFD was sampled at 0-30, -50, -100, -150, -200, -250ms windows after initiation of force, defined by an onset point of 2.5% of peak force and used in the statistical analysis. The force signal was sampled at 1000Hz by the integrated software (MuscleLab, version 10.5.69.4815).

Figure 3 Rate of Force Development Set-up

Picture of the custom-made bench-set up. Velcro straps were used to attach the ankle to the dynamometer.

3.6 Statistical Analysis

Descriptive results of the study sample at baseline were calculated using Microsoft Excel (Microsoft Excel, Version 16.66.1, Microsoft Corporation, Redmond, USA). The distribution of data was assessed by visually inspecting Q-Q plots combined with the Shapiro-Wilk normality test. Statistical analysis was performed in Jamovi (Jamovi, Version 2.3 The Jamovi project, Sydney, Australia). Depending on the distribution of data, independent sample t-test or Mann-Whitney U-test were used to analyze between-group differences of changes in each performance variable. Paired sample t-test or Wilcoxon matched-pairs test was used to investigate within-group pre to post changes. Results are presented as absolute and percentage means with standard deviations, confidence intervals and p-values. Confidence limit was set at 95% and the significance at $p<0.05$.

The reliability of the tests was based on the baseline and familiarization test results and assessed in comparison with external reliability studies. The coefficient of variation (CV) was calculated as the standard deviation (SD) of the difference between the results at familiarization (test 1) and baseline (test 2) and divided by the mean of test 1 and 2 and presented in relative terms (CV%). The absolute typical error (TE) was calculated as the SD of difference between test 1 and 2/(sqrt(2)) as described by Swinton et al., (2018) and presented in absolute or relative terms (TE%). Smallest worthwhile change (SWC) was calculated as 0.2 multiplied by the between-subject SD of the specific test (Conway, 2017). Figures were made using GraphPad Prism (GraphPad Prism, Version 9.5, GraphPad Software LLC, San Diego, USA).

4 Methodological Discussion

There are multiple ways of designing and conducting a study, which includes a range of different possible strengths and limitations. The most relevant factors that might affect the interpretations and generalizability of the present study include its external and ecological validity, not having a control group and lack of blinding, sample size and characteristics, intervention fidelity, and the validity and reliability of the measurements and equipment used. All these matters will be further discussed.

4.1 Study Design

The present study employed a randomized controlled trial design, which is often regarded as a gold standard for assessing causality due to its requirements of conduct concerning internal validity. However, the effort of maintaining internal validity can have a major effect on the study's external validity. That is, whether the results can be applicable to others, rather than the specific group in the same context that was studied (Rothwell, 2005). This study's results cannot be expected to be relevant for all athletes nor settings. Thus, it is important to present and conclude the present study in a manner that facilitates readers and practitioners in making judgments regarding its applicability.

The present study does not include a control group, which purpose is to validate the experiment and provide the basis of evaluating the effect of the interventions per se. As the control group would´ve controlled for known confounders such as handball training, but also the unknown confounders. Nevertheless, the decision to not include a control group was made to avoid decreasing the statistical power when comparing the two groups, as including a third group would result in fewer participants per group. Additionally, it would be unethical to ask aspiring athletes to refrain from resistance exercise when research has shown that doing so can lower their physical performance (Marques & González-Badillo, 2006). Besides, the aim of the present study is not to evaluate the effect of in-season strength training in general but compare the effect of two different interventions.

However, even if not essential in accord with the aim of the study, a control group would still have been beneficial for assessing whether the eventual changes are meaningful, when comparing the group differences. With this in mind, the lack of a control group can be considered a limitation of the study. Additionally, a group following their usual program with both heavy-loads and plyometrics could have been used as a “control-group” to compare the effects of the present study’s programs with a mixed-method approach which is commonly used in handball (Spieszny & Zubik, 2018).

Even if the broad definition of an RCT doesn’t require a control group in strict terms, as the decision of appropriate control groups is tied to the aims of the study (Bespalov et al., 2020), it still needs to be randomized. Randomization is done in order to prevent selection bias due to different baseline or confounding characteristics of the participants. If the sample is large enough, randomization can ensure that sample is divided into two similar groups more representative to the studies population. However, the sample size in the present study is relatively small and certain characteristics that could influence the dependent variables are known. These characteristics are on-court position and team played for. Thus, stratifying the randomization is more effective in creating two equal groups as it accounts for the selected variables of team membership and position, ensuring that the groups are more comparable than would be possible with a simple randomization.

Oftentimes when conducting an RCT, the procedure of blinding the researchers for participant group allocation is done in order to maintain objectivity, by preventing biases from the researchers affecting the results (Holman et al., 2015; Polit & Beck, 2010). This, however, was not prioritized in the present study due to prioritizing the intervention fidelity by having weekly follow-ups of the participants during training. Nevertheless, having the researchers oversee, rather than being blind of whether the intervention were carried out satisfactorily to its intention, is a strength that can be argued to outweigh the limitations of not blinding the researchers to group allocation. Nevertheless, a limitation of the design of present study is that neither the researchers nor the participants expectations of effectiveness toward the assigned programs were controlled for, as these factors have been observed to effect results of training interventions (Holman et al., 2015; Lindberg et al., 2023).

4.2 Study Sample

The study sample is important to the external validity and the statistical strength of the study. Sample size is important as it is likely to be more representative the larger it is. It is also known that the sample size does affect the ability to detect group differences. A small sample size reduces the statistical power, and increases the risk of type II errors, which is when analyses fail to show that that the independent and dependent variables are related, even when they are (Polit & Beck, 2010). The sample size in the present study consisted of 31 participants, with 15 and 16 in each group. With a power level of 80%, referring to the chance of detecting a group-difference, and the significance set to 0.05, groups of 14 participants were recommended to be able to detect a between-group difference of 8±7 (calculated in G*power, version 3.1, University of Dusseldorf, Germany). Additionally, a strength of the study is that the participants plays at a high-level, as few other studies has been conducted on this population.

An issue concerning the external validity of the present study is the characteristics of our included sample. As the participants are from the Norwegian 2. division, our findings might not be applicable to handball players of higher or lower divisions, playstyles, or leagues with different seasonal fixture plans.

4.3 Training Intervention

Based on a systematic review on studies investigating the effect of the different training methods on the variables of interest in general, a 12 week duration and the volumes used, should be considered sufficient enough to have measurable effects (Bragazzi et al., 2020). Most of the included studies in the systematic review were 8 weeks or shorter, and only 3 of the 18 included studies had a longer intervention period than 12 weeks. A 12-week training period is also longer than most other studies investigating strength training in the population of interest. Thus, the duration of the present study can be considered a strength.

A strength of the study is the intervention fidelity, as the researchers consistently followed-up half of the weekly workouts of each team. The researchers could assist, guide, and monitor the participants to assure quality training and maximal efforts. To better succeed with this, the researchers brought several accelerometers (Vmaxpro, BM Sports Technology, Magdeburg, Germany) connected to tablets. With the aid of accelerometers, the researchers could monitor levels of effort and fatigue to ensure maximum effort in the power-plyo group and that repetitions were close to failure in the high-load group. The participants themselves were also able to get instantaneous visual feedback on the velocity drop for each repetition, which has been shown to motivate to increased efforts and enhance training adaptions (Weakley et al., 2019). The augmented feedback and weekly follow-up can be considered a strength, as it could be assured that most of the prescribed program was followed satisfactorily.

4.4 Statistics, Reliability, and Validity of Measurements

Data obtained from measurements will always have a certain degree of error, concealing the true score. Even though a true score is an unattainable ideal, researchers aim to reduce the plethora of factors contributing to measurement errors, to come as close as possible to the true score (Polit & Beck, 2010). Using tests and instruments with high validity and reliability is important to reduce measurement error. Reliability can be defined as the reproducibility of values of a test in repeated trials on the same individual (Hopkins, 2000), while validity is defined as the degree of which a test measures what it is intended to measure (Thomas et al., 2015).

A test with a high reliability increases the likelihood of identifying real changes in performance. For instance, if the SWC is larger than the typical error (e.g., TE or CV) and the change is over the SWC value it could be interpreted as a meaningful change. On the other contrary, if the CV is more than the calculated SWC, it would be more beneficial to use CV to identify real changes. However, as the test is conducted twice, the CV needs to be doubled (2CV) to account for the potential chance of variation in both tests. This poses a problem, as 2CV might be unachievable due to the test-retest variation being too high, which can potentially mask if true changes have been made (Conway, 2017). This illustrates the importance of having high reliability in the tests and instruments used.

To increase the reliability during testing, a standardized protocol was used to ensure similar procedures in baseline and post intervention testing. The study also included a familiarization session, to reduce the learning effect of the tests, thus increasing the reliability. However, 6 and 1 participant(s) did not participate in the on-court-familiarization session and lab-familiarization respectively. Thus, a learning effect could have affected the results of these individuals. However, a large learning effect for the familiarization-absentees is unlikely, as the average percentage difference between the tests ranged from -3.5% to 2.1% from familiarization to baseline testing.

Although the reliability calculations (TE and CV) were based on the familiarization sessions, which is not ideal due to the potential learning effect. It is worth noting that the mentioned percentage test-retest range (-3.5% - 2.1%) indicates that any learning effect would also have been trivial to the reliability calculations of the present study. Furthermore, a reliability study using similar equipment and tests procedures as the present study found good test-retest reliability for CMJ, Jump-and-reach, Leg-press and 10 m, 20 m, and 30 m across four testing sessions (Lindberg et al., 2022). Which further indicates that a learning effect by the participants would be marginal, and that the CV and TE calculations can be considered applicable for the specific tests.

A lot of confounders were controlled for during testing sessions such as percieved recovery status, and order of test-completion. However, confounders such as, time of the day, caffeine intake, verbal encouragement, number of observers in the room, and background music, were not controlled, and are known to potentially influence test results (Halperin et al., 2015). However, these factors were probably similar in both groups. Furthermore, the tests were sometimes performed with different test-leaders due to the logistics of testing whole teams within a short time frame. Thus, a possible difference in interpretation of the protocol could have potentially caused dissimilarities in test completions. However, combined, the known confounders that were not controlled for limits the internal validity of the study.

4.4.1 Ecological Validity of Measurements

Ecological validity, a subtype of external validity, refers to the extent to which experimental findings can be generalized to real-world settings (Nikolopoulou, 2022). In the present study, it is related to how well the tests represents the high-intensity actions performed on the handball court. While some tests, such as the Jump and reach, sprint and throw tests, are considered more sport specific and have high ecological validity, others might be considered to have lower ecological validity. However, even though the isometric knee extension and leg-press test may not be associated with sport specific movements, they measure physiological features that are strongly linked to performance in other more sports specific actions. For instance, there is seldom a need of an isometric knee extension, nor a sitting leg-press during a handball match. However, measurements such as the RFD and P_{max} values obtained from these tests are highly correlated to athletic performance (Lindberg et al., 2021; Walker, 2016b).

4.4.2 Throw Velocity

According to the manufacturer, the Bushnell speed radar gun is reported to have an accuracy of +/- two km/h (Bushnell, 2022). Compared with three-dimensional motion capture systems, considered the golden standard for measuring the velocity of moving objects (Ozkaya et al., 2018), radar guns are considered to give valid and reliable measurements if used correctly (Weisberg et al., 2020). Radar guns measure the radial velocity, which means that accuracy decreases as the angle between the radar and the measured object increases. Accordingly, factors such as ball trajectory and radar positioning can affect the measurements (Weisberg et al., 2020). This means that the validity of the measurements could be slightly off compared with the gold standard. However, a high degree of reliability can still be achieved to attain valid measurements in terms of changes in performance. The radar gun was positioned towards the middle of the goal during all test sessions to maintain reliability throughout the study, even if the participants did not manage to shoot in the middle where they were instructed to.

The calculated TE from both throws during familiarization and baseline testing revealed a TE of 4.0% and 4.8% for standing and three-step throw respectively. It is unlikely that the participants had a learning effect between the two trials, as they were familiar with both types of throws.

4.4.3 Countermovement Jump

Force platforms are considered one of the gold standards for measuring vertical jump height ability (Rago et al., 2018). The average of the two best jumps were used in the analysis to reduce the measurement error, thus providing a representative estimate of the individuals jump height. Calculations derived from the present study's baseline and familiarization testing revealed a TE of 3.4% Which is similar to the findings of another reliability study of the CMJ performed on a similar AMTI force plate, which reports a TE of 4.6% (Lindberg et al., 2022).

4.4.4 Jump and Reach

This test has high ecological validity for sports, where maximal reach height in the flight phase is critical for performance (Muehlbauer et al., 2017). A study examining the test-retest reliability of the jump & reach test reports a TE of 3.9% (Lindberg et al., 2022), which is in line with the results of the present study, which observed a TE of 3.5%, which can be considered good.

4.4.5 Linear and Change of Direction Sprint

The use of Single beamed photocells can be considered a weakness compared with dual-beamed photocells when measuring short sprints (Haugen & Buchheit, 2015). However, measures were taken to increase the reliability by mounting the photocells at hip-height in accordance with the recommendation of Yeadon, Kato & Kerwin (1999) thus avoiding a premature break of the beam caused by arm or leg swing. The participants also started their sprint at their own initiative, removing the influence of reaction time as a confounding factor. The tests were completed at the team's home court, thus the air resistance, temperature, humidity, and running surface remained identical, as a variability in these factors combined could have affected the reliability of the tests (Haugen & Buchheit, 2015).

One might expect a learning effect to have occurred in the CoD sprint, as this test can be argued to be motorically advanced enough and that they did not have any experience in this test. However, the percentage change between familiarization and baseline revealed an increased sprint time of 0.92%, indicating no such learning effect. Additionally, the reliability data of the CoD test sessions revealed a TE% of 2.1% in the CoD-test. The linear sprint is a relatively easy test, and a study found that high levels of reliability of short sprints could be achieved without the need of a familiarization session (Moir et al., 2004). Additionally, the percentage increase between familiarization and baseline in the present study ranged from 0.31 to 0.87%, rather indicating a slight increase.

Despite some participants completing sprints on different surfaces between baseline and post-testing, this potential weakness is likely trivial based on a study that found different normal track compliances to have minimal effects on 0-30m sprint performance (mean difference: >0.03 seconds) (Stafilidis & Arampatzis, 2007). Furthermore, the range of % change within these subgroups was somewhat similar (High-load, identical: -1.2 – 1.5% vs different: -0.6 - 1.3%; Power-plyo, identical: -0.8 – 0.6% vs. different: -4 - -1.3%).

The present study found a TE% of 5.7% at 5m gradually decreasing to 1.6% at 30m. The higher TE% at 5m is likely due to increased error caused by limb movements at short distances. However, more reliable measurements could have been obtained by using dual-beamed, instead of single-beamed photocells (Haugen & Buchheit, 2015).

4.4.6 Leg-Press Power

The Keiser leg press device is a widely used apparatus and records valid and reliable measurements of lower limb power (Redden et al., 2018.). The average TE% of test-retest measurements of the average power, and theoretical maximal power (P_{max}) of the instrument is reported at 5.4%, and 4.4% respectively, which can be considered acceptable reliability (defined as TE <10%, or good reliability TE < 5% (Lindberg et al., 2022; Redden et al., 2018.). These results are also in line with our reliability data on P_{max} which shows a TE% of and 4.2%. The use of the Keiser leg press test can be seen as a strength of the present study's ability to detect changes in lower-limb power.

4.4.7 Bench Press Power

Linear encoders are a widely used and validated technology for tracking barbell velocities. A CV of 1.9% has been reported for average velocity measurements from a similar encoder and set up as used in the present study (Myrholt et al., 2023). However, the calculated CV at 1.9% were for velocity. As power is derived from both velocity and force, a larger margin for error is to be expected. A study using a similar encoder to assess bench press power output at different loads (30 – 100%1RM) reports a CV% ranging from 4.7% to 7.9% (Izquierdo et al., 2002). Calculations from the present study, derived from the difference between familiarization and baseline revealed a CV% ranging from 8.6% - 11.4% at loads of 20%, 37%, 54%, 70% of 1RM, although at loads of 84% of 1RM the CV% were calculated to 29.8%. The lower CV% in the study of Izquierdo et al. (2002) might be due to the bench press being performed in a smith machine. In the present study reliability calculations of P_{max} revealed a TE% of 6%. Even if these power measures has lower reliability than other measures in the present study, the measurements still offers acceptable reliability, and can provide good assessments of upper body power.

4.4.8 Rate of Force Development

Measuring RFD during rapid contractions is a common method for assessing the explosive strength of athletes. However, it can be difficult to evaluate RFD validly and reliably, as it is a highly sensitive measurement. The time-interval measurements, is considered the most reliable RFD measure (Walker, 2016b) and was used in the present study. Unfortunately, the custom-made set-up as used in the present study, has not yet been tested for reliability. However, the custom-made set-up was made rigid, with non-padded seating and the connection between dynamometer and ankle had minimal compliance, as recommended by Maffiuletti et al. (2016). Further recommendations, which included: setting the sampling rate at >1000Hz to maximize accuracy; completing a familiarization session; standardized instructions; standardizing seating positions and using short 1-second contractions with short rest periods were followed to reduce confounders and variability.

A study measuring the RFD test-retest reliability during a similar dominant limb MVC performed as an isometric knee extension reported a CV of 12.4%, 8.9% and 7.1% for RFD_{0-50}, RFD_{0-150} and RFD_{0-250} respectively (Courel-Ibáñez et al., 2020). However, the set-up had more compliant padding, and the instruments and had a much lower sampling rate (80Hz), thus the RFD test set-up in the present study could be argued to measure more accurate and reliable.

4.5 Strengths and Limitations

The study's main strengths include the study sample consisting of high-level players, a comprehensive test battery, randomization, and familiarization session, as well as the high training attendance of 90% in both groups. Another significant strength is the intervention fidelity, which was maintained through regular follow-ups, ensuring that the intervention was received in accordance with the intention. Combined with the intervention period which lasted 12 weeks, this can be argued to be a methodical strength not too many other strength-intervention studies has matched. Other strengths include the high validity and reliability of the Keiser leg-press, Jump, and throw measurements, providing good assessments of throwing speed, lower limb power and jump heights.

The study has weaknesses that limit its internal validity. Firstly, not all plausible confounders were controlled for, such as total training volume in the programs, dietary habits, on-court playing time, and other forms of exercise, during the study period. Another limitation is that neither the researchers nor the participants expectations of effectiveness toward the assigned programs were controlled for. Additionally, there were variations in test leaders, background music, verbal encouragement, and observers in the room during testing, which may have influenced the results. Moreover, not all participants completed the familiarization session, and a few completed the post-testing at different conditions than at baseline, although the impact was likely negligible based on the results within these sub-groups.

It should also be mentioned that with all the different possibilities when creating a high load/power/plyometric program in regards of exercises, intensities and volumes chosen, and the specific characteristics of our studied sample in mind. One must be careful about generalizing the findings of the present study to other contexts, sports, populations, and programs. However, the training programs had different focuses on training stimuli and should provide enough volumes to induce notable effects across various performance measures. Thus, the results can be considered sufficient to compare the generic effect of the two different training modalities on the studied sample.

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PART 2

RESEARCH PAPER

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Optimizing Physical Performance During the Competitive Season for Female Handball Players: A Comparative Study on the Effects of High-Load Strength Training versus Power and Plyometric Training

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Purpose: The present study aimed to compare the effects of high-load strength training and low-load power and plyometric training on explosive performance measures in in-season female handball players. **Methods:** Thirty-one sub-elite handball players (age, 20±3 years; height, 70±6 cm; weight, 68±11 kg) were randomly assigned to a high-load (weekly: 5-20 sets ≥80% of 1RM per muscle group) or low-load power and plyometric training group (power-plyo) (13 sets ≤50% of 1RM and 165 bodyweight jumps). Training sessions were performed biweekly and supervised once per week for 12-weeks. Pre- and post-measurements were countermovement jump (CMJ) height, single-leg vertical jump-and-reach, standing- and 3-step throw velocity, linear sprint (0-30m) and change of direction (CoD) times (4x180°turns), lower- and upper-body theoretical maximal power (Pmax) and power at low to high loads (pneumatic resistance leg-press, and bench press) and rate of force development (RFD). Results were analyzed using t-tests with a significance level set at $p<0.05$. **Results**: No significant between-group differences were observed in any of the variables. Compared to baseline, the high-load and power-plyo group improved CMJ (6.6% and 7.2%) and jump-and-reach height (5.6% and 6.1%), Pmax in leg-press (11.7% and 8.3%) and bench-press (8.1% and 5.5%: tendency; 0.068) respectively. Throwing velocity and linear sprint remained unchanged, but the high-load group significantly improved in CoD (2% vs. 1%) and RFD (6.7-13.4% vs. -2.2-4.4%). **Conclusion:** The findings suggest that female handball players can achieve similar benefits from either a high-load or a low-load power and plyometric oriented strength program in improving or maintaining in-season explosive abilities.

Keywords: Handball, resistance training, in-season, high-load, power, plyometric

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1 INTRODUCTION

Handball is one of the fastest and most intense team sports where a regular match can involve more than 800 high-intensity actions[1]. These high-intensity actions involve sprints, rapid changes of directions, jumps and shots. The higher the degree of effort and intensity put into these power demanding actions means a correspondingly higher chance of success of feints won, shots blocked, goals scored, and ultimately games won[2]. Performance in these abilities are highly dependent of the athlete's overall strength level and ability to express high power outputs[3,4]. Accordingly, elite players are often stronger, more explosive, throws harder, jump higher, and run faster than their sub-elite counterparts, emphasizing the importance of strength training for increased handball performance[5].

Strength training may, however, receive less attention during the competitive period when the players' readiness to perform at their best during matches and handball specific training has the highest priority. This poses a challenge when planning an in-season strength program as the fatigue induced by strength and power training could potentially impede the on-court performance[2,6,7]. Nevertheless, strength and power training should likely be included, given that a total absence of this type of training has been observed to decrease in-season sprint, throwing velocity, and jump performance[8,9]. Another consideration is that matches and handball specific training also cause neuromuscular fatigue, thereby negatively impacting the potential for optimal adaptations following strength training[2,6]. Yet, performing strength training at a time that minimizes interference with handball play and in a state where full recovery is not always achieved, may be a necessary compromise to maintain physical capacities during the competitive period. As such, planning an in-season strength program is challenging as it needs to give sufficient training stimulus to maintain or improve explosive abilities, while simultaneously avoiding unnecessary fatigue that could lower on-court performance during matches and handball-specific training[10].

High-load strength training, lower-load power training and plyometric training, have all been shown to increase or maintain physical performance in power-demanding actions during the competitive period for handball players[10–17] However, high-load strength training seems to require a longer recovery time than exercise with lighter loads[18] When considering the time required to reach full recovery, it can be questioned whether prioritizing low-load power and plyometric training during the competitive period may be advantageous as compared to high-load training. Conversely, as handball players regularly perform explosive actions during matches and handball specific training, it is yet to be determined whether additional power and plyometric training can result in further adaptations when set up against heavy-load training. Thus, in-season strength programming is of great interest to many researchers and coaches. However, it is predominantly male players that has been examined in studies examining the effect of in-season strength training. Additionally, previous research either compares a combination of heavy-load strength training and lower-load power training, or power, plyometrics, and heavy-load strength isolated, with a control group following no other additional strength training. Therefore, it is still unclear which form of in-season strength training elicits the greatest benefits, especially for female handball players.

Based on the gap in the literature, this study aims to examine the effects of high-load strength training compared to low-load power- and plyometric training on a variety of different physical-power performance measures in female handball players during the competitive season. The results of this study can provide additional information on the effects of different types of strength training, and new information for strength coaches on how to better plan in-season strength training for female handball players.

2 MATERIALS AND METHODS

2.1 Participants

Female handball players from two senior teams playing in the Norwegian 2. division were invited to participate. To be included the participants had to be in the age range of 16 – 35 and be familiar with resistance training. The participants were excluded if injuries prevented them from participation. Thirty-four players were initially included, but three were excluded, due to injuries (n=1) or motivation related drop-out (n=2). Thirty-one players (mean ± SD: age: 20±3 years; height: 170 ± 6 cm; weight: 68±11 kg) completed the intervention and the physical performance test sessions at baseline and post-intervention. All participants were informed of their right to withdraw, the risks involved, and how their personal data and results would be treated. Written informed consent was obtained from all participants before participating. The study was approved by the Norwegian Centre for Research Data and the ethical board of the University of Agder (Faculty of Health and Sport Sciences) and performed in accordance with the principles of the Helsinki Declaration.

2.2 Study Design

The study was conducted as a randomized controlled trial, where the participants were in each team pair-matched based on playing position and randomized into two groups that either followed a strength oriented (high-load) (n=16) or a power and plyometric (power-plyo) (n=15) oriented program for 12 weeks during the first half of the competitive period (Figure 1). Other forms of strength training besides the one prescribed to each participant were prohibited during the entirety of the intervention period.

FIGURE 1 Study design

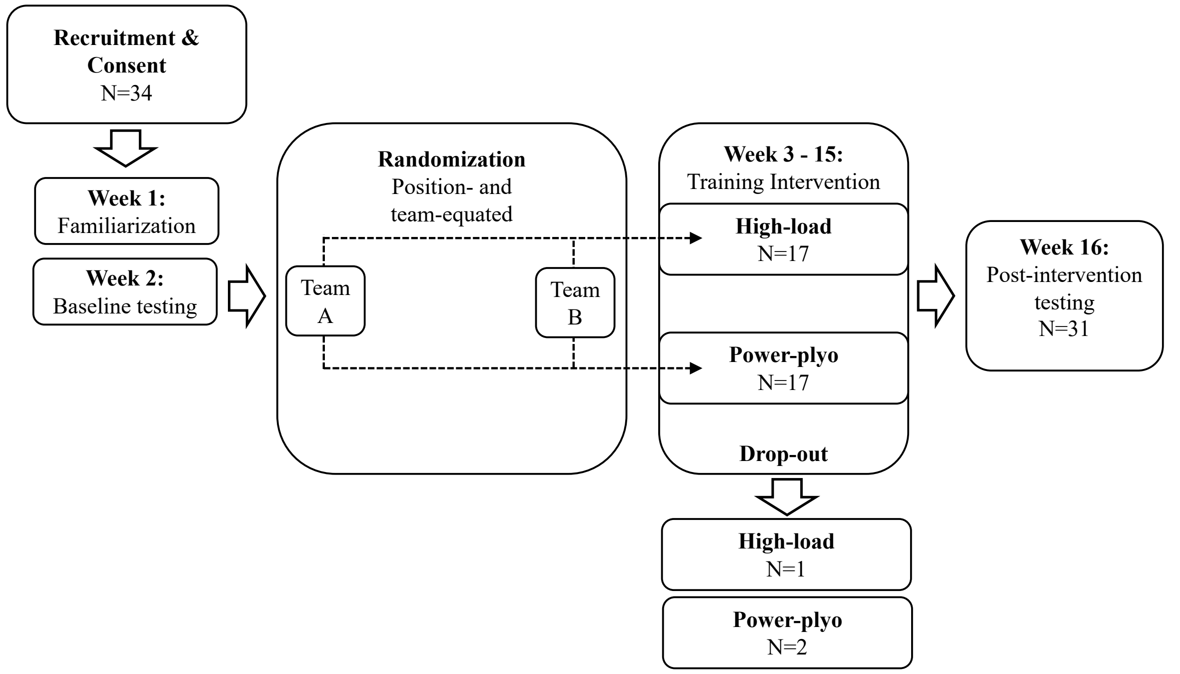

Figure 1 Illustrates an overview of the study design

Training Intervention

.The high-load program focused on developing maximal strength and consisted mainly of sets of 5-6RM. The loads of the exercises employed in the high-load program were adjusted based on repetitions in reserve (RIR), as described by Helms et al.[19]. Loads at 80% of their baseline 1RM were used in the squat and bench press exercise during the first sessions and were re-adjusted based on RIR as the participants became stronger. The power-plyo program included sets of bench press and squat jumps with external loads at 50% of baseline 1RM, but consisted mainly of medicine ball throws, and a variety of body weighted plyometric jumps. An overview of both training programs, with their respective sessions are presented in Table 1. The participants in the power-plyo group were instructed to perform all exercises with the intent of maximal effort and quality in each repetition. Both programs consisted of two weekly sessions; a supervised higher-volume session (Workout A), and lower-volume unsupervised session (Workout B), separated by >48 hours of rest. During the supervised sessions, the participants were able to get instantaneous visual feedback (via tablet or smartphone) of barbell velocities in each repetition measured by accelerometers (Vmaxpro, BM Sports Technology, Magdeburg, Germany). The visual feedback were intended to enhance training adaptions[20], either by contributing to increased repetition efforts in the power-plyo group, or ensure that participants in the high-load group were close to failure. To avoid injuries and ensure proper technique, both programs included a two-session familiarization period where load or repetition intensities were gradually increased (Session one - session two: high-load, 3RIR – 2RIR; Power-plyo, 80 – 90% repetition intensity).

TABLE 1 Overview of the training programs

High-Load Program						
Workout A		**Exercises**	**Load**	**Set x Rep**	**RIR**	**Rest intervals**
Frequency:	1x/week	Parallel squat	≥80% 1RM	3 x 5	1	3 min
		Split squat		3 x 5	1	3 min
When:	Pre-planned day together with the rest of the team	*Superset 1* : Hip-thrust		3 x 5	1	3 min
		Superset 1 : Single-leg calf raise		3 x 10	1	2 min
		Romanian deadlift		2 x 5	1	3 min
Supervised:	Yes	*Superset 2* : Bench press	≥80% 1RM	3 x 5	1	2 min
		Superset 2 : Pull ups/lat pulldown		3 x 5	1	2 min
		Shoulder press (dumbbell/barbell)		2 x 5	1	2 min
		Weighted sit-ups		2 x 10	1	2 min
Workout B		**Exercises**	**Load**	**Set x Rep**	**RIR**	**Rest intervals**
Frequency:	1x/week	Parallel squat	≥85 % 1RM	2 x 5	1	3 min
		Superset 1 : Nordic hamstring curl		2 x 5	1	3 min
When:	At a self chosen time	*Superset 1* : Superman (sling/rollout)		2 x 10	1	2 min
		Bulgarian lunge		2 x 5	1	3 min
Supervised:	No	Bench press (dumbbell)		2 x 5	1	3 min
		Superset 2 : Cable row/Bent over dumbbell row		2 x 5	1	2 min
		Superset 2 : Overhead dumbbell tricep extension		2 x 5	1	2 min
Power and Plyometric Program						
Workout A		**Exercises**	**Intensity/Load**	**Set x Rep**	**Effort**	**Rest intervals**
Frequency:	1x/week	Parallel squat jumps	≤50% 1RM	4 x 5	Maximal	3 min
		Push Jerk	≥1ms	3 x 5	Maximal	2 min
When:	Pre-planned day together with the rest of the team	*Superset 1* : Single leg hip-thrust jumps	Bodyweight	3 x 5	Maximal	2 min
		Superset 1 : Bench press w/Elastic bands	≤50% 1RM	3 x 5	Maximal	2 min
		Drop jumps	>20cm	3 x 10	Maximal	3 min
Supervised:	Yes	*Superset 2* : Kettlebell swing	12kg +	3 x 8	Maximal	2 min
		Superset 2 : Standing medicine ball push throw	2-3kg	3 x 8	Maximal	2 min
		Bulgarian lunge jumps	Bodyweight	3 x 5	Maximal	3 min
		Superset 3: Box jumps	Bodyweight	3 x 10	Maximal	2 min
		Superset 3 : (Week 1- 6) Reverse row (barbell/slings)	Bodyweight	3 x 5	Maximal	2 min
		Superset 3 : (Week 6 - 12) Medicine ball slam	4 - 6kg	3 x 5	Maximal	2 min
Workout B		**Exercises**	**Intensity/Load**	**Set x Rep**	**Effort**	**Rest intervals**
Frequency:	1x/week	Parallel squat jumps	≤50% 1RM	3 x 5	Maximal	3 min
		Superset 1 : Single leg hip-thrust jumps	Bodyweight	2 x 5	Maximal	2 min
When:	At a self chosen time	*Superset 1* : (Week 1 - 6) Standing medicine ball push throw	2-3kg	2 x 5	Maximal	2 min
		Superset 1 : (Week 7 - 12) Lying medicine ball push throw	2-3kg	2 x 5	Maximal	2 min
		Hinder jumps (Week 1 - 6)	Bodyweight	2 x 10	Maximal	2 min
		Frog Jumps (Week 7 - 12)	Bodyweight	4 x 5	Maximal	2 min
Supervised:	No	Split-squat jumps	Bodyweight	3 x 5	Maximal	2 min
		Horizontal jumps (Week 1 - 6)	Bodyweight	2 x 5	Maximal	2 min
		Single-leg horizontal jumps (Week 7 - 12)	Bodyweight	2 x 5	Maximal	2 min
		Superset 2: Box jumps	Bodyweight	2 x 10	Maximal	2 min
		Superset 2: Reverse row (barbell/slings)	Bodyweight	2 x 5	Maximal	2 min

Overview of both training programs. Abbreviations: 1RM, one-repetition maximum; RIR, repetitions in reserve; Min, minutes; Ms, meter per second; Cm, centimeter; Kg, kilo.

Physical Performance Testing.

Physical performance was assessed during on- and off-court test sessions completed on separate days, at baseline and post intervention. The participants were familiarized with both test batteries prior to baseline testing to minimize a potential learning effect. The on-court physical performance test battery included measurements completed at each team's home court in the following order: throwing velocity, countermovement jump (CMJ), jump and reach, 30-meter linear sprint and change of direction (CoD) sprint times. The off-court test battery was conducted in a laboratory and included measures of explosive strength such as bench- and leg-press theoretical maximal power output (P_{max}) including power output at different loads, and a test of rate of force development (RFD). The participants percieved recovery status (PRS) was obtained through questionaries prior to all test sessions, which gave an evaluation the participants restitution status and readiness for the upcoming test session[21].

2.3 Measurements

Throwing Velocity

Throwing velocity was measured using a standard women's handball (size 2) during two types of throws: a standing throw and a three-step running throw. The standing throw involved throwing from a stationary position at the penalty mark, while the three-step running throw allowed for a run-up of three steps before throwing at the same distance (7m). Ball velocity was measured with a handheld radar (Bushnell velocity speed gun [101911], Overland Park, USA), standing diagonally behind the shooters dominant arm. Participants were given two sets of three attempts for each type of throw, and their best results were used for further analysis.

Countermovement Jump.

Jump height was measured by performing a CMJ on a force plate (Advanced Mechanical Technology, Inc Waltham Street, Watertown, USA) with a sampling frequency of 2000Hz. The participants stood in their preferred jumping position, which was about a shoulder-width distance between their feet. The participants were instructed to jump as high as possible, hands akimbo, with a self-chosen depth during the countermovement. The participants were given two sets of three jumps. If height increased or the technique was considered faulty, more attempts were given. Jump height was calculated from the impulse during takeoff using a custom-made MATLAB script (MATLAB, MathWorks, Natick, USA). The average of the two best results was used for further analysis.

Jump and Reach.

Jump and reach ability was assessed by performing a three-step run-up with the intent of reaching the highest vane possible on a Vertec vertical jump tester (Vertec, Sportsimports [800-556-3198], Columbus, USA). The participants were instructed to start the lift-off phase from their dominant foot, corresponding to how they would do a jump shot. Standing reach height was measured with both feet together, without lifting their heels, and their dominant arm fully extended using the whole shoulder range of motion. Jump height was calculated by subtracting their standing reach height from the highest vane reached during the jump test. The participants performed two sets of three attempts with maximal effort. If jump height increased, more attempts were given. The best attempt in terms of maximal jump height was used for further analysis.

30 m Linear Sprint.

Linear sprint ability was assessed by performing a 30-meter sprint, with split times recorded at 5, 10, 15, 20, and 30-meters. Sprint times were measured with single-beam MuscleLab timing gates with infrared photocells (Ergotest Innovation AS, Porsgrunn, Norway). The first photocell was placed 30cm above the ground while the rest were placed at 100cm above the ground. The participants initiated their run from 30 cm behind the starting line, without countermovement (Figure 2). All participants were given three attempts, with three minutes of rest between the attempts. Split times used in the analysis were retrieved from their best 30-meter attempt. If the 30-meter time improved, they were given additional attempts. The sprint times were extracted using the manufacturer's software (MuscleLab, Ergotest Innovation AS, Porsgrunn, Norway).

Change of Direction

. CoD ability was assessed by using the A180 test, the standard COD test used at the Norwegian Olympic Sports Centre, consisting of four 180-degree changes of direction between two marked turning lines at 12.5 and 7.5 meters, resulting in a total of 40 meters. For each CoD the participants alternated between their dominant and non-dominant foot. Sprint times were recorded with single-beamed timing gates with infrared photocells (Brower

Timing Systems, Draper, USA) placed 30cm above ground at the starting line, and 100cm above the ground at the finish line. The participants initiated their run similar to that of the linear sprint test, and were given three attempts, with three minutes of rest between attempts. If CoD sprint time improved, further attempts were given. The best attempt was used for further analysis.

Bench Press Power.

Bench press power was assessed by performing five sets at different external loads with maximal concentric effort repetitions. The external load started at 10kg before gradually increasing to loads near 90% of an estimated 1RM (post study calculations revealed the average relative load of the sets to be: 1st: 20%, 2nd: 37%, 3rd: 54%, 4th: 70% and 5th: 84% of baseline 1RM). The number of repetitions decreased from five to one, with fewer repetitions performed as the weight increased. A linear encoder (MuscleLab Linear Encoder; Ergotest Innovation, Porsgrunn, Norway) was attached to the barbell measuring the displacement and time of the concentric phase. The repetitions with the highest velocity from each load were selected for further analysis to determine the average power-output at different loads. The same repetitions were used to establish a force-velocity and a power-velocity (parabolic curve) relationship and P_{max} (at an optimal load) were calculated as the apex of the parabolic power-velocity curve by the manufacturer's own software (MuscleLab; Ergotest Innovation, Porsgrunn, Norway)

Leg-Press Power.

Leg-press power was assessed using a pneumatic resistance-based Keiser A300 (Keiser sport, Fresno, California, USA) by performing a standardized maximal effort ~10-repetition test that starts at a low resistance, gradually increasing for each repetition until failure is reached. The resistance increase of each increment was preprogrammed by the Keiser A420 software (Fresno, California, USA) based on the participants maximal capacity which had been assessed in the familiarization session. Rest periods increased with gradual increments of 5 to 38 seconds between repetitions. The seating position was adjusted for each participant to the position where the femur was as close to perpendicular to the floor as possible. Average power values at each load were used to establish a power-load relationship, and P_{max} in absolute (w) and relative (w/kg bodyweight) were retrieved form the manufacturers own software.

Rate of Force Development.

RFD was measured during a maximal isometric unilateral knee extension with a dynamometer (MuscleLab, Ergotest AS, Porsgrunn, Norway) tightly fixed to the ankle of their dominant leg at a 90° knee-joint angle, sampling at 1000Hz. The participants were encouraged to extend their leg as "fast and hard" as possible for ~1 second. Three attempts were given, with at least 15-seconds of rest between each attempt. Further attempts were given if RFD performance at 0-50ms improved. RFD values were obtained by the integrated software (MuscleLab, version 10.5.69.4815) (and quality controlled manually), sampled at 0-30, -50, -100, -150, -200, -250ms windows after initiation of force, defined at an onset point of 2.5% of peak force and used in the statistical analysis. The participants best result was used for further analysis.

2.4 Statistical Analyses

With 80% statistical power and a significance level at 5%, 14 participants were needed in each group to be able to detect an 8 ± 7% between-group difference (calculated in G*power version 3.1, University of Düsseldorf, Germany). The data material from the familiarization and baseline sessions were used to calculate the smallest worthwhile change (SWC) and test-retest typical error (TE). SWC was calculated as 0.2 multiplied by the between-subject SD of the specific test as described by Conway[22]. TE was calculated as the SD of the difference between test 1 and test 2/(sqrt(2)) of the specific test as described by Swinton et al.[23], and presented in absolute or relative terms (TE%). Good reliability was considered as TE < 5% and acceptable reliability as TE < 10%[24,25]. Normality of the data material was assessed by visually inspecting Q-Q plots and calculating the z-score of the skewness and kurtosis[26], combined with the Shapiro-Wilk normality test. Standard t-tests were used to analyze within group changes, and the between group pre-post differences in changes of physical performance. Results are presented as absolute and percentage means with standard deviations, confidence intervals and p-values. Confidence limit was set at 95% and the level of significance set at p <0.05. All Statistical analyses were performed using Microsoft Excel (Version 16.6, Microsoft Corporation, Redmond, USA) and Jamovi (Version 2.3 The Jamovi Project, Sydney, Australia).

3 RESULTS

At baseline, there were observed no differences between the groups in age (20 ± 3 vs. 20 ± 3 years), body mass (70 ± 14 vs. 66 ± 7 kg) and height (170 ± 6 vs. 170 ± 6 cm) between the high-load and power-plyo group respectively. Nor were there observed any significant between-group baseline differences in any of the performance measures ($p<0.05$). Both groups completed the same amount of training sessions with 90 ± 8% attendance in the high-load group and 90 ± 9% in the power-plyo group. No difference were observed PRS from baseline to post intervention testing between the groups (high-load: 5.7 ± 0.8 to 6.1 ± 0.8, power-plyo: 5.6 ± 1.3 to 6.0 ± 0.9) for baseline to post testing respectively.

No significant between-group differences were observed in changes of performance in any of the tested variables.

The SWC%, TE%, pre-post changes and between-group comparisons for all measurements are presented in Table 2 and in Figures 2-4, except for the RFD and power-load relationship measurements in bench press and leg press, which are illustrated in figures 5 and 6.

TABLE 2 Baseline and post values with results of relative change from baseline and group differences.

					Change from Baseline					**Between group difference**		
			SWC%	**TE%**	**Baseline**	**Post test**	**Δ %**	**95% CI**			**95% CI**	
Test variables		**n**	0.2*SD	SD/√2	Mean ± SD	Mean ± SD	(Mean ± SD)	(LB, UB)	***p*- value**	Group diff. (%)	(LB, UB)	***p*- value**
CMJ (cm)	High-load	15	3.6	3.4	29.8 ± 5.5	31.7 ± 5.7	6.6 ± 6.9	(2.8, 10.4)	**0.018**	0.6	(-5.7, 3.1)	0.455
	Power-plyo	15			30.1 ± 5.3	32.2 ± 5.7	7.2 ± 5.4	(4.2, 10.2)	**< .001**			
Jump and reach (cm)	High-load	16	2.3	3.5	54.5 ± 6.7	57.3 ± 5.4	5.6 ± 8.0	(1.4, 9.9)	**0.018**	0.5	(-5.7, 6.2)	0.984
	Power-plyo	15			55.2 ± 6.2	58.3 ± 5.7	6.1 ± 9.5	(0.9, 11.4)	**0.014**			
Standing throw (km/h)	High-load	15	1.4	4.0	76.3 ± 5.2	77.5 ± 4.4	1.8 ± 5.2	(-1.1, 4.6)	0.269	1.5	(-6.1, 3.1)	0.505
	Power-plyo	12			74.6 ± 5.5	76.8 ± 2.9	3.3 ± 6.4	(-0.8, 7.4)	0.146			
Throw with run-up (km/h)	High-load	15	1.5	4.8	79.3 ± 6.1	81.9 ± 5.3	3.6 ± 7.5	(-0.6, 7.8)	0.114	0.9	(-7.4, 5.6)	0.777
	Power-plyo	11			77.6 ± 5.9	80.7 ± 3.0	4.5 ± 8.4	(-1.1, 10.1)	0.137			
CoD-sprint (s)	High-load	16	1.2	2.1	9.93 ± 0.57	9.73 ± 0.50	-2.0 ± 2.5	(-3.3, -0.7)	**0.008**	1.0	(-2.9, 0.9)	0.305
	Power-plyo	14			9.76 ± 0.39	9.65 ± 0.39	-1.0 ± 2.6	(-2.5, 0.5)	0.150			
5m sprint (s)	High-load	16	1.3	5.7	0.97 ± 0.04	0.97 ± 0.08	0.2 ± 7.5	(-3.8, 4.3)	0.926	0.8	(-7.0, 5.4)	0.799
	Power-plyo	15			0.97 ± 0.08	0.98 ± 0.07	1.0 ± 9.4	(-4.2, 6.2)	0.836			
10m sprint (s)	High-load	16	1.1	3.1	1.81 ± 0.09	1.79 ± 0.10	-1.3 ± 4.0	(-3.5, 0.9)	0.201	1.1	(-4.6, 2.4)	0.525
	Power-plyo	15			1.80 ± 0.11	1.79 ± 0.08	-0.2 ± 5.4	(-3.2, 2.8)	0.764			
15m sprint (s)	High-load	16	0.9	2.4	2.54 ± 0.11	2.52 ± 0.13	-0.9 ± 3.0	(-2.5, 0.7)	0.253	0.7	(-3.3, 1.9)	0.585
	Power-plyo	15			2.53 ± 0.13	2.52 ± 0.10	-0.2 ± 3.9	(-2.4, 2.0)	0.751			
20m sprint (s)	High-load	16	0.9	2.0	3.25 ± 0.15	3.22 ± 0.16	-1.0 ± 2.5	(-2.3, 0.3)	0.121	0.5	(-2.7, 1.6)	0.614
	Power-plyo	15			3.24 ± 0.16	3.22 ± 0.13	-0.5 ± 3.4	(-2.4, 1.4)	0.559			
30m sprint (s)	High-load	16	1.0	1.6	4.64 ± 0.24	4.59 ± 0.23	-1.0 ± 2.0	(-2.1, 0.1)	0.159	0.1	(-1.9, 1.8)	0.959
	Power-plyo	15			4.64 ± 0.23	4.589 ± 0.19	-1.0 ± 2.9	(-2.6, 0.6)	0.206			
Leg-press Pmax (W)	High-load	16	3.2	4.2	1055 ± 148	1177 ± 166	11.7 ± 7.6	(7.7, 15.8)	**< .001**	3.4	(-2.4, 9.2)	0.241
	Power-plyo	15			983 ± 177	1062 ± 182	8.3 ± 8.2	(3.8, 12.9)	**0.002**			
Leg-press Relative Pmax (W/bw)	High-load	16	2.8	4.1	15.3 ± 1.8	16.9 ± 2.2	10.5 ± 7.6	(6.4, 14.5)	**< .001**	1.9	(-3.5, 7.4)	0.475
	Power-plyo	15			15.0 ± 2.5	16.3 ± 2.6	8.5 ± 7.3	(4.5, 12.6)	**0.003**			
Bench press Pmax (W)	High-load	15	3.0	6.0	290 ± 49	313 ± 54	8.1 ± 9.8	(2.7, 13.6)	**0.004**	2.6	(-4.0, 9.9)	0.371
	Power-plyo	14			268 ± 32	282 ± 38	5.5 ± 10.2	(-0.4, 11.4)	0.068			

Table 2 The table presents absolute mean values of baseline and post intervention results standard deviations (SD). Δ%: percent change from baseline- to posttest with 95% Confidence Intervals (95%CI) with lower (LB) and upper bounds (UB). The Smallest Worthwhile Change (SWC%) and Typical Error (TE%) for all tests were calculated from the familiarization and baseline results and presented in relative values. Note that the TE% was larger than the SWC% for all variables except the Countermovement Jump (CMJ). Good test-retest reliability (<5.0% TE) was found for all tests, except 5m sprint (5.7 TE%) and bench press Pmax (6.0 TE%) which showed acceptable reliability (<10 TE%). Abbreviations: Cm, centimeter, Km/h; kilometer per hour; Pmax, maximal theoretical power; W, watt; W/bw, power-to-weight ratio (watt / kilos of bodyweight).

Both training groups showed significant within-group changes from baseline in CMJ height and jump-and-reach height (Figure 2a-b). No such changes were observed in either group for both of the throwing velocity tests (Figure 2c-d).

FIGURE 2 Changes from Baseline in CMJ, Jump-and-Reach and throw performance

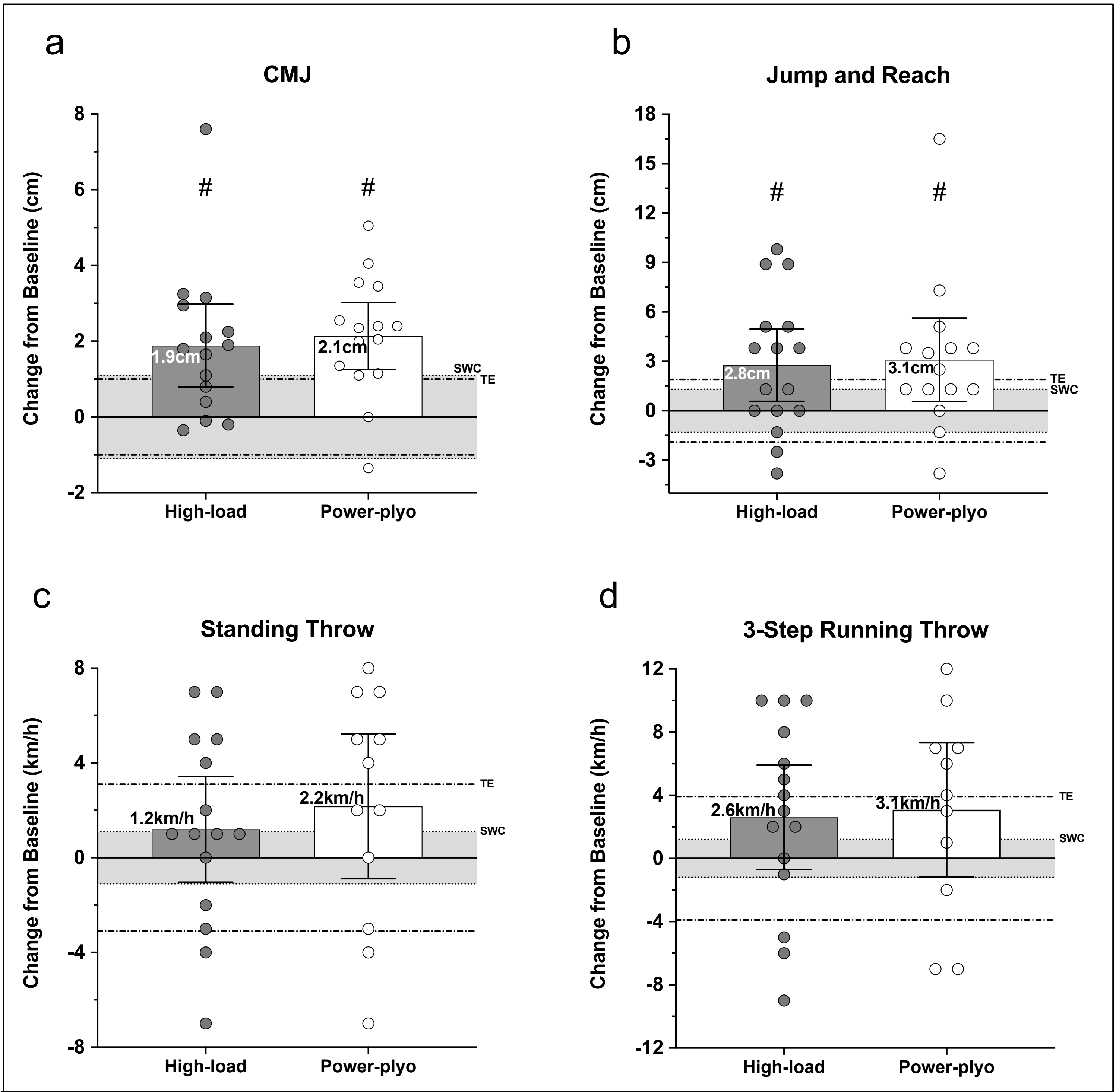

Figure 2a-d Illustrates the absolute mean change from baseline for both training groups in Countermovement jump (CMJ), Jump and Reach height, standing throw, and 3-step-running throw velocity with 95% Confidence Intervals (95%CI). The area marked in light grey illustrates the upper and lower limit absolute Smallest Worthwhile Change (SWC), and the dotted-stapled line represents the absolute test-retest Typical Error (TE), each dot represents an individual value. #: $p < 0.05$. Abbreviations: Cm, centimeter; Km/h, kilometer per hour.

The high-load group showed significant within-group changes in CoD-sprint performance compared to baseline (Figure 3a). Neither group had a significant change from baseline in any distance of the linear sprint test (Figure 3b)

FIGURE 3 Changes from Baseline in CoD and Linear Sprint

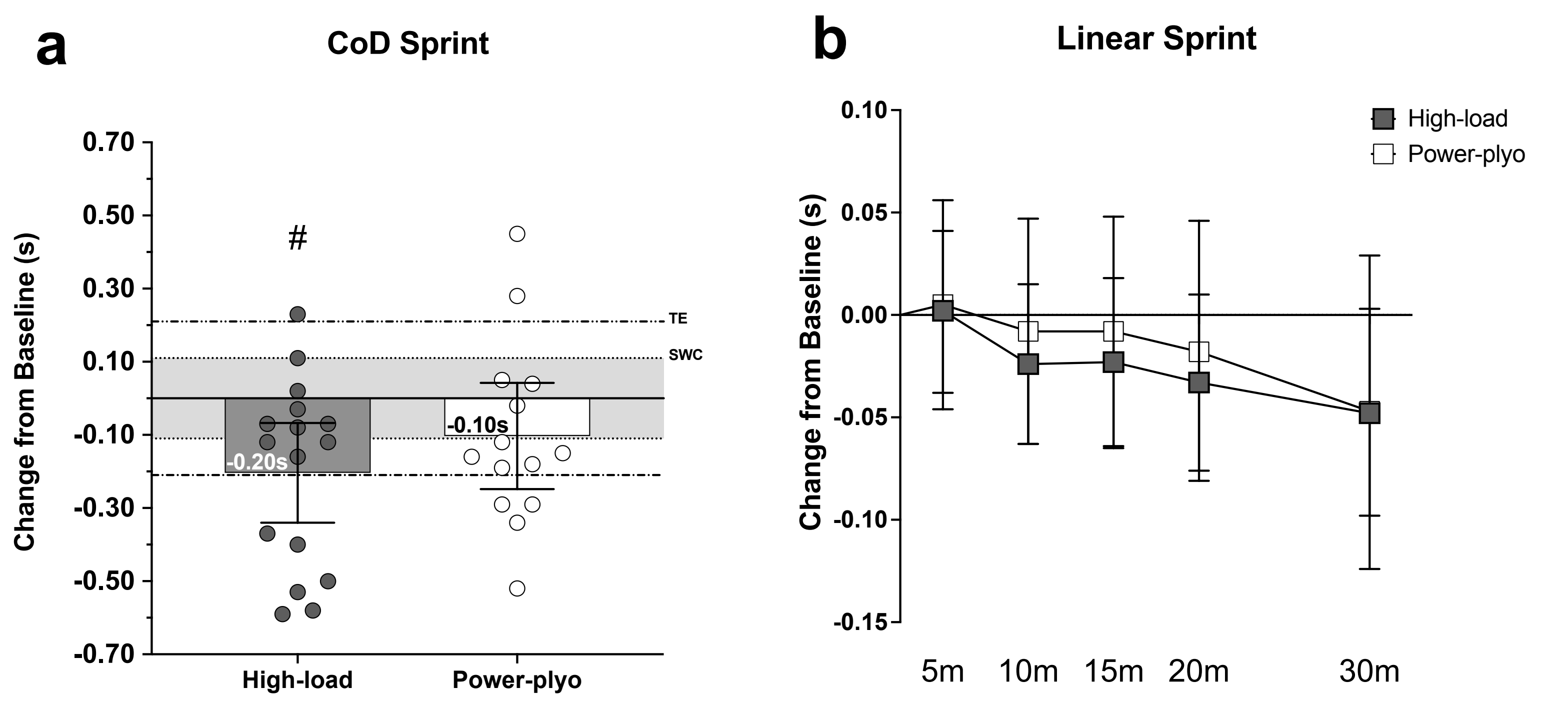

Figure 3a Illustrates the mean group change from baseline in Change of Direction (CoD) performance, with error bars representing the 95% Confidence Interval (95% CI). The area marked in light grey illustrates the upper and lower limit absolute Smallest Worthwhile Change (SWC), and the dotted-stapled line represents the absolute test-retest Typical Error (TE), each dot represents an individual value. # p <0.05 within-group change from baseline**.**

Figure 3b Illustrates the group mean change from baseline for both training groups with error bars representing the upper and lower limit 95% CI at all distances. Abbreviations: S, second; M, meter.

The extrapolated theoretical maximal power at optimal loads (P_{max}) increased significantly in bench press for the high-load group, while the power-plyo group had a tendency of change (p=0.068)(Figure 4a). Both groups showed significant within-group increases in absolute and relative P_{max} in the leg-press compared to baseline (Figure 4b-c).

FIGURE 4 Changes from baseline in P_{max} Leg-Press and Bench Press

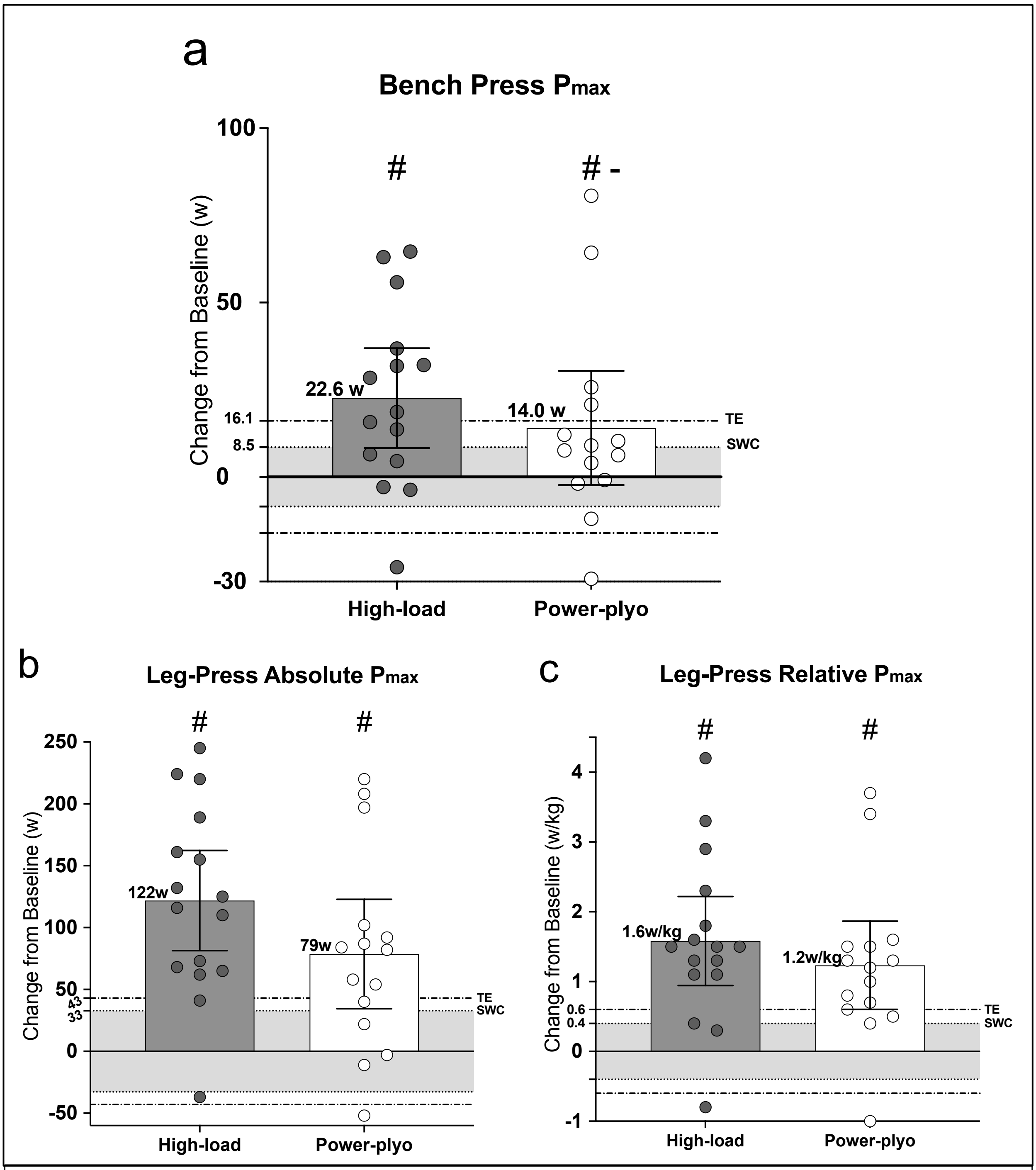

Figure 4a, b and c Illustrates the absolute mean change from baseline for both training groups with 95% Confidence Intervals (95%CI) for theoretical maximal power (P_{max}) in bench press, leg press (absolute) and leg press (relative) respectively. The area marked in grey illustrates the upper and lower limit absolute Smallest Worthwhile Change (SWC), and the dotted and stapled line represents the absolute test-retest Typical Error (TE), each dot represents an individual value. **#:** $p<0.05$, **# -** ; $p<0.10$ within-group change from baseline. Abbreviations: W, watt; W/kg, power-to-weight ratio (watt per kilo bodyweight)

The bench press power-load relationship revealed a significant within-group increase from baseline for both groups in the power output at 20% of 1RM, additionally the high-load group had significant increases from baseline at 37% of 1RM (high-load: 9 ± 11% vs. power-plyo: 3 ± 11% increase) and 54% of 1RM (high-load: 8 ± 11% vs. power-plyo: 4 ± 13% increase) (figure 5a-c).

Both groups also significantly increased their leg-press power-output compared to baseline at all loads between 40% to 87% (Figure 5e-f) ranging from 8.7% to 32.5% and 5.4% to 24.1% for the high-load and power-plyo group respectively (figure 5d). The high-load group also improved significantly at 30% of last completed repetition at baseline (Figure 5e)

FIGURE 5 Changes in the power-load relationship of average power at different loads in bench press and leg-press

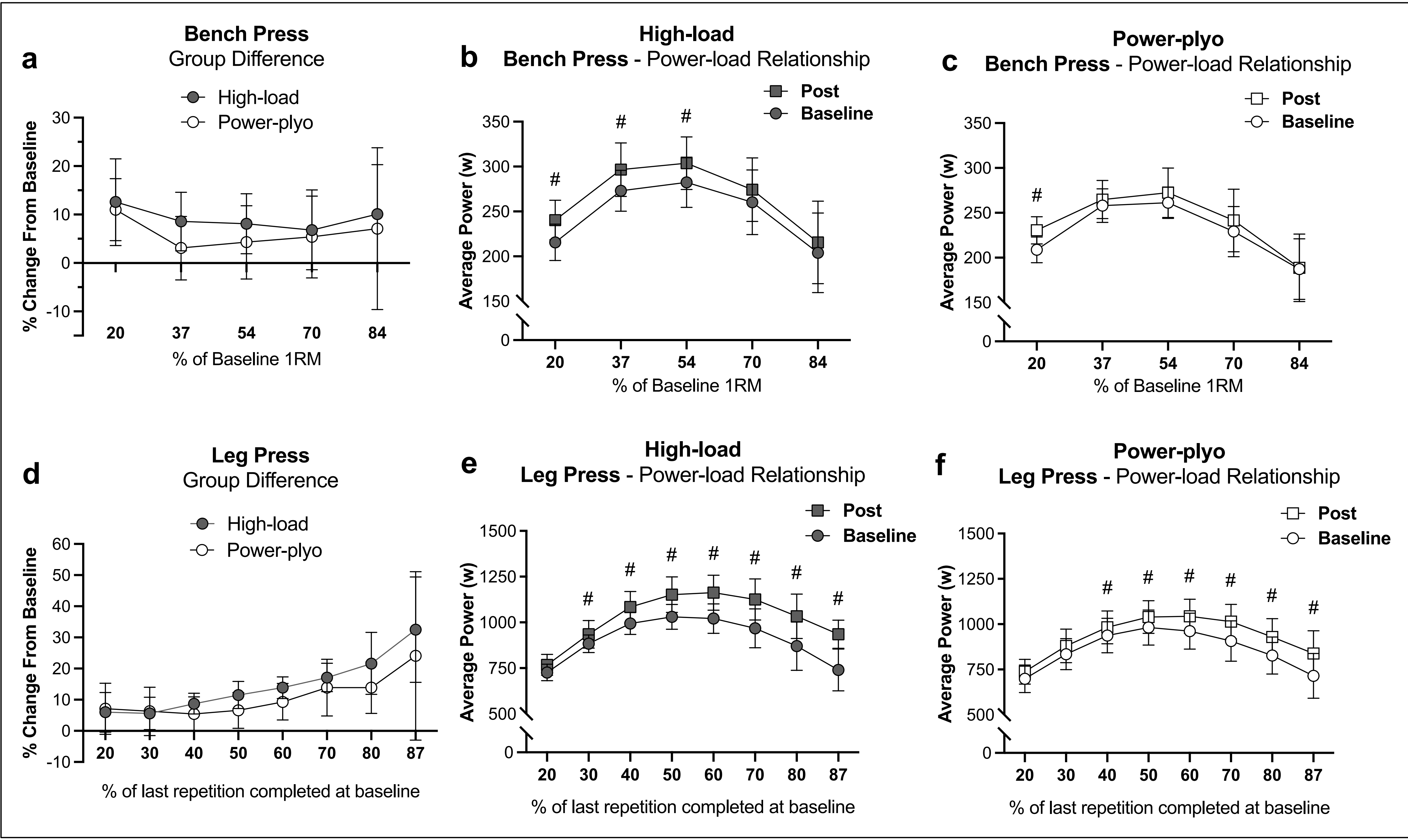

Figure 5a and **d** Illustrates the mean relative change from baseline with 95% Confidence Intervals (95%CI) for both training groups at gradually increasing loads in bench press and leg press respectively. **Figure 5b-c** and **Figure 5e-f** Illustrates the absolute values of the group mean at baseline and post intervention at different loads with 95% CI for bench press and leg press respectively. # $p<0.05$, Significant within group change from baseline. Abbreviations: 1RM, one-repetition maximum; W, watt.

RFD in all sampling windows improved significantly in the high-load group (figure 6b).

FIGURE 6 Changes in RFD between group comparison and within-group changes from baseline

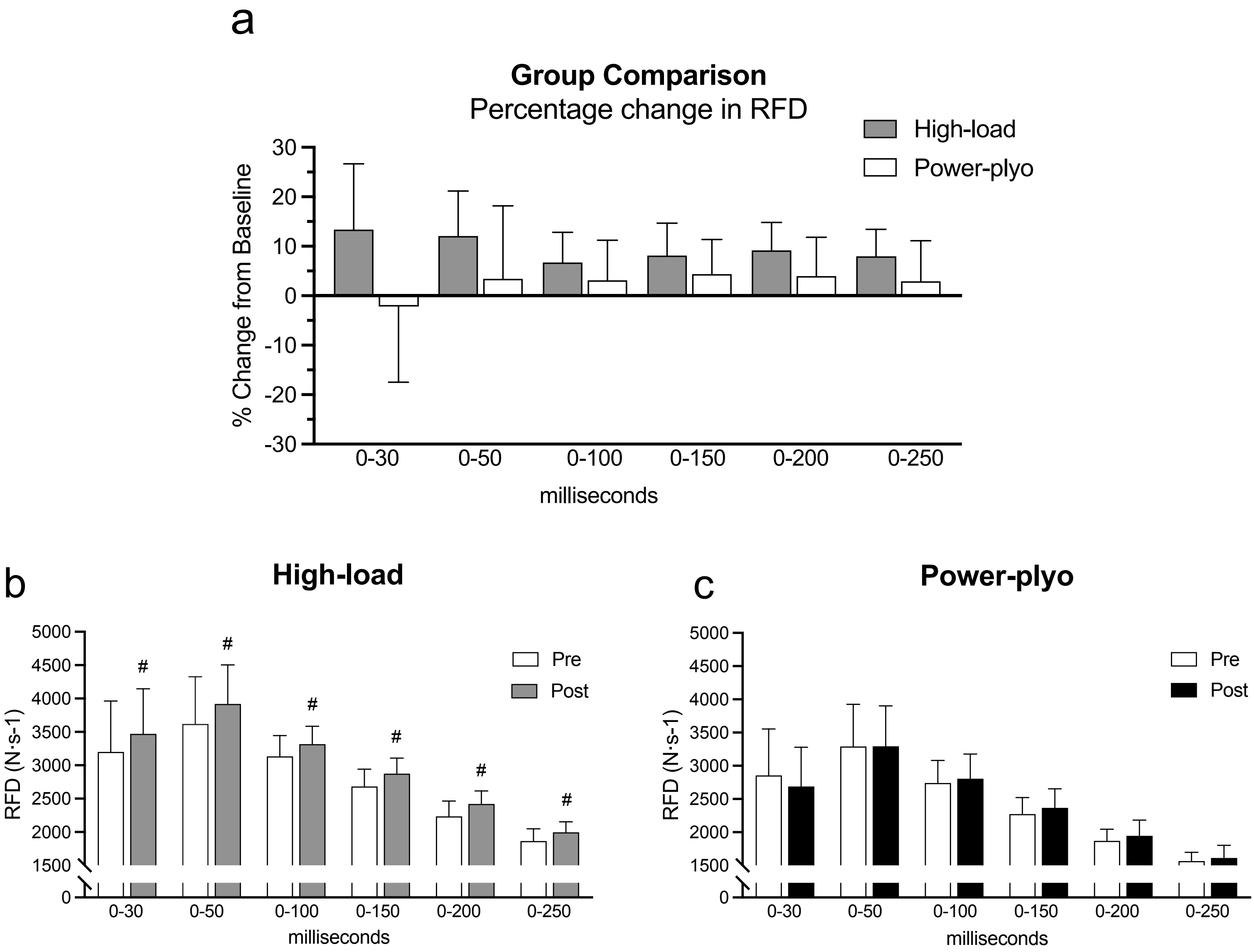

Figure 6a Illustrates the mean relative change from baseline with 95% Confidence Intervals (95%CI) for both groups at different sampling windows. **Figure 6b-C** Illustrates the absolute values of the group mean at baseline and post intervention at the different sampling windows with 95%CI for. # $p<0.05$ Significant within group change from baseline. Abbreviations: RFD, Rate of Force Development; N, newton; S, seconds.

4 DISCUSSION

To the authors knowledge, this is the first study to compare the effect of high-load strength training versus a combination of power and plyometric training on female handball players during the competitive period. The primary findings of the present study indicates that there is no apparent difference in changes in jump, throw, sprint and CoD performance, nor upper and lower body muscular power, and RFD between a high-load strength program and a lower load power-plyometric oriented program. However, both programs were effective in improving jump height and lower-body power-output and maintaining other important abilities related to the physical performance of female handball players.

Jump performance.

The present study found no significant between group differences related to jump performance (Table 2). Although compared to baseline, both training groups increased CMJ and Jump and Reach performance significantly (Figure 2a-b).

It can be argued that power and plyometric training is more sport-specific than high-load training, especially when it comes to jump ability, but also in general due to similar movements, loads and velocities. For instance, considering that the power-plyo group performed 165-weekly bodyweight jumps, one might have expected this training method to be more effective than high-load training in enhancing jump performance.

However, as for the high-load group, even if not as sport-specific, one might speculate that the stimuli acquired from applying high-loads might have been effective in enhancing adaptions in other important factors for the development of this ability. For instance, consider the similar increases in jump-and-reach performance between the groups (high-load: 5.6 ± 8.0%, power-plyo: 6.1 ± 9.5%). The higher-loads might have caused greater enhancements of CSA in type II muscle fibers, neural drive and firing frequency, resulting in the increased RFD observed in this group (figure 6a)[27], consequently increasing their jump-and-reach performance. As increases in RFD were not observed in the power-plyo group, yet they improved jump height, it is possible that both these training methods improved jumping performance through different physiological adaptions. For example more effective SSC and inter-muscular coordination in the power-plyo group[28]. Therefore, a combination of these methods might be more optimal. This considered, it can be speculated that the high-load group had the best preconditions, as they were exposed to both high-loads and the explosive actions performed on-court.

The results of the present study is in accordance with previous studies that has observed increases in jump height following variations of these training methods on in-season handball players of both sexes[13–16,29].

However, few of these studies compared one intervention against another, and the observations made are contradicting. For instance, Chelly et al.[12] observed that plyometric training were significantly more efficient in improving jumping performance than a moderate load strength program (60% of 1RM). While Spieszny and Zubik[10] observed that a combined high-load strength and power program increased jump height significantly more compared to a plyometric oriented program. Both of these studies were completed on male-players during the competitive period. Additionally, Falch et al[13] conducted a similar study on in-season female handball players, which compared plyometric training with high-load strength training. No significant between-group differences in jump height were observed, although both groups increased performance compared to baseline results. It should be mentioned that the study only lasted six weeks, had few participants in each group (n=10) and was conducted on adolescents (17 ± 2 years). Additionally, it is important to consider that the discrepancies between studies could be attributed to variations of the resistance training, such as volumes and exercises applied, or methodological differences such as measuring methods, performance level and sex of the studied sample.

In, summary it is highly uncertain of which method provides the greatest benefits. However, the present study supports the findings of Falch et al[13], suggesting that both lower-load velocity based training and high-load strength training may be equally efficient on increasing jump height in this population.

Throwing Velocity.

The present study found no significant difference in throwing velocity between the training groups. Both groups showed slight increases in throw velocity in both types of throws (range: 1.8 - 4.5%), but these changes were not significant compared to their baseline values (Figure

2c-d). This suggests that the resistance exercise regimes had a limited effect on improving Throw velocity during the competitive period. Nevertheless, Spiezny and Zubik[10] observed that throwing velocity could decrease significantly (range: -6.1 to -7.3%) if no additional resistance exercise were performed during the in-season. Thus, one can speculate that the groups in the present study might have had a substantial maintenance effect, if they were compared to a control group. One might also therefore speculate that a type II error has occurred, as both groups increased performance in both types of throws.

Change of Direction.

The results revealed no between group difference between the two groups in CoD performance. Although the high-load group improved significantly from baseline, it was not by a large degree compared with power-plyo (-2% vs. -1%) (Figure 3a). However, these results matches with the study conducted by Falch et al[13] that investigated the effects of high-load strength training versus plyometric training on CoD performance in adolescent female handball players. No between-group differences on changes of CoD sprint times were observed. And similar to the present study, the high-load group was the only group that significantly increased CoD performance relative to baseline results (-2.7% vs -1.3%). Combined these findings may suggest that high-load strength training might be slightly more effective in improving the 180° CoD-ability in the studied population.

A possible explanation for these findings might be explained by the difference in the training stimulus from the two different programs, and the forces required to make a quick 180° CoD. As the angle of the CoD decreases, a greater degree of force is required to change the momentum and reaccelerate the different direction[30]. Thus, it could be speculated that the lack of significant improvements in CoD performance in the power-plyo group, may be due to insufficient stimulus by the lower loads to generate the necessary forces for pivoting in a 180° CoD, as compared to the high-load exercises. However, the findings could be different if more velocity-oriented CoDs were included (e.g., 45-90 degrees).

Sprint Performance.

The findings of the present study revealed no between group differences at any distance of the 30m sprint. Similarly, there were no significant changes from baseline in both training groups, with the largest relative change at an 1.3% improvement (Table 2). These findings contradict to another study comparing the effect of high load versus plyometric training on short sprint ability in female handball players. Falch et al[13], observed that both a plyometric oriented program and a high-load program were effective in increasing 30m sprinting ability, while the high-load group also significantly improved in 20m sprint. A possible explanation for these results might be due to the difference in age and skill level. In the study of Falch et. al[13] the participants were 17 ± 2 yrs and their baseline 30m sprint times were 5.3s, compared to 4.6s in the present study. Therefore, due relatively high level of sprint performance in the present study, further enhances of sprint performance might not be as easily achieved. Which is also supported by the study of Granados et al[14], which found no increases in short sprint (>15m) performance in elite female handball players after an entire season of high-loaded strength and power-training. As the age and skill level are somewhat similar, the present study supports the findings of Granados et al[14], suggesting that high-level female players needs more sprint specific training implemented in their training regimens to cause further enhancements in sprint performance. Additionally, as horizontal force production is important in sprints[31], better results might have been obtained with larger volumes of such exercises. Or by implementing exercises that has great transfer to sprinting ability, such as quarter/half squats[32], which were also included in a strength intervention study reporting significant increases in sprint times for in-season male athletes[15].

Leg-press and Bench press Power Output and Rate of Force Development.

The ability to produce maximal power output in the relevant upper and lower body musculature is considered important for all the measured sport-specific abilities in the present study[3,4,28,33,34].

Both groups increased Bench press P_{max} (high-load: 8.1% vs Power-plyo: 5.5%), although not significant in the power-plyo group (tendency: p=0.068), and no between group differences were observed for P_{max}, nor power-output at different loads (Figure 5a-c). Both groups also significantly increased P_{max} in the leg-press, both absolute (w) and relative (w/bodyweight) (range: 8.3 – 11.7%) (Table 2, Figure 4b-c). And significantly increased their leg-press power-output at most of the loads in the power-load assessment compared to baseline (Figure 5-e-f) ranging from 8.7% to 32.5% and 5.4% to 24.1% for the high-load and power-plyo group respectively (figure 5d). Indicating that both programs were effective in increasing lower-body power output. The results are similar to that of Granados et al.[14] which found that power-output throughout the competitive period increased significantly in bench press (12 – 21%) and half-squat (7 – 13%) relative to baseline values after following a combined high-load strength and power program. Additionally, unlike the present study, throwing velocity increased significantly from baseline. The greater increase in bench press power-output (12 – 21% vs. 5.5 – 8.1%) might explain the differences observed in of throwing velocities between the studies.

The high-load group significantly increased RFD in all sampling windows (figure 6b), which might be due to increased CSA of type II muscle fibers, neural drive and firing frequency following high-load training[27,28]. RFD is considered important for the performance of all the tested measures[27]. For instance, the increases in RFD 0-150 and 0-200ms which is approximately the ground contact time during a high-jump (170-180ms)[35], were positively correlated with increased jump-and-reach performance (RFD 0-150ms r= 0.407, p= 0.007; RFD 0-200ms, r= 0.452, p= 0.003) (data not presented).

As significant increases in RFD were not observed in the power-plyo group (6.7 – 13.4%, p<0.05 vs. power-plyo: -2.2 – 4.4%, p>0.05) (Figure 6a). It can be speculated that the similar increases in lower-body power, CMJ and Jump and Reach in both groups were associated with different physiological adaptions induced by their respective training interventions. However, no conclusions can be made as of which training method is the most efficient at increasing RFD nor upper-and lower body power, as no significant between group differences were observed. Further research with larger sample sizes may be necessary to detect possible differences.

Main strengths and limitations

An intervention that involves assigning two halves of a team to different training programs can be very difficult to conduct on high-level players, especially during the competitive period, as can be seen by the lack of such studies in the current literature. Therefore, a major strength of this study is that the participants were playing at such a high-level, adding to the understanding of the topic in this population. Another major strength is the inclusion of a comprehensive test battery, measuring several crucial abilities central for the performance in handball. Additionally, the intervention fidelity and duration can be considered a strength, as both groups were followed up weekly over the course of twelve weeks and had a high training attendance of 90% in both groups.

A limitation of the present study include that the programs were not adjusted for volume, and not controlling for plausible confounders such as dietary habits, on-court playing time or other forms of conditioning exercise during the study period. Another limitation is that the researchers were not blinded for group allocations, and neither the researchers nor the participants expectations of effectiveness toward the assigned programs were controlled for, which might have impacted the results[36,37].

5 CONCLUSION AND PERSPECTIVE

The findings suggest that both types of in-season strength training were effective in improving jump height, lower-body power-output, and maintaining other relevant explosive abilities important for the performance of female handball players. Some practical considerations might be of interest. As the effects on physical performance were similar between the groups, and that the power-plyo sessions were much less time consuming and required less equipment, while also considering the greater time to full recovery after high-load training[18]. These points combined can suggest that typical low-load power and plyometric training is a time and resource efficient method that can more easily than high-load training be implemented during in-season training by coaches and handball trainers. However, a combination may be the optimal choice, as high loads might be required to increase performance in certain abilities such as the RFD.

Future research should investigate the combined use of these training methods in-season. And examine whether these training modalities have distinct effects on the physiological mechanisms underlying the performance of these abilities. Such studies can contribute to a deeper understanding of how the different approaches can maximize athletic performance in female handball players.

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CONFLICT OF INTEREST
The author declares that he has no conflict of interest

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Appendices

Appendix 1: Approval from local ethical committee

Thomas Bjørnsen

Besøksadresse:
Universitetsveien 25
Kristiansand

Ref: [object Object]

Tidspunkt for godkjenning: : 18/08/2022

Søknad om etisk godkjenning av forskningsprosjekt - Effekten av styrketrening i sesong på prestasjonsevne hos håndballspillere

Vi informerer om at din søknad er ferdig behandlet og godkjent.

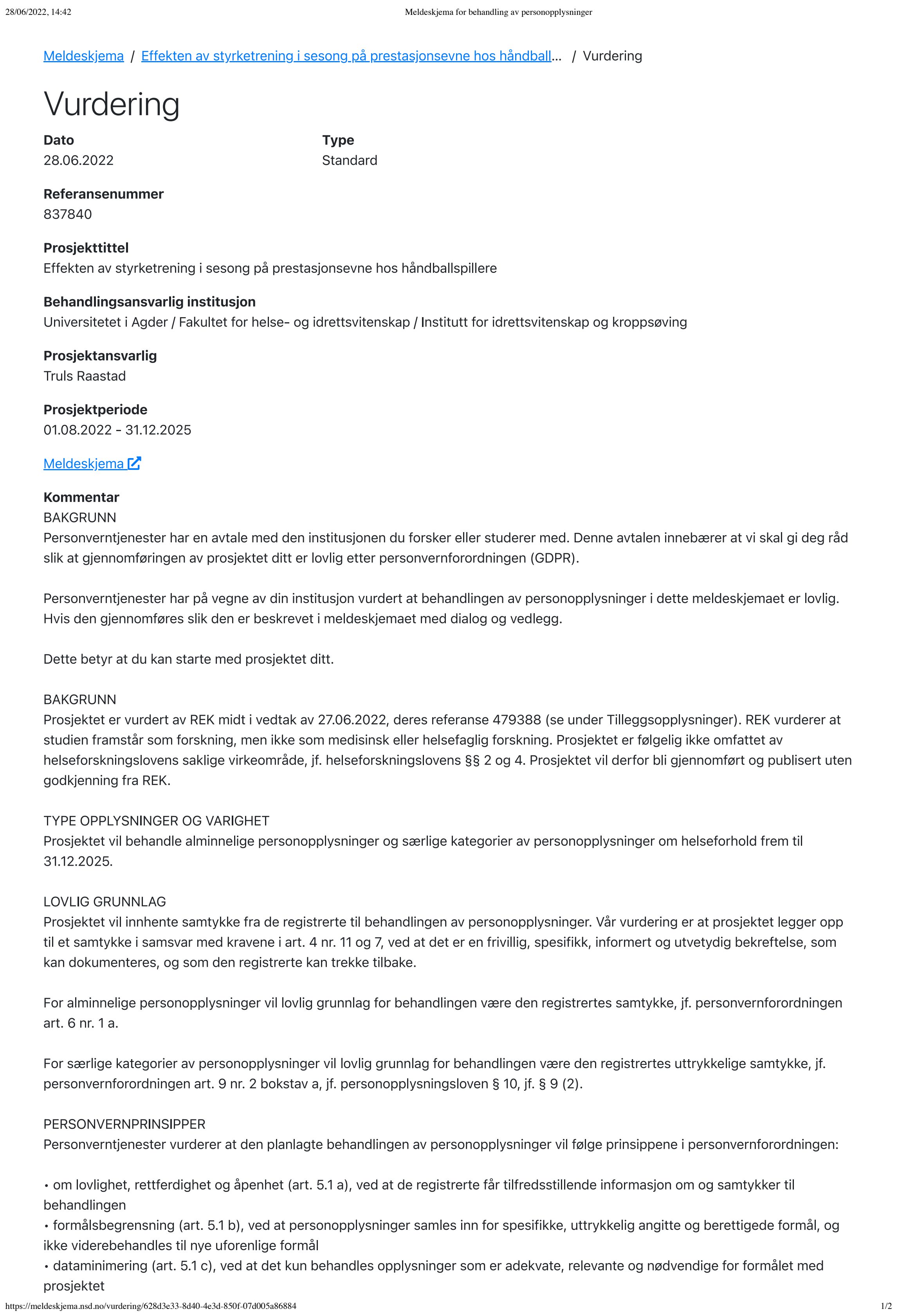
Kommentar fra godkjenner:

Hilsen
Forskningsetisk komite
Fakultet for helse - og idrettsvitenskap
Universitetet i Agder

UNIVERSITETET I AGDER
POSTBOKS 422 4604 KRISTIANSAND
TELEFON 38 14 10 00
ORG. NR 970 546 200 MVA - post@uia.no -
www.uia.no

FAKTURAADRESSE:
UNIVERSITETET I AGDER,
FAKTURAMOTTAK
POSTBOKS 383 ALNABRU 0614 OSLO

Appendix 2: Approval by the Norwegian Centre for Research Data (NSD)



28/06/2022, 14:42 Meldeskjema for behandling av personopplysninger

Meldeskjema / Effekten av styrketrening i sesong på prestasjonsevne hos håndball... / Vurdering

Vurdering

Dato
28.06.2022

Type
Standard

Referansenummer
837840

Prosjekttittel
Effekten av styrketrening i sesong på prestasjonsevne hos håndballspillere

Behandlingsansvarlig institusjon
Universitetet i Agder / Fakultet for helse- og idrettsvitenskap / Institutt for idrettsvitenskap og kroppsøving

Prosjektansvarlig
Truls Raastad

Prosjektperiode
01.08.2022 - 31.12.2025

Meldeskjema

Kommentar
BAKGRUNN
Personverntjenester har en avtale med den institusjonen du forsker eller studerer med. Denne avtalen innebærer at vi skal gi deg råd slik at gjennomføringen av prosjektet ditt er lovlig etter personvernforordningen (GDPR).

Personverntjenester har på vegne av din institusjon vurdert at behandlingen av personopplysninger i dette meldeskjemaet er lovlig. Hvis den gjennomføres slik den er beskrevet i meldeskjemaet med dialog og vedlegg.

Dette betyr at du kan starte med prosjektet ditt.

BAKGRUNN
Prosjektet er vurdert av REK midt i vedtak av 27.06.2022, deres referanse 479388 (se under Tilleggsopplysninger). REK vurderer at studien framstår som forskning, men ikke som medisinsk eller helsefaglig forskning. Prosjektet er følgelig ikke omfattet av helseforskningslovens saklige virkeområde, jf. helseforskningslovens §§ 2 og 4. Prosjektet vil derfor bli gjennomført og publisert uten godkjenning fra REK.

TYPE OPPLYSNINGER OG VARIGHET
Prosjektet vil behandle alminnelige personopplysninger og særlige kategorier av personopplysninger om helseforhold frem til 31.12.2025.

LOVLIG GRUNNLAG
Prosjektet vil innhente samtykke fra de registrerte til behandlingen av personopplysninger. Vår vurdering er at prosjektet legger opp til et samtykke i samsvar med kravene i art. 4 nr. 11 og 7, ved at det er en frivillig, spesifikk, informert og utvetydig bekreftelse, som kan dokumenteres, og som den registrerte kan trekke tilbake.

For alminnelige personopplysninger vil lovlig grunnlag for behandlingen være den registrertes samtykke, jf. personvernforordningen art. 6 nr. 1 a.

For særlige kategorier av personopplysninger vil lovlig grunnlag for behandlingen være den registrertes uttrykkelige samtykke, jf. personvernforordningen art. 9 nr. 2 bokstav a, jf. personopplysningsloven § 10, jf. § 9 (2).

PERSONVERNPRINSIPPER
Personverntjenester vurderer at den planlagte behandlingen av personopplysninger vil følge prinsippene i personvernforordningen:

• om lovlighet, rettferdighet og åpenhet (art. 5.1 a), ved at de registrerte får tilfredsstillende informasjon om og samtykker til behandlingen
• formålsbegrensning (art. 5.1 b), ved at personopplysninger samles inn for spesifikke, uttrykkelig angitte og berettigede formål, og ikke viderebehandles til nye uforenlige formål
• dataminimering (art. 5.1 c), ved at det kun behandles opplysninger som er adekvate, relevante og nødvendige for formålet med prosjektet

https://meldeskjema.nsd.no/vurdering/628d3e33-8d40-4e3d-850f-07d005a86884 1/2

28/06/2022, 14:42 Meldeskjema for behandling av personopplysninger

- lagringsbegrensning (art. 5.1 e), ved at personopplysningene ikke lagres lengre enn nødvendig for å oppfylle formålet.

DE REGISTRERTES RETTIGHETER
Personverntjenester vurderer at informasjonen om behandlingen som de registrerte vil motta oppfyller lovens krav til form og innhold, jf. art. 12.1 og art. 13.

Så lenge de registrerte kan identifiseres i datamaterialet vil de ha følgende rettigheter: innsyn (art. 15), retting (art. 16), sletting (art. 17), begrensning (art. 18) og dataportabilitet (art. 20).

Vi minner om at hvis en registrert tar kontakt om sine rettigheter, har behandlingsansvarlig institusjon plikt til å svare innen en måned.

FØLG DIN INSTITUSJONS RETNINGSLINJER
Personverntjenester legger til grunn at behandlingen oppfyller kravene i personvernforordningen om riktighet (art. 5.1 d), integritet og konfidensialitet (art. 5.1. f) og sikkerhet (art. 32).

Ved bruk av databehandler (spørreskjemaleverandør, skylagring, videosamtale o.l.) må behandlingen oppfylle kravene til bruk av databehandler, jf. art 28 og 29. Bruk leverandører som din institusjon har avtale med.

For å forsikre dere om at kravene oppfylles, må prosjektansvarlig følge interne retningslinjer/rådføre dere med behandlingsansvarlig institusjon.

MELD VESENTLIGE ENDRINGER
Dersom det skjer vesentlige endringer i behandlingen av personopplysninger, kan det være nødvendig å melde dette til Personverntjenester ved å oppdatere meldeskjemaet. Før du melder inn en endring, oppfordrer vi deg til å lese om hvilken type endringer det er nødvendig å melde:
https://www.nsd.no/personverntjenester/fylle-ut-meldeskjema-for-personopplysninger/melde-endringer-i-meldeskjema
Du må vente på svar fra Personverntjenester før endringen gjennomføres.

OPPFØLGING AV PROSJEKTET
Personverntjenester vil følge opp underveis (hvert annet år) og ved planlagt avslutning for å avklare om behandlingen av personopplysningene er avsluttet/pågår i tråd med den behandlingen som er dokumentert.

Lykke til med prosjektet!

Appendix 3: Informed written consent signed by the participants

UiA Universitetet i Agder

FORESPØRSEL OM DELTAKELSE I FORSKNINGSPROSJEKT

EFFEKTEN AV STYRKETRENING I SESONG PÅ PRESTASJONSEVNE HOS HÅNDBALLSPILLERE

Lurer du på hvordan du bør trene styrke under sesong for å øke din styrke og eksplosive ferdigheter som spenst, sprint og kasthastighet?
Kunne du tenkt deg å bidra til økt kunnskap tilknyttet hvordan styrketrening best bør legges opp i sesong for håndballspillere?
Dette skrivet gir deg informasjon om målene for prosjektet og hva deltakelse vil innebære for deg

PROSJEKTETS FORMÅL

Elitespillere i håndball har ofte en betydelig større muskelmasse, de er sterkere, raskere, hopper høyere og kaster hardere enn amatørspillere. Styrketrening er derfor en viktig del av treningen til håndballspillere, men det kan være utfordrende å få trent nok styrketrening i sesong, samt vite hvordan den best bør legges opp. Og dersom man kun trener håndballspesifikk trening alene under sesong, er det blitt observert at spillere kan miste muskelmasse og styrke samt sprint- og spenstegenskaper.

Håndballspillere kombinerer ofte tradisjonell styrketrening med høy motstand på ene siden, samt sprint- og spensttrening (plyometrisk trening) med kroppsvekt og kastetrening på den andre siden. Imellom disse ytterpunktene har vi olympiske løft og «power-trening» med lav-moderat motstand. Det er en utfordring for mange utøvere å vite hvilken av disse treningsformene som bør trenes, og samtidig sørge for at man er restituert og klar til å prestere på håndballtrening og kamp.

For mannlige håndballspillere i sesong har forskning vist at tradisjonell tung styrketrening kan vedlikeholde eller øke styrke og eksplosive egenskaper. Det samme er blitt observert med både sprint- og spenst-trening, samt power-trening. Men det mangler både forskning som direkte sammenligner effekten av de ulike treningsformene på håndballspillere i sesong, og generelt hvordan kvinnelige håndballspillere i sesong blir påvirket av styrketrening.

Av den grunn er det av interesse å sammenligne tilpasninger i muskelmasse, styrke, spenst og hurtighet mellom disse treningsformene under en treningsperiode i sesong. Resultatene kan hjelpe deg og andre håndballspillere til å sette opp hvilken styrketreningsform som bør prioriteres i sesong for utøvere med ulike utgangspunkt og egenskaper. I tillegg vil vi undersøke om treningsøktene gir ulike akutte treningsstimuli og restitusjonsforløp som kan forklare tilpasningene. Mer kunnskap om det kan hjelpe i å planlegge styrketreningen opp imot håndballkamper og trening. Dette er et tema som landslagstrener Thorir Hergeirsson har kommet med spesielt ønske om å undersøke nærmere for å forbedre prestasjonsutvikling i sesong for håndballspillere.

For å utforske dette inviterer vi nettopp deg til å delta. Du må være aktiv håndballspiller mellom 16 og 35 år (foreldresamtykke dersom under 18 år) og ha erfaring med styrketrening. Du kan ikke delta om du har skader i muskelskjelettapparatet som hindrer deg i å trene og yte maksimalt i styrke-spenst- og sprint-tester. Du kan heller ikke delta dersom du som kvinnelig utøver er gravid.

Prosjektet blir gjennomført av forskere tilknyttet Universitetet i Agder, Norges idrettshøgskole og Olympiatoppen, i samarbeid med Thorir Hergeirsson og landslagets fysiske trener Benjamin Jensen.

HVA INNEBÆRER DET FOR DEG Å DELTA I PROSJEKTET?

Deltakelse innebærer at hver utøver gjennomfører fysiske tester ved Universitetet i Agder. Deretter blir man randomisert (tilfeldig fordelt) i to treningsgrupper som skal trene i 16 uker under kampsesong. Tidspunkt for testing og trening er planlagt for høsten 2022 og 2023. I tillegg vil vi kartlegge treningsbelastning fra perioder med håndballtrening og kamper med sporingsenheter.

For å kunne delta er det ønskelig at hver deltaker:

- Gjennomfører fysiske tester fordelt på totalt syv dager
    - Én tilvenningsøkt og tester før og etter treningsperioden (opptil 2 timer per økt)
    - 4 «akutte» testdager i slutten av prosjektet (opptil 1 time per økt)
    - Testene må gjennomføres i utvilt tilstand før og etter treningsperioden samt på akutt testdag 1. Uthvilt tilstand betyr uten å ha gjennomført hard anstrengende trening de siste 48 timene og unngå all *uvant* trening de siste 72 timene.

- Gjennomfører styrketreningsprogrammet som er blitt utdelt under hele treningsperioden.
- Registrerer kostholdet i sju dager fordelt på tre perioder; i starten, midtveis, og på slutten av prosjektet.
- Registrering av sykdom og skader og enkel loggføring av styrketrening hver 14.dag
- For kvinnelige deltagere: registrerer menstruasjonssyklus i egen app og rapporterer inn avvik.

Testene som utføres før og etter treningsperioden:

- Høyde, vekt, subjektiv vurdering av opplevd restitusjon og menstruasjonssyklus.
- En kroppsscan (dual-x-ray-absorptiometry [DXA]) som måler din totale muskelmasse i kroppen samt hvor sterkt skjelettet er.
- Muskelvevsprøve i lårmuskulaturen (m. vastus lateralis) etter bedøvelse totalt 3 ganger.
- Muskelstørrelse av samme lårmuskulatur med ultralyd.

Deretter er det en 10 minutters lang oppvarming etterfulgt av 3 forsøk for hver test og med 3 minutter pause mellom hvert forsøk:

- 30 meter sprint (med splittider) og sprint med retningsforandring.
- Kastehastighet.
- Svikthopp og en 3-steg hopp-rekkevidde test («jump & reach»).
- Styrke og power med beinpress og benkpress.

I tillegg vil det gjennomføres et akutt forsøk i slutten av treningsperioden.
Subjektiv grad av opplevd restitusjon og testene muskelvevsprøve og svikthopp utføres rett før en treningsøkt, i tillegg til styrke og elektrisk stimulering av musklene for å måle tretthet i muskulaturen. Deretter vil deltakerne trene en økt med de oppsatte treningsøktene som de har fulgt i treningsperioden. Rett etter treningsøkten vil deltakerne rapporterte subjektiv grad av opplevd anstrengelse før en ny runde med de samme testene som deltakerne gjorde rett før treningsøkten. Testene, med unntak av muskelvevsprøver, vil gjentas 24- og 48-timer etter økten.

Kartlegging av treningsbelastning fra håndballspesifikk trening vil gjennomføres med at hver deltaker spiller håndball med enheter som festes til treningstoppen under aktivitet. Dette vil brukes til å se effekten av styrketrening opp imot treningsbelastningen fra idretten. Vi vil gjøre 3 perioder med målinger på 2-3 uker; i starten, midten og slutten av prosjektet.

Treningsgruppene
Selve intervensjonsopplegget (treningen) utarbeides ut fra erfaring med oppfølging av håndballspillere gjennom Olympiatoppen, innspill fra landslagsteamet, samt tilsvarende program som er brukt i tidligere forskning på lagspillutøvere.

Deltakerne vil bli tilfeldig delt inn i to treningsgrupper. Treningen i den ene gruppa vil bestå av maksimal styrketrening med høy motstand (~70-90 % av 1RM) på ulike styrkeøvelser for bein og overkropp. Imens den andre gruppen to vil trene eksplosiv «power» styrketrening med lavere belastning (20-60% av 1RM) på bein og overkropp, samt plyometrisk trening (sprint- og spenstøvelser) med kroppsvekt. Gruppene vil trene 2-3 ganger per uke under hele prosjektperioden, ved siden av lagtreninger og kamper.

MULIGE FORDELER OG ULEMPER

Mulige fordeler med deltakelse:

- Treningsprogrammene er laget for at du skal oppnå en prestasjonsøkende effekt.
- Du vil få treningsoppfølging og veiledning.
- Du vil få kjennskap til hvordan den spesifikke treningen påvirker deg.
- Du vil få økt kunnskap om din kapasitet og prestasjon relatert til styrke, spenst, hurtighet og power, som normalt ikke er tilgjengelig.
- Resultatene kan inngå i egen treningsplanlegging.
- Du vil bidra til å øke kunnskapen på temaet og fremheve prestasjonsfremmende forskning på håndballutøvere.
- Du vil få mulighet til å stille spørsmål om det du måtte lure på angående trening.
- Du kan få økt kunnskap om idrettsernæring ved å bli invitert til å delta på foredrag

Mulige ulemper med deltakelse:

- Deltakelse i prosjektet vil kreve at du setter av tid til testing og trening
- Trening og testing kan føre til stølhet og oppfattes som ubehagelig/smertefullt i etterkant, og det fører også med seg en viss risiko for skader. Denne risikoen anses imidlertid ikke som større enn ved den treningen du er vant til fra før.
- DXA-kroppsskann medfører en lav røntgenstrålingsdose, men anses ikke som farlig og tilsvarer dosen en utsettes for under en interkontinental flyreise.
- Muskelprøvetaking kan være ubehagelig, selv om huden og bindevevet rundt muskelen bedøves for å minimere ubehag. I om lag et døgn etter muskelprøven opplever man ømhet og stølhet i området rundt snittet. Ømheten vil deretter avta og forsvinner vanligvis i løpet av én-fire dager. Enkelte personer kan få tydelig arrdannelse etter

kobler navnet ditt til forsøkspersonnummeret. Det er kun prosjektleder (Prof. Truls Raastad) og prosjektkoordinator (Fredrik Tonstad Vårvik) som har tilgang til denne listen. Prosjektet avsluttes 31.12.2025 og da vil kodelisten destrueres, noe som betyr at innsamlet informasjonen er anonymisert og ingen opplysninger kan spores tilbake til deg. Anonymisert innsamlede data vil bli slettet fem år etter prosjektslutt, eller når resultatene er publisert. Deltakerne kan også bli kontaktet på et senere tidspunkt dersom det skulle bli aktuelt med oppfølgingsstudier. De kan velge å takke nei selv om de er med i treningsintervensjonen.

HVA SKJER MED PRØVER SOM BLIR TATT AV DEG?

Muskelprøvene som tas av deg skal oppbevares i en forskningsbiobank tilknyttet prosjektet. Ansvarlig for biobanken er prosjektleder Prof. Truls Raastad. Biobanken opphører ved prosjektslutt. Ved å delta i prosjektet, samtykker du også til at opplysninger om muskeltykkelse, -styrke, samt muskelvev kan overføres til utlandet som ledd i forskningssamarbeid og publisering. Prosjektleder vil sikre at dine opplysninger blir ivaretatt på en trygg måte. Koden som knytter deg til dine personidentifiserbare opplysninger vil ikke bli utlevert. Dersom data overføres til utlandet skal prøvene destrueres ved prosjektslutt eller når resultatene er publisert.

GODKJENT PROSJEKT

Prosjektet vil søke om godkjenning fra Regional komité for medisinsk og helsefaglig forskningsetikk, samt godkjenning for behandling av personopplysninger fra Norsk senter for forskningsdata (NSD). Etter ny personopplysningslov har behandlingsansvarlig UiA og prosjektleder Prof. Truls Raastad et selvstendig ansvar for å sikre at behandlingen av dine opplysninger har et lovlig grunnlag. Dette prosjektet har rettslig grunnlag i EUs personvernforordning artikkel 6 nr. 1a og artikkel 9 nr. 2a, ditt samtykke.

Hvis du har spørsmål knyttet til NSD sin vurdering av prosjektet, kan du ta kontakt med dem på epost: personverntjenester@nsd.no eller på telefon: 55 58 21 17.

FORSIKRING

Alle deltagere er forsikret gjennom Universitetet i Agder, som statlig institusjon, er selvassurandør.

INFORMASJON OM UTFALLET AV PROSJEKTET

Du vil få informasjon om resultatene av studien. Det vil bli gjennomført en presentasjon på et informasjonsmøte for forsøkspersonene i etterkant av studien. Resultatene vil bli publisert i nasjonale/internasjonale vitenskapelige tidsskrift, kronikker og foredrag.

SPØRSMÅL OM PROSJEKTET? TA GJERNE KONTAKT

Prosjektansvarlig/stipendiat Fredrik Tonstad Vårvik
E-post: fredriktv@uia.no / Tlf: 928 54 969

Prosjektleder/Professor Truls Raastad
E-post: truls.raastad@nih.no / Tlf: 23 26 23 28

SAMTYKKEERKLÆRING

JEG SAMTYKKER TIL Å DELTA I PROSJEKTET OG TIL AT MINE PERSONOPPLYSNINGER OG BIOLOGISK MATERIALE BRUKES SLIK DET ER BESKREVET

Sted og dato Deltakers signatur

Deltakers navn med BLOKKBOKSTAVER

Prosjektmedarbeider bekrefter å ha gitt informasjon om prosjektet

Sted og dato Signatur

Rolle i prosjektet