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Effect of in-season resistance exercise-induced changes in muscle size and strength on match-related handball external load measurements

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Sammendrag

Hensikt: målet med denne studien var å undersøke om endringer i maksimal styrke og fettfri masse i bein etter styrketrening kunne påvirke endringer i håndballrealterte eksterne variabler i sesong. **Metode:** tjue kvinnelige håndballspillere fra to ulike håndballag i 2.divisjon (alder 19.6 ± 2.4 år, høyde 168.7 ± 6.3 cm, og vekt 69.3 ± 13.3 kg) gjennomføre et 12-ukers treningsprogram, tung styrke og power/plyometri, i sesong. Utøverne ble deretter delt inn i høy- og lav-respondere basert på endringer i 1 repetisjon maksimum i knebøy, kraft i beinpress, og fettfri masse i bein. Forbedringer i fettfri masse og en av de to styrketestene som oversteg minste verdifulle endring og koeffisientavvik ble definert som høy-respondere. Ukentlig standardisert håndballrelatert ekstern belastning ble målt som PlayerLoad og hendelser med høy intensitet (HIE) ved hjelp av «inertial measurement units». Endringer i eksterne variabler mellom høy- og lav-respondere ble analysert med t-tester (tre første vs. tre siste målinger), «Nonoverlap of all Pairs» (NAP) kalkulator for å se på forskjeller på individnivå samt korrelasjoner mellom endringer i eksterne variabler og kombinert 1RM, kraft og FFM («composite score»). **Resultat:** det var ingen signifikante forskjeller mellom eller innad i respondere i endring i ekstern belastning ($p>0.05$) eller korrelasjoner mellom endringer i «composite score» og eksterne variabler ($r= -0.04- -0.20$, alle $p>0.05$). NAP analysene viste ingen signifikante forskjeller på individnivå (effektstørrelser: PlayerLoad: 0-0.66, HIE: 0.25-0.61). **Konklusjon:** disse funnene tyder på at endringer i maksimal styrke og fettfri masse i bein ikke påvirker håndballrealterte variabler som PlayerLoad og HIE i sesong.

Nøkkelord: styrketrening, håndball, eksterne variabler, PlayerLoad, hendelser med høy intensitet

Abstract

Purpose: this study aimed to investigate if in-season resistance training-induced changes in maximal lower-body strength and fat-free mass could influence changes in match-related handball external load measurements. **Method:** twenty female handball players from two senior sub-elite teams (19.6 ± 2.4 years, 168.7 ± 6.3 cm in height, and 69.3 ± 13.3 kg body mass) completed a 12-week in-season strength- and power training program. Players were then divided into high- and low-responders based on changes in squat 1 repetition maximum, leg press force, and leg fat-free mass (FFM). Improvements in FFM and one of the two strength tests that exceeded the smallest worthwhile change and coefficient of variation were defined as high-responders. Weekly standardized match-related handball external load was measured as Player Load and high intensity events (HIE) with inertial measurement units. Changes in external load between high- and low-responders were analyzed with t-tests (three first- vs. three last measurements), single-cases with Nonoverlap of all Pairs (NAP) as well as correlations between changes in external load and the combined 1RM, force and FFM (composite change score). **Results**: There were no significant differences between or within responders in change in external load (p>0.05) or any correlations between changes in the composite score and external load (r= -0.04- -0.20, all p>0.05). The NAP analyses revealed no significant differences on an individual level (effect sizes: PlayerLoad: 0-0.66, HIE: 0.25-0.61). **Conclusion:** These findings indicate that changes in maximal leg extensor strength and fat-free mass do not influence match-related in-season handball PlayerLoad and HIE measurements.

Key-words: resistance training, handball, external load, PlayerLoad, high intensity events

Abbreviations

LPS	Local Positioning systems
IMU	Inertial Measurement Unit
HIE	High Intensity Events
PL	PlayerLoad
RFD	Rate of Force Development
Acc	Acceleration
Dec	Deceleration
COD	Change of Direction
1RM	One-Repetition Maximum
GPS	Global Positioning System
VJ	Vertical jump
RCT	Randomized Controlled Trial
SWC	Smallest Worthwhile Change
CV	Coefficient of variations
TE	Typical Error
FFM	Fat-Free Mass
Fmax	Force Maximum
Fmax/kg	Force maximum Relative to Bodyweight
DXA	Dual-x-ray-absorptiometry
Hz	Hertz
RIR	Repetition in Reserve
NAP	Nonoverlap off All Pairs

Structure of the thesis

Part 1: Includes a section of the theoretical background for the study, a methodological chapter detailing how the study was performed, and a section that discuss this methodology.

Part 2: Presents a research paper, written by the guidelines from the open access of the Scandinavian Journal of Medicine & Science in Sports. This part takes the form of an AMA-style manuscript including an introduction, methods, results, discussion, strength and limitations of the study, as well as perspectives.

Part 3: Presents attachments including detailed training programs, approval, informed consent for the participants, as well as an application for ethical approval.

PART 1

THEORETICAL BACKGROUND AND METHODS

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1.0 Introduction

Team handball is not only a very popular sport enjoyed by people worldwide, but it is also an Olympic sport played professionally in many European countries (Hammami et al., 2019; Manchado et al., 2013). The game is divided into two halves of 30 min each, and is characterized by two teams shifting between offensive and defensive play. The defenders try to prevent the opponents from approaching the goal, and in these actions the athletes have a lot of body contact (Marques, 2010). The sport thus require different physical attributes, such as strength, explosive power, speed and endurance (Manchado et al., 2013; Marques, 2010).

Throughout the game, all of the physical and technical-tactical elements are of great importance (Manchado et al., 2020). They are closely related to each other, which makes handball a particularly complex sport (Manchado et al., 2020). It is one of the fastest team sport and alternates between high- and low-intensity activities and movements, some intense and short and some longer periods of lower intensity (Manchado et al., 2013). Handball play is characterized by repeated jumps, sprints, changes of direction, body contact at high speed, and specific technical movement patterns occurring in response to the varying tactical situations of the game (Karcher & Buchheit, 2014; Manchado et al., 2013).

When discussing success and results in handball, anthropometric characteristics such as body size and body mass plays a highly important role (Manchado et al., 2013). Research has shown that elite female handball players have higher values in different physical demands than the amateur players (Granados et al., 2007). According to some research, taller and more powerfully built players may have an advantage (Granados et al., 2007). This is evidenced by the fact that elite female handball players outperform the amateur players in terms of body height, fat-free mass, sprint and endurance running abilities, as well as ball throwing velocity (Granados et al., 2007). This gives the elite players an advantage in sustaining forceful and frequent muscle contractions required during certain handball game actions (Gorostiaga et al., 2005).

Research has shown a significant relationship between high-intensity actions and lower limb strength and power (Bragazzi et al., 2020). Therefore, both strength- and power-training should be monitored to make sure that the athletes maintains a high level of strength throughout the competitive season (Bragazzi et al., 2020). To improve athletic performance in elite athletes, the use of training programs designed to increase underlying strength and power qualities is commonplace, and this relationship between strength assessment and performance holds significant importance for research regarding strength and conditioning (McGuigan et al., 2012; Nuzzo et al., 2008). Although this connection does not necessarily imply a causal relationship, it can assist researchers in selecting suitable tests for evaluating the effects of experimental interventions on strength, power and other performance metrics (Nuzzo et al., 2008). Furthermore, a deeper comprehension of strength assessments and their correlation with lower body force, velocity, and power may offer further evidence for the incorporation of specific training approaches (Nuzzo et al., 2008). How these parameters change during a season in elite handball players is to date, unclear (Marques, 2010).

To meet actual on-court playing demands, there is a need to examine, develop and implement optimal physical training regimes in modern female team handball (Michalsik et al., 2014). Through continuous observation of the players actions during match-play, time-motion analysis enables researchers and handball coaches to gain insights into the physical demands imposed on their players (Ziv & Lidor, 2009). Local positioning systems (LPs) with an inertial measurement unit (IMU) have been developed in the past decade (Luteberget, Spencer, et al., 2018). When examining the physical demands of team sport, the athletes total effort is often assessed by measuring their overall workload (Luteberget, Spencer, et al., 2018). This workload is determined by both the intensity and duration of the tasks performed and is commonly quantified using parameters like total distance covered and distance covered in different speed zones (Luteberget, Spencer, et al., 2018). Using variables such as number of sprints, number of accelerations or distance covered above a predefined speed threshold, high intensity events (HIE) and Player Load (PL) can be reported (Luteberget, Spencer, et al., 2018). To improve individualization of physical preparation, it is necessary to get better knowledge of on-court demands of handball players at the highest level (Manchado et al., 2020). Specific to team handball, there is a lack of research (Luteberget & Spencer, 2017). There is also a need for more research on whether change in physical performance can influence these parameters.

It is not investigated if changes in physical and anthropometric parameters can influence on-court performance. It is neither investigated if in-season resistance training-induced changes in maximal lower-body strength and fat-free mass could influence changes in match-related handball external load measurements.

1.1 Purpose

The purpose of this study is therefore to investigate if in-season resistance training-induced changes in maximal lower-body strength and fat-free mass could influence changes in match-related handball external load measurements.

2.0 Theoretical framework

2.1 Handball and physical demands

Handball is characterized by fast transitions between offensive and defensive actions and these attack phases are dynamic, consisting of fast movements and a high frequency of fast passes (Manchado et al., 2020; Marques, 2010). Whether handball players play in offensive or defense during a match, the players must be physically trained to maintain the game´s speed and intensity and perform at a high level throughout the entire game (Manchado et al., 2020; Marques, 2010).

The game of team handball has evolved substantially over the last decades (Michalsik et al., 2014). Therefore, handball has become more physically demanding and so has the requirements for female elite team handball (Hermassi et al., 2014; Michalsik et al., 2014). Modern elite team handball has transformed into a fast and intense game performed by well-trained players, with the intensity of game-play elevated (Michalsik et al., 2014). This is because of the high number of matches combined with a higher amount of training, including a change of rule that allows a quick throw-off, which has led to an increased number of attacks during match play (Ronglan et al., 2006). This makes handball an explosive sport, and all of the explosive movements like sprints, jumps, change of direction and explosive ball throwing appears during training and match play (Marques, 2010).

Because of this, and that the sport is characterized by high intensity actions performed at high velocities, success depends partly on well-developed muscular strength (Carvalho et al., 2014). In general, there is a direct correlation between muscle-cross-sectional area and absolute strength (HÄkkinen et al., 1984). This means that a larger muscle tends to be a stronger muscle, and this observation could suggest that increasing muscle mass can result in enhanced athletic performance (Young et al., 2019). Maximal power production is influenced by the fundamental quality of strength, and short-term muscle power has become crucial in may decisive game situations (Cormie et al., 2011b; Hermassi et al., 2014). For handball players to have an advantage in blocking, hitting, and pushing of ball throwing velocity, most researchers agree that higher maximal power and strength may be associated (Manchado et al., 2013).

Essential components of overall training includes strength and power, and therefore handball players often train these traits through the season (Hammami et al., 2019). Efficiency of training is a key issue for athletes and coaches at all levels, and therefore it is crucial to maximizing the transfer of training to performance (Young, 2006). In order for coaches to effectively incorporate all the important performance factors involved in the complexity of team handball, it is important to develop good and effective strength and conditioning programs that provide information on training-related issues (Luteberget, Trollerud, et al., 2018; Ziv & Lidor, 2009). To help coaches select the optimal training stimulus to improve individual performance of their athletes, understanding the effects of specific strength and plyometric training on body composition, vertical jump performance and muscular strength is important (Carvalho et al., 2014).

2.2 Importance of muscle mass and maximal strength for athletic performance

2.2.1 Muscle mass

As written earlier; a larger muscle tends to be a stronger muscle because of the direct correlation between muscle-cross-sectional area and absolute strength (HÄkkinen et al., 1984; Young et al., 2019). To give the whole handball team an advantage to sustain the forceful muscle contractions required during some game actions, strength and power exercises should be emphasized in the conditioning routine (Manchado et al., 2013). This is to improve the percent of muscle mass and the required levels of maximal explosive strength of the upper and lower extremity muscles (Manchado et al., 2013). Body composition is well known to be relevant to performance with particular attention on the rations of fat and lean mass (Kale & Akdoğan, 2020). It is ideal for successful handball players to have a high fat-free body mass and less body fat (Eler & Joksimovic, 2019). Several studies have demonstrated that handball players present distinct differences in their body size and shape when compared to the general population (Olds et al., 1996). Players that have a higher skill level are taller and have a higher fat-free mass, and elite players are heavier, have a higher fat-free mass and higher body mass than amateur players (Manchado et al., 2013; Ziv & Lidor, 2009). Therefore, a high body mass and specifically high fat-free mass is advantageous in handball, and somatic traits can be one of the predictors of success in this sport (Olds et al., 1996; Ziv & Lidor, 2009).

An additional advantage of increased body mass for athletes is the potential to move with grater momentum (Young et al., 2019). As momentum equals mass multiplied by velocity, a heavier athlete running at a constant velocity will possess greater momentum. This increased momentum can have practical benefits, such as enhancing an athlete´s ability to withstand collisions. However, it´s important to note that if an athlete gains body mass over time, their running momentum will only increase if their velocity does not decrease enough to offset the momentum gained. Therefore, it may be difficult to achieve a higher velocity and run faster after gaining body mass (Young et al., 2019). However, the above discussion uncovers that body mass gains can be beneficial by possessing increased inertia, but in many cases, the benefits are often only achieved if the increase in strength is proportionally greater (Young et al., 2019).

2.2.2 Maximal strength

Maximal strength can be defined as "one´s ability to exert maximal force against an external resistance and requires a maximal voluntary contraction" (Thompson et al., 2020). Muscular strength has been characterized as the capacity to apply force to an external object or resistance (Suchomel et al., 2016). In several sports where an athlete need to generate force against their own body´s resistance, relative strength (strength relative to body mass) can be more advantageous than developing absolute strength (maximum strength capacity regardless of body size) (Young et al., 2019). Depending on the requirements of their specific sport or event, an athlete may need to generate significant force against gravity in order to control their own body weight, control their own weight combined with their opponent´s, or manipulate an object or projectile (Suchomel et al., 2016).

For success in elite handball, maximal strength and power are considered as major determinants and many studies have highlighted the major role of the lower limb strength and power (Bragazzi et al., 2020). Maximal power represents "the greatest instantaneous power during a single movement performed with the goal of producing maximal velocity at take-off, release or impact" (Cormie et al., 2011a). Prior research has suggested that achieving a high level of muscular strength is essential for effectively utilizing techniques during handball competitions and that muscular strength is one of the underlying determinants of strength-power performance (Lijewski et al., 2021; Suchomel et al., 2016). An individual cannot possess a high level of power without first being relatively strong, this is because it exists a fundamental relationship between strength and power (Cormie et al., 2011b). Stronger individuals have superior power production capabilities than significantly weaker individuals (Cormie et al., 2010).

Numerous studies have shown significant correlations between sprinting across different distances and a variety of measures related to strength and power (Young, 2006). These connections between strength and power and sprint performance suggest that the muscle functionality evaluated through strength and power tests shares some similarities with athletic performance (Young, 2006). According to Young (2006) is it important for various sports to have the ability to generate relatively high forces against large resistance (strength) and to produce a high work rate (power) (Young, 2006). Often, handball players needs to develop high values of power in a very short time to have an advantage in all of the applied techniques such as passes, throws, jumps, starts, changes of running direction, as well as the technical and tactical behaviors (Spieszny & Zubik, 2018). These activities depends not only on maximal strength, but also on power and agility and therefore, power applies to the vast majority of sports (Cormie et al., 2011a; Hermassi et al., 2017)

In terms of athletic performance, two of the most crucial performance characteristics are considered to be high rates of force development (RFD) and successive high external mechanical power (Suchomel et al., 2016). RFD is the rate of rise in force over the change in time, and can also be termed “explosive strength”. Numerous studies suggest that resistance training is beneficial in enhancing an individual´s RFD by building strength. The development of muscular strength can impact essential force-time attributes that are relevant to performance. Theoretically, the improvement of force-time characteristics should translate into an enhanced capacity to execute fundamental sporting skills (Suchomel et al., 2016). According to mathematical principles, individuals that can exert more force within a specific time frame (greater impulse), should be able to achieve the highest velocity when accelerating or changing momentum (Suchomel et al., 2016). There is a strong correlation between maximal strength and RFD, which makes it logical to assume that an individual´s sprinting performance is linked to their level of strength. Previous research has demonstrated that improvement in strength are associated with enhancements in short sprint performance (Suchomel et al., 2016).

In sports that involve sprinting, particularly in small playing areas with limited sprint distance, horizontal acceleration is required and rapid change-of-direction (COD) tasks are among the most frequently performed activities during matches in elite handball (Karcher & Buchheit, 2014; Suchomel et al., 2016). COD consists of acceleration, followed by a deceleration, before re-accelerating into a new direction (Falch et al., 2022). It is determined by a mix of different motor skills, such as linear speed, ability to decelerate rapidly, and reactive strength (Sheppard & Young, 2006). The ability to decelerate is important in situations where an attacker aims to create space from a pursuing defender (Suchomel et al., 2016). When comparing tasks involving COD speed over short distances it would appear that strength and power measures have an influence on COD speed, and as a result, an athlete´s strength and body mass characteristics can also impact their ability to perform COD speed and agility movements (Sheppard & Young, 2006; Suchomel et al., 2016).

2.3 Strength training for increased muscle size, strength and athletic performance

To enhance dynamic performance, there are a variety of resistance training methods (Wilson et al., 1993). To result in optimal performance gains in dynamic sports such as sprinting, jumping and throwing, there appear to be three distinct schools of thoughts: traditional weight training (80-90% of 1 repetition maximum (1RM) for 4-8 repetitions), plyometric training (the accelerations and deceleration of body weight is used to overload the exercises), and power training (approximately 30% of 1RM at high speed) (Wilson et al., 1993). It is a common practice among team sports coaches when aiming to optimize the player´s performance during the in-season period to combine general strength training with specific power or plyometric exercises such as plyometrics (Carvalho, 2014). Combining strength and power training seems to be more efficient in improving muscular power compared to strength or power training alone (Ebben, 2002).

2.3.1 Muscle size

The development of muscle mass (hypertrophy) through resistance training (RT) is a common goal in strength and conditioning (Young et al., 2019). Strength training offers significant benefits for athletes who aim to increase their muscle mass (McGuigan et al., 2012). Muscular hypertrophy is one of the most noticeable physical adaption resulting from heavy resistance training (Fry, 2004). For increasing strength and power, gaining muscle mass is considered desirable, as well as for increasing body mass in certain sports (Young et al., 2019). It is well documented that heavy resistance training increases maximal voluntary strength and cross-sectional area in females (Jensen et al., 1997).

While various RT training loads can effectively lead to hypertrophy development, emphasizing relatively heavy loads is crucial for maximizing strength gain (Young et al., 2019). Multiple studies have determined the effectiveness of low-volume RT training performed using either high (≥ 85% 1RM) or maximal loads (i.e. at or very close to the 1RM) in enhancing strength and muscle hypertrophy (Fyfe et al., 2022).

2.3.2 Maximal strength

For increasing maximal strength, research has shown that resistance training with external loads corresponding to 80-100% of 1RM for few repetitions (4-8) is most effective for optimal increases (Marques, 2010; Wilson et al., 1993). This method has also been shown to enhance power and movement speed (Wilson et al., 1993). Another research has shown that maximal strength gains are obtained among athletes who train at a mean training intensity of 85% of 1RM, 2 days per week, and 8 sets per muscle group as a mean training volume (Peterson et al., 2004). A mean training intensity of 50-70% of 1RM will show minimal strength increases, this can be seen by the dose-response curve. Further examination of this curve reveals that as the mean intensity approaches 85% of 1RM, there is an upward trend in strength development as the intensity increases (Peterson et al., 2004). Increases in muscular strength will result from a regular exposure to heavy resistance exercise (Fry, 2004).

Maximal strength and power production in sport depends on a series of neuromuscular factors (Cormie et al., 2011a; Young, 2006). It appears to be critical in sports that require optimal combinations of muscle strength and speed to maximize optimal performance, the ability of the neuromuscular system to produce maximal power output (Izquierdo et al., 2002). To optimize the force-velocity relationship and increase muscle power output, neuromuscular strength and power adaptions are extremely important (Cormie et al., 2007).

Improvement in strength, power, and speed has been shown through strength and resistance training in a number of athletic populations (McGuigan et al., 2012). According to research, well-planned resistance exercises with focus on maximal strength and power are more effective in developing muscular power, and induce a comparable increase in jumping ability as plyometric exercises (Spieszny & Zubik, 2018). Falch et al. (2022) research showed that in young female handball players, both strength and plyometric training was indicated to be effective in enhancing performance in different strength, plyometric, and power tests (Falch et al., 2022). It is worth noting that strength training produces different effects than those resulting from explosive resistance training. Furthermore, the impact of strength training on the strength-speed curve can vary depending on the load applied (Spieszny & Zubik, 2018).

2.3.3 Athletic performance

Research has shown strong relationship between the development of physical capacities such as force production, power, and RFD using strength training and sport-specific skills such as speed and agility (McGuigan et al., 2012). The muscle function assessed by strength and power tests has some commonality with performance, because of the significant relationship between strength and power and sprint performance (Young, 2006). In team sports, the demands of sprinting are often characterized by frequent changes of direction rather than running in a straight line (Falch et al., 2022). To be a successful sprinter, one must possess the ability to quickly react (reflex speed), accelerate for as long as possible (power), achieve the highest attainable running speed (maximum velocity), sustain this velocity for as long as possible (maximum speed endurance), and minimize the reduction in speed caused by fatigue (Smirniotou et al., 2008). For coaches to help improve the quality of training programs according to the specific needs of their athletes, the evaluations of strength-power parameters would allow coaches to predict sprinting performance during the training seasons (Smirniotou et al., 2008). Therefore, it is important to increase the time dedicated to sprint training and leg muscular strength, but should be accompanied by a decrease in the total of the physical training volume, and be specific to the actual demands of women team handball (Manchado et al., 2013).

Research has indicated significant correlations between a range of measures of strength and power and sprinting performance over various distance (Young, 2006). Based on these results, it is a reason to believe that an improvement in strength and power may lead to improvement in sprint performance. It needs more research in this topic related to the fact that correlations does not indicate cause and effect. For improving maximum strength in a squat test, high-resistance weight training of the leg-extensor muscles is effective, but this has not transferred to sprint speed. Similar findings have been reported for power training, although sprint performance may be more related to power than to strength (Young, 2006).

For getting better CODs, a greater magnitude of force to change momentum is required, and applying force for a longer time (Falch et al., 2022). This is to create a propulsive force to re-accelerate into a new direction. To positive influence COD performance, increasing strength relative to bodyweight is suggested, as force is a product of mass x acceleration. This is to tolerate the higher loads. Also, research has shown that performing plyometric exercises at higher muscular contraction velocities can enhance COD performance (Falch et al., 2022).

2.4 Tracking on-court handball match-play

Monitoring player workload has become increasingly important in recent years to better understand the impact of workload on athletic performance, fatigue, and injury risk (Müller et al., 2022). In sports, the physical demands can be classified as either internal or external workload. Internal load refers to the psychological and physiological responses that occur as a result of external loads. Indicators of internal load include ratings of perceived exertion and heart rate. External load refers to the physical activity performed during training or competition, such as the distance covered, velocity generated, accelerations, changes in direction, or jumps executed. This can be measured using inertial measurement units (IMUs) which have demonstrated adequate validity in measuring accelerations and decelerations in all three orthogonal axes (Müller et al., 2022).

2.4.1 External load match assessment

Local positioning system (LPS) and Inertial measurement unit (IMU)

Global Positioning System (GPS) is a network of satellites that enable tracking devices to obtain information on both their location and the current time (Malone et al., 2017). At all levels of individual and team sports, commercial GPS systems have become a prevalent tool, but during indoor competitions, this method becomes unavailable (Boyd et al., 2011; Malone et al., 2017). Therefore, local positioning system (LPS) have been developed, and most of the commercially available LPS devices contain an inertial measurement unit (IMU) (García-Sánchez et al., 2023). The development of this small wearable IMUs have provided new possibilities to investigate the physical demands in indoor sports (Luteberget & Spencer, 2017). The IMUs consist of accelerometers, gyroscopes and magnetometers, and has allowed for more detailed quantification of both high-intensity, sport-specific actions and external load (Wik et al., 2017). These devices facilitate detailed movement analysis and can provide a conceptual framework by having detailed information about the movements such as the distance covered by players, the velocities of their movements, and positioning in 2-dimensional space during a game (Manchado et al., 2013). Therefore, the devices provide an alternative to labor-extensive video coding (Luteberget & Spencer, 2017).

It has become popular to measure distance, acceleration, decelerations and ability to change direction in relation to handball match and training using the IMU system and it is already a common practice in team sports such as Australian Football, field hockey, rugby and soccer to use for physical activity profiling (Luteberget & Spencer, 2017; Wik et al., 2017).

PlayerLoad (PL) and High Intensity Events (HIE)

PlayerLoad has been developed as a measure of physical performance based on changes in acceleration, with the aim of capturing non-running based work such as jumping, changes of direction and tackles (Wik et al., 2017). The IMUs commonly utilize three-dimensional accelerometer data to compute the PlayerLoad (García-Sánchez et al., 2023). This would not be captured as precisely using traditional time-motion analysis alone (Wik et al., 2017). PlayerLoad has gained significant traction over the past few years and is now one of the most commonly used variable for tracking external load (García-Sánchez et al., 2023). High Intensity Events is referred to as the sum of all accelerations, decelerations and change of directions (Luteberget & Spencer, 2017).

Previous research

In a study by Wik et al., 2017, female handball players were tracked using the IMU system during matches. In the analysis, consecutive 5-minutes periods fulfilling the inclusion criterion for field time were analyzed. The results showed that the outfield players had a mean value of 9.52 ± 1.1 in PlayerLoad/min ± SD (Wik et al., 2017). Another study by Luteberget et al., 2018 showed that the female handball-players had mean values of PlayerLoad * min-1 for all players combined at 9.71 ± 0.3, *min-1, playing 6 vs 6 for 5 minutes (Luteberget, Trollerud, et al., 2018). Mean values for HIE were 3.03 ± 0.17 *min-1 (Luteberget, Trollerud, et al., 2018). Another study by Luteberget & Spencer (2017) showed that the mean HIE for the players were 3.90 ± 1.58 HIE/min (Luteberget & Spencer, 2017).

2.5 In-season training and physical performance

Athletes develop muscle size, muscular strength and power during the preparatory period, and the task is to maintain or even improve these levels during the competitive period (Spieszny

& Zubik, 2018). In elite team handball, it has not been very clear how parameters like muscle size, strength and sprint abilities change during the season (Marques, 2010; Marques & González-Badillo, 2006). Some research suggest that the strength and power of players can be preserved and increased with in-season strength and conditioning training, and that training sessions performed twice a week can increase muscle strength of athletes (Hermassi, Chelly, et al., 2019; Spieszny & Zubik, 2018). Although; for improving adaptions during a long-term in-season period, increasing overall training volume does not always provide a better stimulus (Marques, 2010).

When a group of male handball players supplemented their regular in-season training with an 8-week program of heavy biweekly resistance exercises, they experienced improvements in peak power output for both upper and lower limbs, substantial gains in vertical jumping and sprint performance, as well as increases in muscle volume and 1RM strength (Hermassi et al., 2011). This was also showed in another study were the results indicates that adding strength training to their normal handball training enhanced the maximal strength of the lower extremity and jump performance, and this could also enhance the repeated sprint ability (Hermassi et al., 2017).

Another research showed that an in-season weightlifting training program can enhance the peak power output of the limbs (Hermassi, Schwesig, et al., 2019). The athletes in this study replaced a part of their normal in-season training with a 12-week program of biweekly weightlifting exercises. They had an increase in the rate of force development which presumably is because of the high weightlifting loading (60-86% of 1RM) (Hermassi, Schwesig, et al., 2019).

A training program with heavy loads and slow contractions can lead to increased strength and not increase power, even lead to a reduction, while others have suggested that this type of training can increase power (Aagaard et al., 1994). Granados et al. (1999) findings showed that the athletes who performed this strength training increased significantly in maximal dynamic strength of the leg extensor and the upper extremity muscles (1RM) (12.2% and 23%, respectively) (Gorostiaga et al., 1999).

It exist moderate to high correlations between the relative maximum strength and the parameters of the change of direction (Keiner et al., 2013). When soccer players added strength training to their normal training it had a positive effect on the performance in the change of direction and maximum strength in the front and back squat relative to body weight (Keiner et al., 2013).

The athletes body composition are also of great importance during in-season training. Carvalho et al. (2014) research looked at the impact of an in-season strength training program combined with plyometric exercises on vertical jump (VJ) performance, maximum strength development of lower limbs and body composition. The results showed an improvement in jumping height, greater development of maximal peak torque of the lower limbs and also a decrease in body fat percentage (Carvalho et al., 2014).

3.0 Method

This project is a part of a larger research project, a randomized controlled trial (RCT), that compares two different training programs on adaptions and physical performance measures. In order to better investigate whether meaningful physiological changes affect the external load measurements, the training groups were combined into one group and players were classified as high- vs. low-responders. Overall, this project includes 4 master theses` and other tests will therefore only be presented in brief after the outcome tests for the current thesis.

3.1 Study Design

The current study was a pre-post intervention where female handball players followed two in-season resistance exercise programs and were subsequently divided into groups of high- and low-responders based on changes in muscle size and strength. All the players did familiarization, pre-tests before they trained their program for 12 weeks followed by post-tests. Throughout the training period the participants were tracked with Catapult system in handball practice through a standardized play.

3.2 Subjects

Two female handball senior sub-elite teams took part in this study (n=34). The players where 20 ± 2.8 years, 170.1 ± 6 cm in height, and 68 ± 11.1 kg in body mass. To be included, the subjects needed to be active handball players between 16 and 35 years of age and have experience with resistance training. The participants could not participate if they had any injuries that prevented them from training and performing at a maximum capacity in the strength tests. Additionally, pregnant participants were not permitted to participate.

Matched pair of players based on playing positions in each team were randomly assigned into two groups; one performing only heavy-load resistance training (n=17), and the other performed lower-load power and plyometric training (n=17). Thereafter, the groups were pooled and high- and low responders were chosen based on whether changes in lower-body strength and fat-free mass were higher or lower than the smallest worthwhile change (SWC) and coefficient of variations (CV) of the chosen tests, respectively. Lower-body strength was measured as 1 repetition maximum (1RM) squat and relative strength in Keiser leg press as well as fat-free mass (FFM) in legs. The SWC threshold is normally set by multiplying the baseline between-participant standard deviation by 0.2 (Swinton et al., 2018). In this study we used a value of 0.3 times the between-individual standard deviation. CV (TE) is estimated by computing the difference score for each participant, followed by calculating the standard deviation of these difference scores, and finally dividing the results by 2^{-}√ (Swinton et al., 2018). The SWC for the 1RM squat was 4.1kg (CV 7.0) and 1.1 n/bodyweight for Keiser (CV 1.8) (Lindberg et al., 2022). For the FFM in legs the SWC was 510g (CV 180g). By doing this, we were able to separate the participants who had a meaningful training response. The participants were sorted out based on the SWC and CV, and then split into two groups; high-responders (those who were above SWC in fat-free mass legs, 1RM in squat or/and Keiser) (n=8) and low-responders (n=23, without keepers n=19). These groups where then compared to the results of the Catapult data.

For the analysis, we defined the pre-test for the external load data for both PL and HIE as the average of the first three measurements, and the post-tests as the average of the last three measurements. To be included in the analysis, the participants needed to have at least two measurements per pre-post to get an average value. Participants with only one measurement were excluded. Additionally, four athletes had values above the SWC and 2*CV, and they were classified as super-responders.

3.3 Ethics

All the participants were informed about the potential risks of participating in the study (appendix 4). Participation was voluntary to participate so they could leave the intervention at any given time without reason. They were informed that all results would only be used anonymously. The participants needed to give written consent before participating. All of the participants were insured through the University of Agder. The declaration of Helsinki was followed. We had applied for approval from the Local Ethical Committee at the University of

Agder (appendix 2). Approval did be sought to safeguard the privacy and to secure data storage for the Norwegian center for research data (NSD) (appendix 3).

3.4 Testing

The physical tests found place at the laboratory at the University of Agder. The participants were instructed not to perform hard training (e.g. sport-specific or endurance based) or any resistance exercises the day before or on the same day as the testing. Before the testing began, the participants rated their perceived recovery status (Laurent et al., 2011) as well as their current menstrual cycle phase. We also measured their height (seca) and body weight (seca gmbh & co. kg, Hammer Steindamm 3-25, 22089 Hamburg, Germany). All of the tests were completed in a standardized order.

There were 1-2 weeks in the start of august where the habituation period took place (week 31-32). Then, 1-2 weeks with baseline testing (week 33-34). Training did start in week 35-36 and the post-test took then take place in week 46-47.

3.4.1 Keiser leg press

Seated leg press was tested using Keiser A300 horizontal leg press dynamometer (Keiser sport, Frescno, CA, USA) which is device with pneumatic resistance. The position of the seat was adapted to each participant. The femur should be vertical, with a knee joint angle of 80-90 degrees. The participants did first a warmup and a test attempt before they entered the test. The 10-repetition test from the associated Keiser software was used where the resistance starts low and gradually increases, whereby a set point is estimated and chosen before the test by the test leader. The resistance increments between each repetition are pre-programmed based on the resistance set-point. Participants were instructed to move the pedals as quickly as possible to get the highest power. The resting periods increased gradually with increasing load until failure was reached. Failure was defined as the first resistance they were unable to extend both legs while remaining in a seated position. The results were retrieved from an associated software and the theoretical force maximum (Fmax) was extrapolated based on the force-velocity relationship. Both absolute Fmax and relative to body weight (Fmax/kg) was obtained.

3.4.2 Back squat

Squat 1 repetition maximum (1RM) was tested using a protocol from Cormie et al. (2010). We used the participant´s 1RM from the familiarization to estimate the load for both 1RM and the warmup series before the attempt during baseline. The participants did first a series of warm-up sets; 4-6 repetitions at 30% of their estimated 1RM, 3-4 repetitions at 50% of estimated 1RM, 2-3 repetitions at 70% estimated 1RM, and 1-2 repetitions at 90% estimated 1RM. Resting periods were set at 3 minutes. A series of maximal lift attempts were then performed until 1RM was obtained. The goal was to reach the 1RM in less than five attempts, separated by 5 minutes of recovery. The participants needed to reach a relative knee angle (angle between the midline of the lower leg and the midline of the thigh) so the femurs were parallel (this dept was visually monitored) otherwise the attempt was not considered successful (Cormie et al., 2010). We gave feedback to the participants about the dept of their squat. For safety reasons the test was done in a squat rack with safety arms.

3.4.3 Dual-x-ray-absorptiometry (DXA)

Legs fat-free mass (FFM) was measured in a Dual-x-ray-absorptiometry (DXA) machine (Lunar iDXA, GE, Healthcare, Madison, WI) according to standard procedures from Olympiatoppen. The device was calibrated daily. During the scan, the participants wore shorts and a t-shirt, removed all metal accessories, and refrained from wearing shoes. The scan results were proceeded using Lunar Prodigy (version 15, encore, Madison, WI 53718 USA)

3.4.4 On-court performance

To investigate the outfield players (excluding goalkeepers) on-court handball-specific performance, an accelerometer from Catapult (version 7.40, OptimEye S5) was used (inertial measurement units [IMU]). The participants received a custom-made vest they needed to use during the activity (Catapult Sports, Australia). The vest consists of small monitoring devices located on the upper back, between the shoulder blades (Luteberget & Spencer, 2017). Before the training started, the device was installed underneath their training jersey (Luteberget, Trollerud, et al., 2018). The handball players used the vests during handball practice 8 times, once per week from weeks 1-2 to 10-11. All participants used the same IMU for the monitoring. After their regular handball practice, the players simulated a match playing 6 against 6 for 5 minutes, two times, with 3-5 minutes rest between. The purpose of the training drill based in the game was to simulate a match-like environment. Therefore, the rules remained identical to those of official matches (Luteberget, Trollerud, et al., 2018).

PlayerLoad

To measure the intensity for each player during this play, PlayerLoad relative to playing time and high-intensity events (HIE) was used. PlayerLoad is a measurement based on accelerometer of external physical loading of team-sport athletes (Luteberget & Spencer, 2017). PlayerLoad is defined as "instantaneous rate of change of acceleration divided by a scaling factor and is expressed as the square root of the sum of the squared instantaneous rate of change in acceleration in each of the three vectors (x,y, and z axes) divided by 100 Hz" (Luteberget & Spencer, 2017). The equation for calculating PlayerLoad is described as

$$\text{PlayerLoad} = \sqrt{\frac{\left(a_{y1} - a_{y-1}\right)^2 + \left(a_{x1} - a_{x-1}\right)^2 + \left(a_{z1} - a_{z-1}\right)^2}{100}}$$

where a_y = forward acceleration, a_x = sideways acceleration, and a_z = vertical acceleration (Wik et al., 2017).

High intensity events

To classify events as either acceleration, deceleration or change of direction, the direction of the applied force is calculated for each event (Luteberget & Spencer, 2017). Any event with a value >2.5 m * s-1 was classified as either an acceleration, deceleration or COD, and the sum of all these events is referred to as HIEs (Luteberget, Trollerud, et al., 2018; Luteberget & Spencer, 2017).

The data obtained from the IMUs were transferred to Catapult Sprint through a USB interface and subsequently exported to Microsoft Excel (version 16.66.1) (Wik et al., 2017). The data were then analyzed with the following software (version 2.5.0, Openfield, Catapult Innovations, Melbourne, Australia). In this software we manually tracked interchanges to ensure that only time spent on the field was included in the analysis. To reduce the variability in reporting absolute values caused by variations in match length and individual on-field time, all variables of interest were normalized per minute of on-field time (Luteberget & Spencer, 2017). Using the Catapult Sprint Software, PlayerLoad, accelerations, decelerations and COD were extracted from the raw files (Luteberget & Spencer, 2017).

Other tests that are also included in the project: muscle biopsy, muscle size and muscle architecture, body composition and bone mineral density, upper- and lower-body power, sprint, throwing velocity, changes in direction ability, vertical jump, isometric strength and electromyography.

3.5 Training

Over the 12-week training period, each group performed strength or power-plyometric training twice a week including one supervised session, in addition to their regular handball training. Both groups received individual adjustments according to the given guidelines. The high-load group did 2-6 sets for each muscle group at 80-85% of their one repetition maximum (1 repetition in reserve (RIR)), whereas the power-plyometric group performed 75-90 bodyweight jumps and 2-4 sets of 3-6 power exercises at ≤50% of their one repetition maximum. After 6 weeks of training, some exercises in the programs were changed. For detailed training programs, see appendix 1.

The two first sessions for both groups were performed at a lower intensity. The strength training group had 3 repetition in reserve (RIR) and did 2 sets per exercise for the first session and 2 RIR for the second. The power training group did also performed 2 sets per exercise and did every exercise with 80% effort the first session, 90% the second, and then 100% for the following sessions.

Session A should preferably be performed the following 1-2 days after a match, and session B the days (1-3) before a match. Session A for both groups were performed together in every team on the same day every week, but the athletes could perform the workouts whenever they wanted to. These sessions were supervised, except in week 6 when session B was supervised.

3.6 Statistical analysis

For the statical analysis in this study, Stata (version 17.0, StataCorp, 4905 Lakeway Dr, College Station, TX 77845, USA) was used. The data were found to be normally distributed based on the Shapiro-Wilk test for normality with a p-value greater than 0.05 and q-q plots. Therefore, we performed t-tests (independent and paired) to determine if there were any differences within both groups and pre-post. To assess whether there was a correlation between changes in physical performance, changes in fat-free mass (FFM) in legs, and changes in external load data, Pearson correlation was used.

To see single-case differences, a Nonoverlap off All Pairs (NAP) calculator was used (*NAP Calculator | Single Case Research*, u.å.). NAP refers to a newly introduced utilization of a well-known effect size that has been recognized in different variations (Parker & Vannest, 2009). Interpretation of effect sizes corresponding to NAP values are interpreted according to previous recommendations: 0-.65 = week effects, .66-.92 = moderate effects, .93-.1.0 = large or strong effects (Parker & Vannest, 2009).

4.0 Methodological discussion

4.1 Main study design

The overall project was conducted as a randomized controlled trial (RCT) that compares two different training programs on physical performance measures. RCTs are considered the gold standard for providing high-quality evidence because observational data is prone to bias (Bhide et al., 2018). One reason for this is the use of randomization, where participants are unaware of their group allocation, also known as concealment (Hariton & Locascio, 2018). This method enables any differences in outcomes to be attributed to the study intervention, which is not possible with any other study design (Hariton & Locascio, 2018). To further reduce bias, RCTs are often blinded, so the participants are unaware of the treatment they are receiving (Hariton & Locascio, 2018). However, in this study, blinding was not possible due to the nature of the training programs, every participant was aware of their assigned group.

RCTs are often associated with high costs in terms of both money and time investments (Hariton & Locascio, 2018). RCTs may also suffer from issues related to generalizability as the participants in the study may not accurately represent the larger population. Dropouts may occur, leading to fewer participants and reduced statistical power. Therefore, despite their advantages, RCTs also have their drawbacks (Hariton & Locascio, 2018).

In our main study, we did not have a control group (non-training group). While it would have been interesting to compare the results to such a group to determine the effects of the strength- and power-training programs per se, it was not considered ethically possible during the in-season period. Athletes needed to maintain their strength and fitness to perform well in matches, so it would not have been optimal for them to completely stop training. To address this issue, one potential approach could be to have a control group continue with their regular training regimen, but then we had to have a larger number of participants.

4.2 Pre-post study and classifications of high- and low-responders

The design of the current study involves an experimental study design where two new groups were created, high- and low-responders, based on the participants performance in leg extensor strength and fat-free mass using Smallest Worthwhile Change (SWC). SWC is defined as "A reference value selected by a practitioner or researcher to indicate a value beyond which a change in true score is likely to be meaningful in practice" (Swinton et al., 2018). By using SWC, it enhance the ability to interpret practical and statistical significance. Rather than using zero as a baseline, researchers may find it more useful to identify the minimum amount of change that is practically meaningful by setting a threshold value above zero. This threshold value is commonly known as the Smallest Worthwhile Change (SWC), and it is usually determined subjectively by practitioners based on their experience with similar interventions and what they consider to be relevant. Alternatively, objective measures such as effect size calculations, such as Cohen´s D, can be used to determine the SWC. A value of 0.2 times the between-individual standard deviation at baseline is often considered to be an appropriate SWC (Swinton et al., 2018). To ensure a meaningful increase in leg extensor strength and FFM values among the participants, stricter requirements were imposed on the high-responders group. Therefore, we went from "a small effect size" and used a value of 0.3 times the between-individual standard deviation. However, this resulted in a smaller sample size (n=8), and even fewer (n=7) during the analysis including this group.

Since all observed measurements contains errors, it is important to estimate the potential magnitude of such errors and quantify the uncertainty associated with an individual measurement (Swinton et al., 2018). The term "test-retest reliability" refers to the degree of consistency observed in measurements when they are repeated (Lindberg et al., 2022). When analyzing the data of high-performing athletes, ensuring interday test-retest reliability is especially crucial, as even slight variations in performance are anticipated. The most used method for measuring within-subject variation is the typical error expressed in absolute (TE) or relative terms (TE%, also known as the coefficient of variation). The TE% should be as low as possible, or at least lower than the magnitude of true changes in performance (Lindberg et al., 2022). The signal-to-noise ratio can be determined by comparing the SWC to the TE (SWC:TE), and this should ideally be greater than one. In a group test-retest design, the TE estimate is derived by computing the difference score for each participant, followed by calculating the standard deviation of these difference scores, and finally dividing the results by 2-√ (Swinton et al., 2018). Therefore, the typical errors are presented below for every test used in this project.

4.3 Study sample

To have more confidence that the conclusions generated from the experiment can be applied to the broader population with confidence, one would always prefer to conduct a study that has an adequate sample size and power (Bhide et al., 2018). If the sample size is too small, it is possible that the study may fail to answer its research question and increases the risk of inability to demonstrate a significant difference, even if such an effect exists (type 2 error) (Bhide et al., 2018; Zhong, 2009). The conventionally accepted level of type 1 error is 0.05, which indicated that a difference is considered “significant” if the likelihood of it occurring is less than 0.05. The well-known p-value represents this probability, with a value of 0.05 suggesting that there is a 1 in 20 chance of finding a difference even when none exists (Bhide et al., 2018). However, it will be more difficult to carry out studies with large sample sizes, in particular athletes, and it requires more resources (Zhong, 2009).

To test a hypothesis, the required sample size is governed by the effect size (Bhide et al., 2018). The required sample size decreases with larger effect sizes, given a certain power and significance level, and increases with smaller effect sizes, and vice versa (Beck, 2013). Manipulating the sample size is the only option for researchers since the significance level is predetermined and the effect size is dependent on the efficacy of the treatment. It is essential to determine what effect size is meaningful (Beck, 2013).

In this study we had two training groups, and if the groups are well-separated from each other and the within-group variability is low, fewer participants are needed in each group to demonstrate that the difference is unlikely to be due to chance and more likely to be a result of the intervention (Bhide et al., 2018).

Because of the SWC, CV and the requirements for the external load values, the participants in both high- and low responders became lower for the analyses (n=7, and n=13). However, due to the strict requirements, we could state with greater certainty whether the results from the physical tests have an impact on the external load variables or not.

4.4 Training

This study implemented a 12-week intervention period. Previous research conducted during the handball season on strength training for handball players has typically lasted between 8-12 weeks and has demonstrated improvements in physical performance (Hammami et al., 2019; Hermassi et al., 2011; Hermassi, Schwesig, et al., 2019). The participants performed two weekly training sessions, in addition to their regular handball training, with one of the sessions being supervised. The presence of supervision may have influenced their level of effort during the workouts and could potentially have increased training quality and thus strength and FFM adaptions.

Both training programs were designed to improve performance through enough stimuli. According to research, it appears that plyometric and resistance training interventions can result in comparable levels of whole muscle hypertrophy for lower extremity muscle groups in untrained and recreationally trained individuals, within intervention periods lasting ≤ 12 weeks (Grgic et al., 2021). It is important to acknowledge the difficulties in comparing the effects of two different modes of exercise on a specific outcome, as training intensity, effort, and total volume of work may not be equivalent. From a training intensity perspective, one repetition of squat my not produce the same level of stress on the body as one repetition of the squat jump (Grgic et al., 2021). In our study, we attempted to equate training volume by matching the total workload in the strength training group with the total workload in the power/plyometric training group. The high-load strength group completed 6-8 heavy sets targeting the quads and glutes in session A, followed by 4 sets in session B. As for the power/plyometric group, they completed three times as many sets in both sessions.

To ensure that the exercises were subjected to the indented load, we utilized reps in reserve (RIR) and VmaxPro. The RIR scale, ranging from 1 to 10, refers to the number of reps that could still be performed at the end of a set (Helms et al., 2016). The main advantage for using the RIR method is that is attempts to regulate the level of exertion, rather than the quantity of reps executed within a set (Halperin et al., 2022). However, in order for RIR strategies to be considered effective, trainers must exhibit an acceptable level of precision when predicting proximity to task failure and make sure that it is properly implemented (Halperin et al., 2022; Helms et al., 2016). Findings from various studies indicate that, on average, individuals tend to underestimate their proximity to task failure by roughly one repetition (Halperin et al., 2022). The accuracy of predictions increased when the participants were closer to the point of task failure, with fewer repetitions completed per set, as well as in later sets (Halperin et al., 2022). To ensure that the RIR was as accurate as possible, we used VmaxPro (*Enode Pro – Next Level Strength Training - Enode Pro*, u.å.).

The VmaxPro is a wireless IMU that can be purchased commercially and includes a three-axis accelerometer, gyroscope and magnetometer (Held et al., 2021). To collect data, the VmaxPro integrates vertical acceleration with respect to time at a sampling rate of 1000 Hz and transmits it via Bluetooth to a smartphone. The device only has to be placed on the barbell with a built-in magnet, and therefore increase the feasibility in daily training compared with linear position transducers. Controlling resistance training through movement velocity is possible because of the strong correlation between the velocity of movement and the relative load of the one repetition maximum (%RM) (Held et al., 2021). One of the most precise methods for estimating relative load during resistance training is suggested to be monitoring training load velocity (Balsalobre-Fernández et al., 2018). Findings from Held et al., (2021) suggest that velocity-based training provides a robust and highly sensitive method to determine relevant strength training indicators. The VmaxPro sensor, demonstrated good to excellent validity, with moderately low limits of agreements for the average concentric velocity during squat (Held et al., 2021). In our study, we required participants in the strength training group to have a velocity <0.4 m/s during the last repetition in the squat exercise (1RIR) (Izquierdo et al., 2006). For the power/plyometric training group, the lowest velocity loss possible was encouraged during the sets of jump squats, and a velocity >1 m/s was set as the standard for all repetitions during the push-jerk exercise.

4.5 Measurements

4.5.1 Keiser leg press

Keiser is a pneumatic resistance-based leg press which utilizing air pressure as a means of resistance (Lindberg et al., 2021). All over the world Keiser is a commercial device available in many sports and research facilities. The resistance from the pneumatic leg press is minimally influenced by inertia and bodyweight compared to weight-based exercises. This comes with several advantages; the resistance is not influenced by acceleration making it achievable to assess extremely low resistance, and it is not necessary to decelerate a large mass when performing maximal attempts. Resultingly, it is possible to measure attempts close to Fmax and also closer to Vmax.

Research by Lindberg er al. (2021) showed that the Keiser leg press device obtained valid measurements over a wide range of force and velocities, also across different devices (Lindberg et al., 2021). To measure force, velocity and power, the Keiser leg press devices can be used interchangeably within a range of ±5%. Typical error for relative Fmax in Keiser is 4.8% (Lindberg et al., 2022).

The Keiser leg press has some weaknesses; the device can underestimate force and power measurements when performing repetitions with maximal effort at low resistance. When performing single repetitions with maximal effort (up to 30%), moderate to large bias can occur in the measurements of power (Lindberg et al., 2021).

4.5.2 Back squat

A protocol from Cormie et al. (2010) was used for the 1 repetition maximum (1RM) back squat (Cormie et al., 2010). The assessment of maximal dynamic strength has often used this protocol in prior literature (Cormie et al., 2010). Regardless of training experience of familiarity, the TE% for the 1RM squat has been documented to vary between 0.3% and 12.2% (Lindberg et al., 2022).

It is possible that the squat dept may have been slightly different during post-testing, which could have influenced the obtained 1RM values (Cormie et al., 2010). As the depth was visually monitored, it is conceivable that there could be some degree of variations.

4.5.3 Dual-x-ray-absorptiometry (DXA)

In recent years, Dual-x-ray-absorptiometry (DXA) has become the gold standard for analyzing body composition, offering precise and repeatable measurements of parameters such as body fat percentage, body fat mass, lean body mass, leg fat percentage, leg fat mass, lean leg mass, torso fat percentage, torso fat mass and lean torso mass (Kale & Akdoğan, 2020). In this project, the DXA-machine used (Lunar iDXA, GE, Healthcare, Madison, WI), was checked for reliability (n=11), and it was found a TE% of 1.1% on FFM legs.

4.5.4 On-court performance

The quantification of both high-intensity, sport-specific actions and external load has become more detailed after the introduction of inertial measurement units (IMUs) with accelerometers, gyroscopes, and magnetometers (Wik et al., 2017). Isometric actions are present in team handball, and the IMU unit will not be able to detect these actions. Thus, using this method, the intensity of team handball players may be somewhat underestimated (Wik et al., 2017).

Measuring physical performance based on changes in acceleration, with the aim of capturing non-running-based work, would not be captured as precisely using traditional time-motion analysis, and therefore PlayerLoad has been developed (Wik et al., 2017). PlayerLoad has been shown to be a reliable and useful measure of player activity in team sports, despite the fact that no published study has validated the algorithm for team handball match play (Wik et al., 2017).

In team handball training sessions using the OptimEye S5, unpublished data from Wik et al. (2017) has demonstrated a CV for PlayerLoadTM *min-1 of 0.9% (90% confidence limits (CL) = 0.8-1.0%) (Wik et al., 2017).

Insufficient validity of a measurement system can lead to harmful outcomes for athletes, such as incorrect training recommendations, reduced performance, and increased health risk. Validation of position system should be carried out in the typical conditions in which it is used (Luteberget, Spencer, et al., 2018). In this study CV (TE%) for PlayerLoad was 100.4% and for HIE 70.2%.

When using IMU´s to measure performance, it is important to consider various factors that can affect the accuracy of the measurements. Achieving precise standardization can be challenging. For instance, the 6 vs 6 drill was always conducted at the end of the handball session. Depending on the intensity of the training, this could impact the measurements. We tried to maintain consistency by conducting the measurements on the same day for each handball team every week, but some weeks it was not possible. However, the fatigue of the athletes could vary depending on how long since they had done the strength training.

We conducted the measurements in the handball teams regular training hall. We only observed the training and match play without actively participating to ensure that the game played out as usual. The performance of athletes can vary due to differences in the nature of the game from one session to another.

4.6 Statistical analysis

T-tests

In this study, both independent- and paired-sample t-test was used to see differences within both groups and pre-post intervention. When examining relationship between independent and dependent variables, an independent sample-test can be used (Atwater et al., 2022). The purpose of a paired-sample t-test is to compare the mean of a single group that has been examined at two different points in time (Ross & Willson, 2017). As the correlation between the groups becomes larger, the paired-sample t-test has more power to detect a difference between the means of two groups (Sunderland et al., 2003). Compared to the paired-sample t-test, the independent-sample t-test has twice the degrees of freedom, and in general, an increase in degrees of freedom is accompanied by an increase in power (Sunderland et al., 2003).

Pearson correlation

Pearson´s correlation coefficient (r) is one of the most frequently used statistics to test the degree of correlation between two or more variables (Armstrong, 2019). The correlation determine whether there exist a statistically significant positive or negative relationship between two or more variables, to quantity the level of statistical significance that can be attributed to a correlation, and establish the percentage of the variation in the dependent (Y) variable that can be attributed to or explained by the independent (X) variable. In this study, the correlation was used to see if there was a correlation between % average change in composite score and % change in external load data. However, a significant r value does not necessarily indicate a causal relationship between two variables (Armstrong, 2019).

Nonoverlap of All Pairs (NAP)

In single-case research, NAP refers to the overlap in index data between different phases (Parker & Vannest, 2009). The NAP is calculated by dividing the total number of comparisons showing no overlap by the total number of comparisons. The extent of non-overlap between the baseline phase (A) and the intervention phase (B) serves a reliable indicator of the amount of performance change (Parker & Vannest, 2009).

Despite that parametric analysis (t-tests) being considered to have higher statistical power, NAP provides certain advantaged over them (Parker & Vannest, 2009). Single-case research offers unique advantages in documenting progress and assessing the efficacy of interventions for individuals and small groups with atypical characteristics (Parker & Vannest, 2009). In this study the NAP calculator was used on four participants in the high-responders group where the physical performance were larger than SWC + 2*CV in 2 of the 3 tests (super-responders). This was to see if there were any differences in external load data pre-post on an individual level.

Overlap-based index offer enhanced interpretability and require minimal assumptions about the data (Parker & Vannest, 2009). NAP demonstrated strong performance in terms of accuracy, calculation efficiency, and external validation compared to both R^2 and visual analyst judgements. Additionally, the implementation of NAP eliminated the risk of human error. However, some researches would hesitant to apply NAP to single-subject time series data for independent groups due to concerns about the lack of independence within the time series data. Additionally, NAP my not perform as well as other tests in terms of precision, which is important in small datasets (Parker & Vannest, 2009).

5.0 Main strength and limitations

Due to strict requirements for the SWC and CV, we could state with greater certainty whether the results from the physical tests have an impact on the external load variables or not. This strengthen the findings of this study, further supported by the good reliability of the testing protocol. The supervision of one weekly session may have led to a higher participant completion rate.

The main limitations in this study is the big variations in the external load data. This makes it harder to make conclusions from the results, due to the multiple mechanisms that could have influenced the outcomes.

6.0 References

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PART 2

RESEARCH PAPER

Effect of in-season resistance exercise-induced changes in muscle size and strength on match-related handball external load measurements

The following paper is written according to the standard of the journal:

Scandinavian Journal of Medicine & Science in Sports

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Abstract

Purpose: this study aimed to investigate if in-season resistance training-induced changes in maximal lower-body strength and fat-free mass could influence changes in match-related handball external load measurements. **Method:** twenty female handball players from two senior sub-elite teams (19.6 ± 2.4 years, 168.7 ± 6.3 cm in height, and 69.3 ± 13.3 kg body mass) completed a 12-week in-season strength- and power training program. Players were then divided into high- and low-responders based on changes in squat 1 repetition maximum, leg press force, and leg fat-free mass (FFM). Improvements in FFM and one of the two strength tests that exceeded the smallest worthwhile change and coefficient of variation were defined as high-responders. Weekly standardized match-related handball external load was measured as Player Load and high intensity events (HIE) with inertial measurement units. Changes in external load between high- and low-responders were analyzed with t-tests (three first- vs. three last measurements), single-cases with Nonoverlap of all Pairs (NAP) as well as correlations between changes in external load and the combined 1RM, force and FFM (composite change score). **Results**: There were no significant differences between or within responders in change in external load ($p>0.05$) or any correlations between changes in the composite score and external load ($r= -0.04- -0.20$, all $p>0.05$). The NAP analyses revealed no significant differences on an individual level (effect sizes: PlayerLoad: 0-0.66, HIE: 0.25-0.61). **Conclusion:** These findings indicate that changes in maximal leg extensor strength and fat-free mass do not influence match-related in-season handball PlayerLoad and HIE measurements.

Key-words: resistance training, handball, external load, PlayerLoad, high intensity events

1 Introduction

Team handball is an Olympic sport played by people worldwide and played professionally in many European countries. [1,2] Handball play is characterized by repeated jumps, sprints, changes of direction, body contact at high speed, and specific technical movement patterns occurring in response to the varying tactical situations of the game. [2,3] The sport thus require different physical attributes, such as strength, explosive power, speed and endurance. [2,4]

Body composition is well known to be relevant to performance. [5] It is ideal for successful handball players to have a high fat-free body mass and less body fat. [6] Research have shown that players that have a higher skill level are taller and have a higher fat-free mass, and elite players are heavier, have higher fat-free mass and higher body mass than amateur players. [2,7] Therefore, a high body mass and specifically high fat-free mass is advantageous in handball, and somatic traits can be one of the predictors of success in this sport.[7,8]

Essential components of overall training includes strength and power, and therefore handball players often train these trains through the season.[1] To give the whole handball team an advantage to sustain the forceful muscle contractions required during some game actions, strength and power exercises should be emphasized in the conditioning routine.[2] For success in elite handball, maximal strength and power are considered as major determinants and many studies have highlighted the major role of the lower limb strength and power.[9] Both strength- and power-training should be monitored to make sure that the athletes maintain a high level of strength throughout the competitive season.[9]

Though continuous observations of the players action during match-play, time-motion analysis enables researchers and handball coaches to gain insight into the physical demands imposed on their players.[7] Local positioning systems (LPs) with an inertial measurement unit (IMU) have been developed in the past decade.[10] When examining the physical demands of team sport, athletes total effort is often assessed by measuring their overall workload, and this workload is determined by both the intensity and duration of the tasks performed and is commonly quantified using parameters like total distance covered and distance covered in different speed zones.[10] Using variables such as number of sprints, accelerations or distance covered above a predefined speed threshold, high intensity events (HIE) and Player Load (PL) can be reported.[10] To improve individualization of physical preparation, it is necessary to get better knowledge of on-court demands of handball players.[11] Specific to team handball, there is a lack of research.[12] There is also a need for more research on whether changes in physical demands can influence these parameters.

Athletes develop muscle size, muscular strength and power during the preparatory period, and the task is to maintain or even improve these levels during the competitive period.[13] In elite team handball, it has not been very clear how these parameters change during the season.[4,14] The purpose of this study is therefore to investigate if in-season resistance training-induced changes in maximal lower-body strength and fat-free mass could influence changes in match-related handball external load measurements.

2 Materials and methods

Participants

Two female handball senior-sub elite teams took part in this study. A total of 34 participated (20 ± 2.8 years, 170.1 ± 6 cm in height, and 68 ± 11.1 kg in body mass.). To be included, the subjects needed to be active handball players between 16 and 35 years of age and have experience with resistance training. The participants could not participate if they had any injuries that prevented them from training and performing at a maximum capacity in the strength tests. Additionally, pregnant participants were not permitted to participate.

Matched pair of players based on playing positions in each team were randomly assigned into two groups; one performing only heavy-load resistance training (n=17), and the other performed lower-load power and plyometric training (n=17). Thereafter, the groups were pooled and high- and low responders were chosen based on whether changes in lower-body strength and fat-free mass were higher or lower than the smallest worthwhile change (SWC) and coefficient of variations (CV) of the chosen tests, respectively. Lower-body strength was measured as 1 repetition maximum (1RM) squat and relative strength in Keiser leg press as well as fat-free mass (FFM) in legs. We used a value of 0.3 times the between-individual standard deviation for the SWC. By doing this, we were able to separate the participants who had a meaningful training response. The participants were sorted out based on the SWC and CV, and then split into two groups; high-responders (those who were above SWC in fat-free mass legs, 1RM in squat or/and Keiser) (n=8) and low-responders (n=23, without keepers n=19). These groups where then compared to the results of the Catapult data.

For the analysis, we defined the pre-test for the external load data for both PL and HIE as the average of the first three measurements, and the post-tests as the average of the last three measurements. To be included in the analysis, the participants needed to have at least two measurements per pre-post to get an average value. Participants with only one measurement were excluded. Additionally, four athletes had values above the SWC and 2*CV, and they were classified as super-responders.

All the participants were informed about the potential risks of participating in the study. Participation was voluntary to participate so they could leave the intervention at any given time without reason. They were informed that all results would only be used anonymously and they needed to give written consent before participating.

Study design

The current study was a pre-post intervention where female handball players followed two in-season resistance exercise programs and were subsequently divided into groups of high- and low-responders based on changes in muscle size and strength. All the players did familiarization, pre-tests, before they trained their program for 12 weeks followed by post-tests. Throughout the training period the participants were tracked with Catapult system in handball practice through a standardized play.

Over the 12-week training period, each group performed strength or power-plyometric training twice a week including one supervised session, in addition to their regular handball training. Both groups received individual adjustments according to the given guidelines. The high-load group did 2-6 sets for each muscle group at 80-85% of their one repetition maximum (1 repetition in reserve (RIR)), whereas the power-plyometric group performed 75-90 bodyweight jumps and 2-4 sets of 3-6 power exercises at ≤50% of their one repetition maximum. After 6 weeks of training, some exercises in the programs were changed.

Session A should preferably be performed the following 1-2 days after a match, and session B the days (1-3) before a match. Session A for both groups were performed together in every team on the same day every week, but the athletes could perform the workouts whenever they wanted to. These sessions were supervised, except in week 6 when session B was supervised.

Testing procedures

Keiser leg press

Seated leg press was tested using Keiser A300 horizontal leg press dynamometer (Keiser sport, Frescno, CA, USA) which is device with pneumatic resistance. The position of the seat was adapted to each participant. The femur should be vertical, with a knee joint angle of 80-90 degrees. The participants did first a warmup and a test attempt before they entered the test. The 10-repetition test from the associated Keiser software was used where the resistance starts low and gradually increases, whereby a set point is estimated and chosen before the test by the test leader. The resistance increments between each repetition are pre-programmed based on the resistance set-point. Participants were instructed to move the pedals as quickly as possible to get the highest power. The resting periods increased gradually with increasing load until failure was reached. Failure was defined as the first resistance they were unable to extend both legs while remaining in a seated position. The results were retrieved from an associated software and the theoretical force maximum (Fmax) was extrapolated based on the force-velocity relationship. Both absolute Fmax and relative to body weight (Fmax/kg) was obtained.

Back squat

Squat 1 repetition maximum (1RM) was tested using a protocol from Cormie et al. (2010).[15] We used the participant´s 1RM from the familiarization to estimate the load for both 1RM and the warmup series before the attempt during baseline. The participants did first a series of warm-up sets; 4-6 repetitions at 30% of their estimated 1RM, 3-4 repetitions at 50% of estimated 1RM, 2-3 repetitions at 70% estimated 1RM, and 1-2 repetitions at 90% estimated 1RM. Resting periods were set at 3 minutes. A series of maximal lift attempts were then performed until 1RM was obtained. The goal was to reach the 1RM in less than five attempts, separated by 5 minutes of recovery. The participants needed to reach a relative knee angle (angle between the midline of the lower leg and the midline of the thigh) so the femurs were parallel (this dept was visually monitored) otherwise the attempt was not considered successful. [15] We gave feedback to the participants about the dept of their squat. For safety reasons the test was done in a squat rack with safety arms.

Dual-x-ray-absorptiometry (DXA)

Legs fat-free mass (FFM) was measured in a Dual-x-ray-absorptiometry (DXA) machine (Lunar iDXA, GE, Healthcare, Madison, WI) according to standard procedures from

Olympiatoppen. The device was calibrated daily. During the scan, the participants wore shorts and a t-shirt, removed all metal accessories, and refrained from wearing shoes. The scan results were proceeded using Lunar Prodigy (version 15, encore, Madison, WI 53718 USA)

On-court performance

To investigate the outfield players (excluding goalkeepers) on-court handball-specific performance, an accelerometer from Catapult (version 7.40, OptimEye S5) was used (inertial measurement units [IMU]). The participants received a custom-made vest they needed to use during the activity (Catapult Sports, Australia). The vest consists of small monitoring devices located on the upper back, between the shoulder blades. [12] Before the training started, the device was installed underneath their training jersey.[16] The handball players used the vests during handball practice 8 times, once per week from weeks 1-2 to 10-11. All participants used the same IMU for the monitoring. After their regular handball practice, the players simulated a match playing 6 against 6 for 5 minutes, two times, with 3-5 minutes rest between. The purpose of the training drill based in the game was to simulate a match-like environment. Therefore, the rules remained identical to those of official matches. [16]

Playerload

To measure the intensity for each player during this play, PlayerLoad relative to playing time and high-intensity events (HIE) was used. [17] PlayerLoad is a measurement based on accelerometer of external physical loading of team-sport athletes. [12] PlayerLoad is defined as "instantaneous rate of change of acceleration divided by a scaling factor and is expressed as the square root of the sum of the squared instantaneous rate of change in acceleration in each of the three vectors (x,y, and z axes) divided by 100 Hz".[12] The equation for calculating PlayerLoad is described as

$$\text{PlayerLoad} = \sqrt{\frac{\left(a_{y1} - a_{y-1}\right)^2 + \left(a_{x1} - a_{x-1}\right)^2 + \left(a_{z1} - a_{z-1}\right)^2}{100}}$$

where a_y = forward acceleration, a_x = sideways acceleration, and a_z = vertical acceleration. [17]

High intensity events

To classify events as either acceleration, deceleration or change of direction, the direction of the applied force is calculated for each event. [12] Any event with a value >2.5 m * s-1 was classified as either an acceleration, deceleration or change of direction (COD), and the sum of all these events is referred to as HIEs.[12,16]

The data obtained from the IMUs were transferred to Catapult Sprint through a USB interface and subsequently exported to Microsoft Excel (Microsoft Corp, Redmond, WA, USA?).[17] The data were then analyzed with the following software (version 2.5.0, Openfield, Catapult Innovations, Melbourne, Australia). In this software we manually tracked interchanges to ensure that only time spent on the field was included in the analysis. To reduce the variability in reporting absolute values caused by variations in match length and individual on-field time, all variables of interest were normalized per minute of on-field time.[12] Using the Catapult Sprint Software, PlayerLoad, accelerations, decelerations and COD were extracted from the raw files.[12]

3 Statistical analysis

For the statical analysis in this study, Stata (StataCorp, 4905 Lakeway Dr, College Station, TX 77845, USA) was used. The data were found to be normally distributed based on the Shapiro-Wilk test for normality with a p-value greater than 0.05 and q-q plots. Therefore, we performed t-tests (independent and paired) to determine if there were any differences within both groups and pre-post. To assess whether there was a correlation between changes in physical performance, changes in fat-free mass (FFM) in legs, and changes in external load data, Pearson correlation was used. To see single-case differences, a Nonoverlap off All Pairs (NAP) calculator was used.[18]

4 Results

31 of the 34 female handball players completed the study. The dropouts were due to injuries (n=2) or not following the training program (n=1). Keepers were excluded (n=2) as well as one participant whose data was not valid for high intensity events (HIE) (included in analysis with Player Load (PL)). In the high-responders group, one participant was excluded for not having enough measurement, as well as 10 in low-responders. Physical characteristics are presented in Table 1. Player Load and HIE throughout the 8 measurements are presented in Figure 1. The high-responders physical performance and external load are presented in Table

2. Four of the high-responders are super-responders and their individual Nonoverlap off All Pairs (NAP) effects in PL and HIE are presented in Figure 2. Pearson correlation between changes in physical performance and external load are presented in Figure 3. Average % change in composite score for high-responders were 10.7%, and 5.1% for low-responders (Table 2 and figure 3).

TABLE 1: physical characteristics of the participants

Characteristics	High-responders	Low-responders
Sample size (n)	7	13
Age	20.7 ± 1.7	19 ± 2.6
Height (cm)	168,9 ± 9.2	168.5 ± 4.5
Weight (kg)	74 ± 20	66.7 ± 7.7

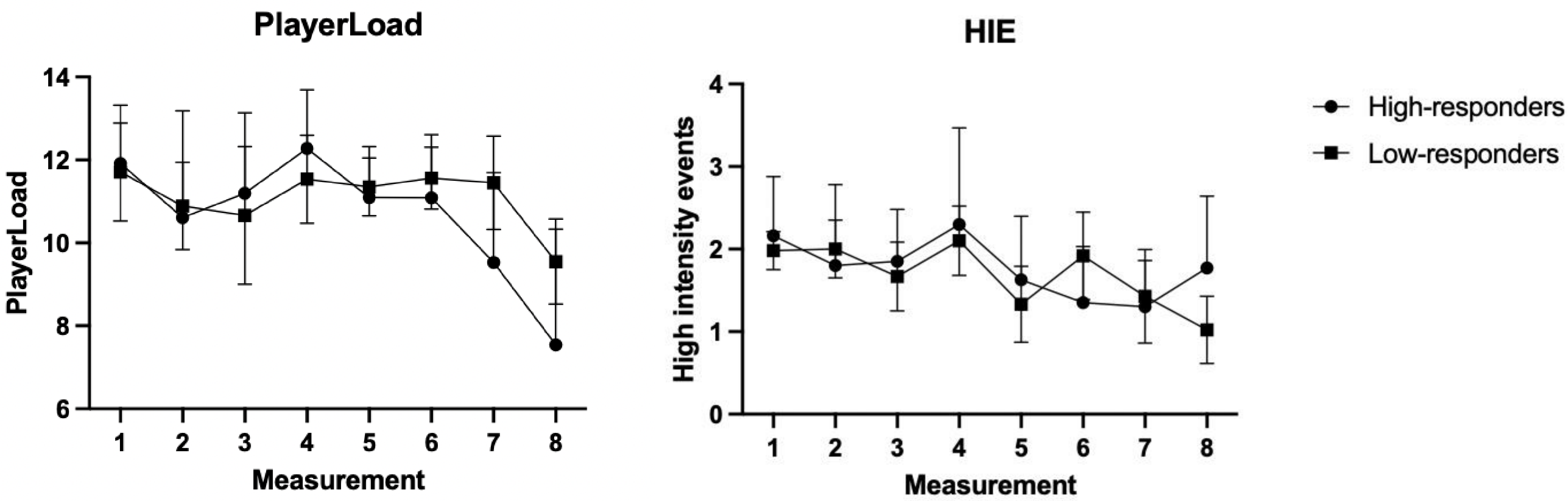


FIGURE 1: PlayerLoad and High Intensity Events per minute for both high- and low-responders for the 8 measurements with 95% CI.

There were no significant changes in pre-tests between high- and low-responders for both PL (p=0.904) and HIE (p=0.891). No significant changes from pre (measurement 1,2,3) to post (measurement 6,7,8) between high- and low-responders in PL (p=0.569) and HIE (p=0.388) were observed. There were no significant changes in high-responders from pre- to post-test in PL and HIE (-10%, p=0.128 and -13%, p=0.104, respectively) nor in low-responders (-17%, p=0.349 and -3%, p=0.460, respectively, table 2). Figure 1 shows external loads values through the intervention (8 measurements) for high- and low-responders.

TABLE 2: physical performance and external load for high-responders.

	Legs fat-free mass kg	**1RM Squat** kg	**Keiser Relative (n/kg)**	**Player-Load** /min	**HIE**/min	**Acc/min** (>2.5)	**Dec/min** (>2.5)	**COD/min** (>2.5)
*Pre-test**				*Pre-test**				
Player 10	13.9	72.5	30.9	11.63	0.8	1.17	1.00	1.83
Player 25	18.9	70	20.9	9.03	2.86	2.83	3.67	7.83
Player 2	22.1	95	25.9	7.56	1.63	0.50	2.00	6.67
Player 9	13.9	52.5	32.6	10.93	1.8	2.75	1.17	0.50
Player 18	17.3	95	25.9	11.28	2.5	2.25	2.75	7.50
Player 30	17.8	80	24.5	13.78	3.2	2.25	3.00	10.75
Player 22	18.1	100	28.8	12.83	2.56	2.83	3.83	6.17
Player 15	15.5	75	23.07	13.81	0.7	0.67	1.33	1.50
Mean high-responders	17.19 ± 2.75	80 ± 15.98	26.57 ± 3.96	11.36 ± 2.2	2.01 ± 0.93	1.97 ± 0.94	2.34 ± 1.13	5.34 ± 3.65
Mean low-responders	16.17 ± 1.26	77.31 ± 12.31	25.35 ± 4.18	11.16 ± 2.70	1.76 ± 0.57	1.77 ± 1.12	2.84 ± 1.02	4.20 ± 1.47
Pre-post absolute change*				*Pre-post* absolute change*				
Player 10	1.1	5	5.8	-1.44	-0.2	-0.67	0	0
Player 25	1	20	1.09	-1.13	0.14	-0.5	-1.34	0.84
Player 2	0.9	15	-2.9	2.01	-1.26	0.33	-1	-2.5
Player 9	0.6	22.5	7.2	-0.74	-0.6	-1.25	0.5	2.67
Player 18	0.9	10	3.6	-3.3	-1.25	-1.75	-0.75	-3.75
Player 30	1	12.5	1.3	n/a	n/a	n/a	n/a	n/a
Player 22	1.4	7.5	1.5	-2.82	-0.4	-0.83	-1.5	-1.17
Player 15	0.6	5	3.01	-1.86	-0.04	0	-0.33	0
Mean high-responders	0.94 ± 0.18	12.19 ± 4.58	2.58 ± 2.16	-1.33 ± 1.28	-0.52 ± 0.41	-0.78 ± 0.56	-0.74 ± 0.59	-0.78 ± 2.25
Mean low-responders	0.2 ± 0.21	7.88 ± 3.37	2.06 ± 1.41	-1.46 ± 0.68	-1.26 ± 0.60	-0.13 ± 0.55	-0.46 ± 0.69	-0.21 ± 0.81

Note: n/a: missing data. The four first players are super-responders.*Pre-test: average of the three first measurements (week 1-3), *post-test: average of the three last measurements (week 6-11). HIE: high intensity events, Acc: accelerations, Dec: decelerations, COD: change of directions.

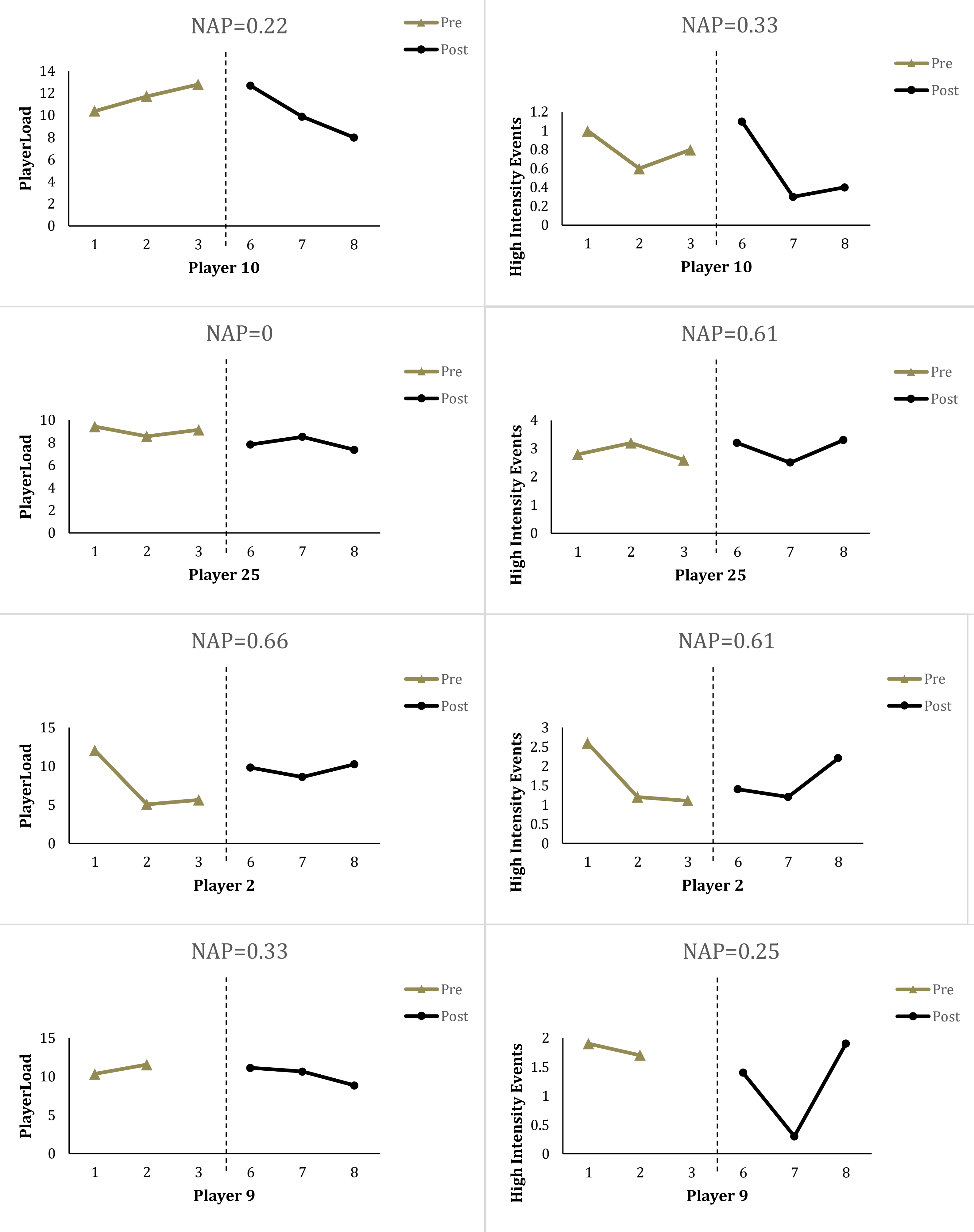
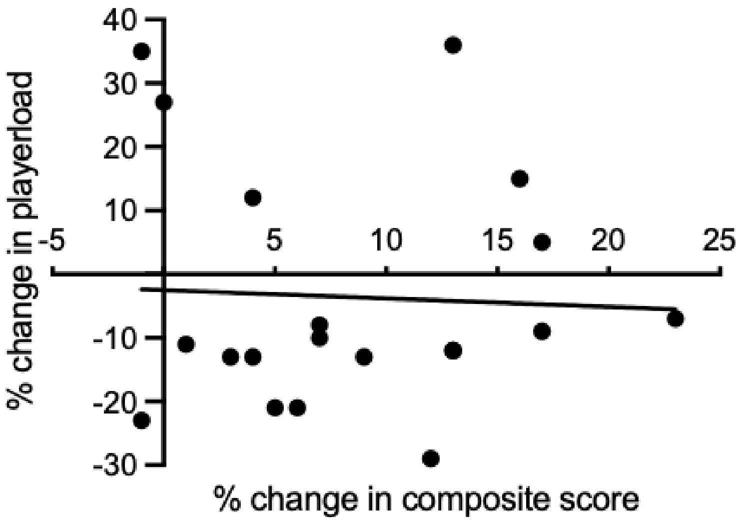


FIGURE 2: Nonoverlap off All Pairs (NAP) analysis results for PlayerLoad and high intensity events for the super-responders in the high-responder group. 1,2,3= three first measurements (pre), 6,7,8= three last measurements (post).

There was no correlation between all of the participant`s % change in composite score and % change in PL and HIE pre-post (figure 3).

P=0.84



P=0.41

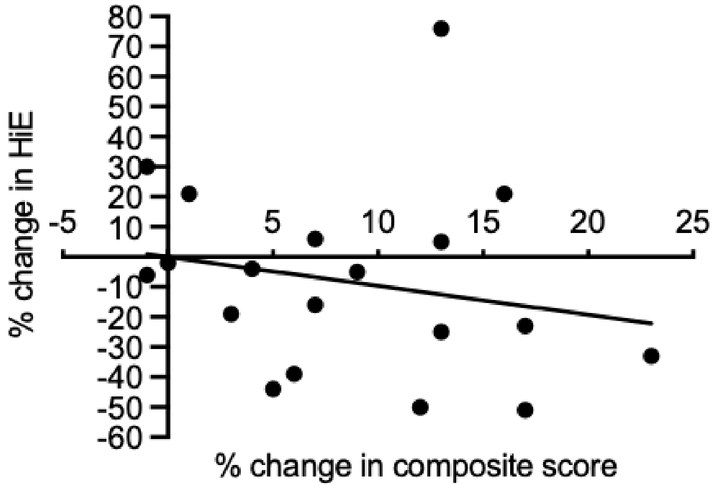
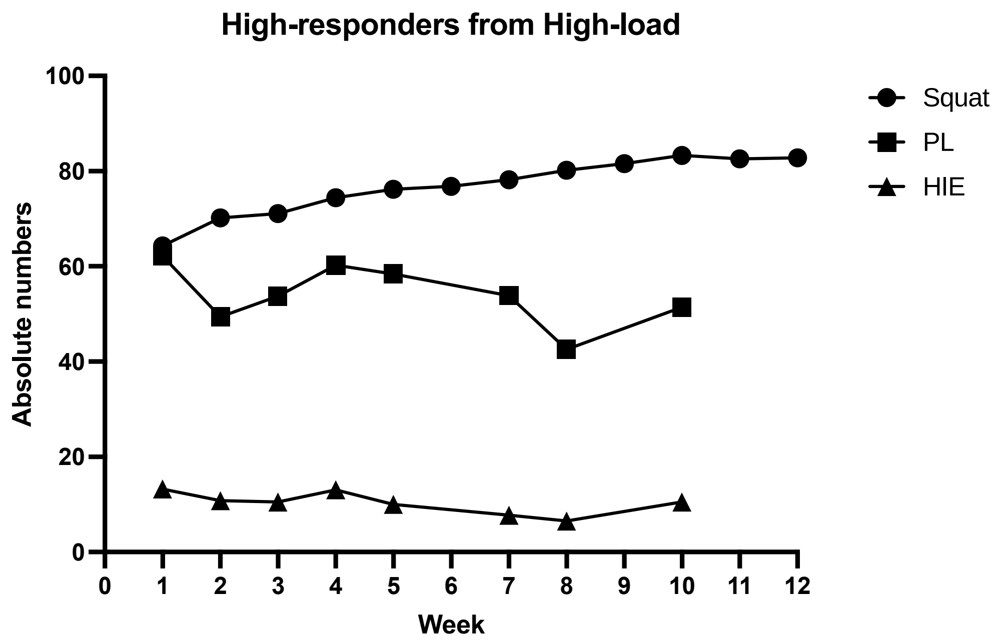


FIGURE 3: correlations between **%** average composite score and % change in PlayerLoad and high intensity events pre-post intervention (r= -0.4- -0.20).

Figure 4 presents the high- and low-responders from the high-load training group`s squat training load and external load values through the intervention.



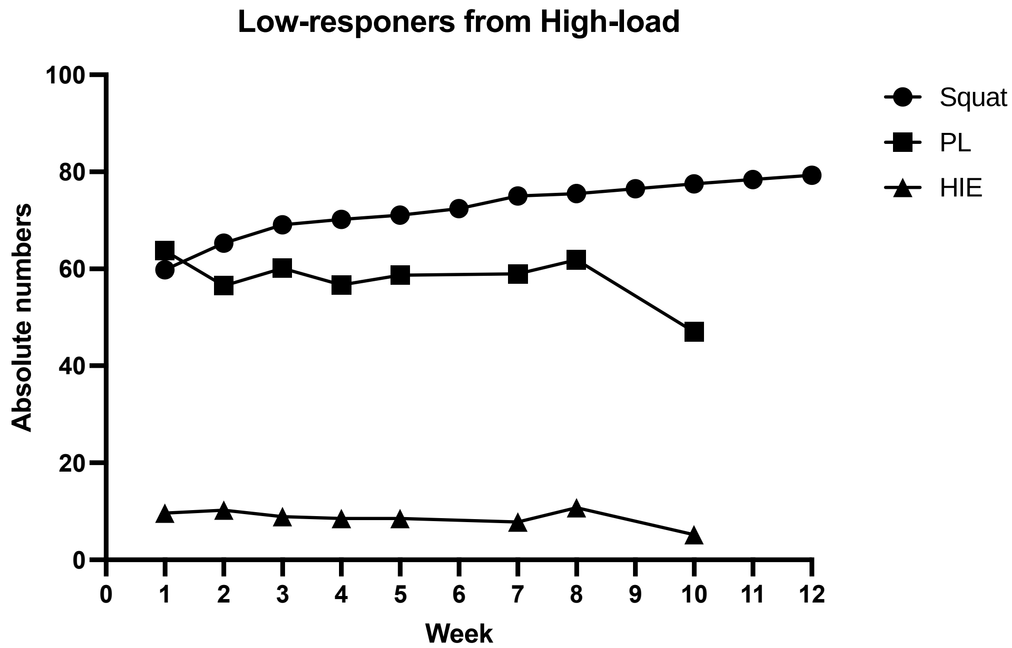


FIGURE 4: Squat training load, total PlayerLoad and high intensity events for high- and low-responders in high-load training group (n=5, n=8) through the training intervention. Player Load and high intensity events are here presented as absolute numbers to better show their values visually against the squat values. The other high-responders are excluded from the graphs since they were in the power-plyometric training group which had a constant squat training.

5 Discussion

The aim of this study was to investigate if in-season resistance training-induced changes in maximal lower-body strength and fat-free mass could influence changes in match-related handball external load measurements. To the best of our knowledge this is the first study to examine if changes in physical performance and fat-free mass in legs affects handball performance. The findings indicates that there are no correlation between changes in physical performance and changes in external load data.

Muscle mass and maximal strength training for athletic performance

The changes in physical performance showed no correlation with the changes in external load data. The relationship observed between exposure doses and responses may be due to confounding factors rather than causality, or it could be a result of several independent effects of the exposure.[19] The beneficial results coming from traditional resistance programs, such as enhanced muscular strength and increased local muscular endurance, is well known.[4] Regardless, there is a need to determine alternate methods of resistance training due to the fact that is unlikely that one traditional form of resistance training appeals to the entire population of trained athletes.[4] This study investigated strength values from two different resistance training programs; heavy load strength and power/plyometric training. The results indicated that the training load in the squat for both high- and low-responders did increase over the period of the intervention. PlayerLoad and HIE did not increase, it even seems that they have slightly decreased through the period.

The effects of training are diverse, and selecting the appropriate measures of exposure and metrics depends on the goal of the training, the primary outcomes of interest, and the specific aspects of training that coaches and researches wish to investigate.[19] Because of the various outcomes, each with their own set of mechanisms, no single measure can capture all the mediators involved in these different outcomes.[19] Although the increase and decrease in the strength and fat-free mass values, there could be other mechanisms that effects the external load values. To optimize training in sports and exercise, any measure of training load should reflect the underlying mechanisms that mediate the expected effects and responses of the specific physical training factor.[19] Both training programs were designed with the aim of improvement and many of the athletes did improve in the strength and fat-free mass variables. With one training session being supervised through the whole intervention, it is possible that this has affected the improvements. However, it is possible that the intensity of the training programs may have been too high for some athletes, resulting in the little decrease in external load.

There also may be a period of time during which an athlete learns how to use increased strength in various sport events, called lag time.[20] This time period may exceed several months, which is often outside the limited experimental bounds of most studies that are limited to few weeks.[20] This could possibly explain why the athletes had increased strength but not handball external load performance. With a longer duration for the intervention, it may be possible that the external load data would increase.

Instead of assuming that more muscle or body mass is always ideal, coaches should aim at determining the optimal level.[21] This means that while building muscle and body mass can be beneficial for athletes with a relatively low training age in sports that is not very force-dominated, there will likely come a point in their development where relative strength and power should become the focus, and reduce the amount of hypertrophy training. In order to gain further strength and power, neural factor should be emphasized. When it comes to team sports, coaches should consider the individual needs of each athlete based on their playing position and role within the team when determining the optimum level.[21] Since all participants in this study had prior experience with resistance training, it is possible that some were already at an optimal level of muscle mass. This factor could potentially impact the correlations between them.

On the contrary, research has shown that elite female handball players have higher values in different physical demands than the amateur players.[22] Elite female handball players share similar body mass and body fat percentage with amateur players, but outperform them in terms of body height, fat-free mass, sprint and endurance running abilities, as well as ball throwing velocity.[22] Since the players were relative young (20 years ± 2.8), and may not have so much experience with resistance training, it is possible that this could be a reason for the good results in the strength and fat-free mass values. However, one could assume that the increases in the physical performance measures would have a strong correlation with the external load performance measures.

A measure should, ideally, reflect the mechanisms that link the exposure to the targeted responses.[19] However, pathways facilitating sporting performance are complex. There are many mechanisms who acts concurrently and may interact with each other. Therefore, a single measure is unlikely to include all the mechanisms that mediate the response of interest.[19]

On-court performance

Compared to other team sports, research on team handball is relatively limited, and methodologically challenging due to technological limitations in monitoring indoor sports and capturing short high-intensity actions performed in tight spaces.[17] Existing sampling rates (i.e. 100Hz) for the IMUs, may not be sensitive enough for the advancement of new algorithms, leading manufactures to consider offering higher sampling data.[23] Therefore, it may be recommended that manufactures disclose any modifications concerning data processing when updating their software or firmware.[23] In our study, we did not update the Catapult software during the intervention to ensure that this would not influence the external load data.

While Player Load (PL) is a valuable tool for assessing physical performance in frequent contact sports like team handball, this is a relatively new field of study.[17] Therefore, it is important to approach results interpretation with caution.[17] Previous studies has explored position-specific Player Load (PL) and high intensity events (HIE) both within and between halves for all players combined, while also incorporating goals scored.[12,16,17] The present study did not include these measurements. Rather, we set a criterion to determine what was a meaningful change in the physical performance measures, which allowed us to classify the participants into two groups; high- and low-responders based on the SWC and CV. By doing this, we were able to examine if those athletes who had a meaningful improvement correlated with the changes in PL and HIE.

One should exercise caution when comparing accelerometer data among different athletes to assess external load, as there is significant level of variation.[23] This reflects our Player Load and high intensity events data, with a CV of 100.4% and 70.2%. For instance, the 6 vs 6 drill was always conducted at the end of the handball session. Depending on the intensity of the training, this could impact the measurements. We tried to maintain consistency by conducting the measurements on the same day for each handball team every week, but some weeks it was not possible. However, the fatigue of the athletes could vary depending on how long since they had done the strength training. Another factor that can explain the differences in the 8 measurements is that the athletes may vary in their performance due to the fact that the game plays out different from one session to another. It is possible that the players did performed better than their usually level due to being aware of being monitored, and after a few weeks, they may have returned to their typical performance level. This can explain the observed decrease in the external load data. Therefore, tracking the players throughout the entire handball season would be valuable to have a better understanding of their performance.

Team handball demands a lot of developed motor skill, such as speed, explosive power, endurance, and strength, and in these actions the athletes have a lot of body contact.[2,4] An athlete may have to manipulate their own body mass plus an opponent's body mass, and therefore have to exert large forces against gravity.[24] Therefore, a high body mass and specifically high fat-free mass is advantageous in handball, and somatic traits can be one of the predictors of success in this sport.[7,8] The intensity if team handball players may be somewhat underestimated because the IMU unit will not be able to detect isometric actions.[17] In this study we defined on-court performance as acceleration, deceleration and changes of direction, but it may have given other results if the IMU were able to detect isometric actions.

Regarding external load, matches with a longer duration results in a significantly higher PL and similar PL per minute when compared to matches with a shorter duration.[25] In our study, we had "matches" with a duration of five minutes two times, this was to compare to other results from the few other studies. We could possibly have tracked the players for longer matches.

High-intensity activities are a relatively small part of the physical aspect of the game, in one study, female players were found to cover 2,5% of total distance in high-intensity-running categorie.[26] It is possible that previous methods relying solely on speed may not have had the necessary sensitivity to identify instances of maximal or near-maximal effort by athletes. Moreover, discrepancies in the definition of high-intensity activity can add further complexity to the interpretation of such methods. [17]

Is it crucial to consider that external load performance is defined by specific criteria and primarily focuses on the external load itself. Handball performance, on the other hand, can be defined by other factors, including the ability to score goals and their overall performance at national and international levels. In team sports, the athletes total effort is often assed by measuring their overall workload, and this workload is determined by both the intensity and duration of the tasks performed and is commonly quantified using parameters like total distance covered and distance covered in different speed zones.[10] For instance, events with a value >2.5 m *s-1 was classified as an acceleration, deceleration or COD, and the sum of this events are HIEs.[12,16] It is possible that athletes who possess greater explosiveness and strength, are able to hit the ball faster and more frequently, resulting in less overall running compared to those with lower strength and explosiveness. These individuals may reach the thresholds that trigger higher external load and more high intensity events more quickly. Therefore, they may need to engage in less running overall. The findings of this study could indicate that higher strength values and fat-free mass do not necessarily correlate with these external load performance values. This observation could also account for the decrease in the external load values. Taking the above discussion into consideration, this decrease may even have a positive implication.

In-season

Research in high performance athletes may be difficult to execute in-season. Small sample sizes can occur, resulting from athletes and coaches declining to participate in research studies.[4] High-performance athletes face a potential risk if the training program leads to a reduction in physical performance. Therefore, we did not include a non-training group in this intervention.

Essential components of overall training includes strength and power, and therefore handball players often train these traits through the season.[1] Some research suggest that the strength and power of players can be preserved and increased with in-season strength and conditioning training, and that training sessions performed twice a week can increase muscle strength of athletes.[13,27] This study have also shown improvement in strength values during in-season, but has not been able to show the benefits from this in external load data. The specific handball training through matches and training in-season could have a greater influence on the external load performance variables compared to strength and fat-free mass.

Female handball players

The literature on this topic is male dominant, and due to fact that game dynamics and player demands differ between sexes in handball, the analyzes of player activity in men may not be accurate for women.[17] Conclusions based on on-court match analysis data in male players can therefore not be transferred directly to female players due to physiological differences.[26]

According to Manchado et al. (2013) results, there are only a few studies on on-court performance and time-motion analysis for women`s team handball players, especially concerning acceleration profiles.[2] There is also a clear need for more research on strength training in women's handball players.[2]

6 Main strength and limitations

Due to strict requirements for the SWC and CV, we could state with greater certainty regarding the lack of impact of physical test results on the external load variables. This strengthen the findings of this study, further supported by the good reliability of the testing protocol. The supervision of one weekly session may have led to a higher participant completion rate.

The main limitations in this study is the big variations in the external load data. This makes it harder to make conclusions from the results, due to the multiple mechanisms that could have influenced the outcomes.

7 Perspective

This is the first study to examine if in-season resistance training-induced changes in maximal lower-body strength and fat-free mass could influence changes in match-related handball external load measurements. Because of the big variations in the external load data, and that the benefits from the enhancement in the strength and fat-free values have not been shown in the external load values, more research are needed regarding this topic. There is also a need for more research in female handball players and physical and external load performance in handball.

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PART 3

Attachments

Attachment 1: training programs for both high-load strength training and power/plyometric training group.

Table 1*:* Training program week 1-12 for strength training group

Session A:	***Set***	***Repetitions***	***Rest***	***Load (RIR) /intensity***
Parallel squat	3	5	3 min	1 RIR
Split squat with dumbbells	3	5	3 min	1 RIR
Superset: hip thrust	3	5	3 min	1 RIR
Superset: one-leg calf raise	3	10	2 min	High
Romanian deadlifts	2	5	3 min	1 RIR
Superset: bench press	3	5	3 min	1 RIR
Superset: pullups/pulldown	3	5	2 min	1 RIR
Shoulder press bar or dumbbells	2	5	2 min	1 RIR
Weighted sit-ups	2	10	2 min	High
Session B:	***Set***	***Repetitions***	***Rest***	***Load (RIR) /intensity***
Parallel squat	2	5	3 minutes	1 RIR
Superset: Nordic hamstring curl	2	5	3 minutes	High
Superset: Superman/rollouts	2	10	2 minutes	High
Bulgarian lunges	2	5	3 minutes	1 RIR
Bench press with dumbbells	2	5	3 minutes	1 RIR
Superset: Cable row or 1-arm dumbbell rows	2	5	2 minutes	1 RIR
Superset: Triceps dumbbell overhead press	2	5	2 minutes	1 RIR

Table 2: Training program week 1-12 for power training group

Session A:	***Set***	***Repetitions***	***Rest***	***Load/intensity***
Squat jump	4	5	3 minutes	50% 1RM
Push jerk	3	5	2 minutes	
Superset: explosive bench press with bands	3	5	2 minutes	50% 1RM
Superset: single-leg hip thrust jump	3	5	2 minutes	BW/max
Drop jump	3	10	3 minutes	BW/max
Superset: Kettlebell swing	3	8	2 minutes	12kg+
Superset: Medicine ball chest throw	3	5	2 minutes	2-4kg
Superset: Bulgarian jumps	3	5	3 minutes	BW/max
Superset: box jumps	3	10	2 minutes	BW/max
Reverse rowing/ med-ball slam*	3	5	2 minutes	BW/max
Session B:	***Set***	***Repetitions***	***Rest***	***Load/intensity***
Squat jump	3	5	3 minutes	50% 1RM
Superset: Single-leg hip thrust jump	2	5	2 minutes	BW/max
Superset: medicine ball chest throw	2	5	2 minutes	2-4kg
Hurdle jumps	2	10	2 minutes	BW/max
Split squat jumps	3	5	3 minutes	BW/max
Horizontal jumps	2	5	2 minutes	BW/max
Superset: box jumps	2	10	2 minutes	BW/max
Superset: Reverse rowing	2	5	2 minutes	BW/max

Note: *new exercise included in weeks 6-12.

Attachment 2: application for ethical approval of research project

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

Attachment 3: approval from the Norwegian center for research data (NSD)

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

- 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!

Attachment 4: informed written consent signed by the participants

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

Side 1/9

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

snittet i huden. Se vedlegg I for bilder av arr etter muskelprøve, og vedlegg II for sårstell etter muskelprøvetagning.

- Elektrisk stimulering av musklene vil få de til å trekke seg sammen og det oppleves som å få et støt. Dette kan oppleves litt ubehagelig, men er helt ufarlig.

DINE RETTIGHETER: FRIVILLIG DELTAKELSE OG RETT TIL Å TREKKE SEG

Det er frivillig å delta i prosjektet. Dersom du ønsker å delta, undertegner du samtykkeerklæringen på side 7. Ved å signere denne samtykkeformen gir du tillatelse til å bruke resultatene til de formål som er beskrevet i dette skrivet. Om du nå sier ja til å delta, kan du senere, når som helst og uten å oppgi grunn, ombestemme deg og trekke deg uten at det har noen konsekvenser for deg. Dersom du trekker deg fra studien, kan du kreve å få slettet innsamlede opplysninger/data, med mindre opplysningene allerede er inngått i vitenskapelige publikasjoner. Det vil ikke være mulig å identifisere deg i resultatene av studien når disse publiseres. Ta kontakt med oss dersom du velger å forlate prosjektet (se side 6 for kontaktinfo).

Dine rettigheter
Så lenge du kan identifiseres i datamaterialet, har du rett til:
- innsyn i hvilke personopplysninger som er registrert om deg, og å få utlevert en kopi av opplysningene,
- å få korrigert eventuelle feil i de opplysningene som er registrert om deg,
- å få slettet personopplysninger om deg, og
- å sende klage til Datatilsynet om behandlingen av dine personopplysninger.

Dersom du har spørsmål til dine rettigheter, kan du kontakte vårt personvernombud:
Johanne Warberg Lavold (johanne.lavold@uia.no, 412 12 048).

HVA SKJER MED OPPLYSNINGENE OM DEG?

Vi vil bare bruke opplysningene om deg til formålene vi har fortalt om i dette skrivet. Vi behandler opplysningene konfidensielt og i samsvar med personvernregelverket.

Opplysninger som registreres om deg er:
- Høyde, vekt, fødselsdato, menstruasjonssyklus på testtidspunkter og avvik i treningsperioden samt subjektive mål av selvopplevd restitusjon og anstrengelse.
- Kosthold i totalt 3 uker
- Maksimal styrke, power, spenst, hurtighet, kroppssammensetning (fettfri- masse, kroppsfett og benmineraltetthet) og biologisk muskelvev
- Trening som gjennomføres utenfor prosjektet

Universitetet i Agder er ansvarlig for all informasjon som samles inn i dette prosjektet. Informasjon om deg vil behandles avidentifisert. Det betyr at vi gir deg et deltakernummer og linker all innsamlet informasjon til dette nummeret. Vi har en kodeliste (ett eksemplar) som 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

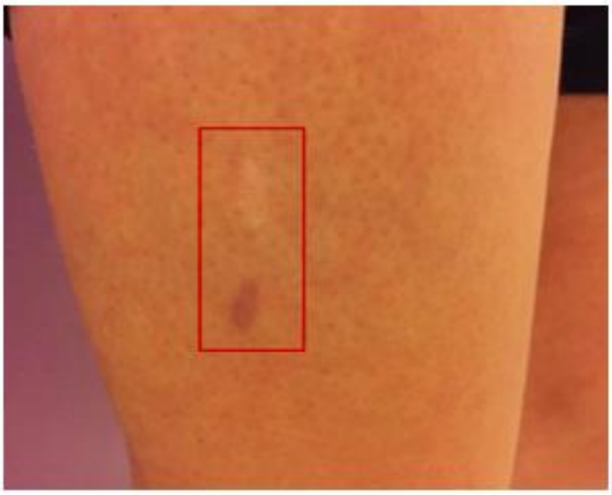
Sted og dato   Signatur

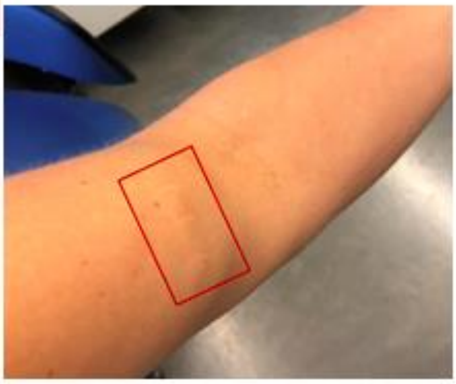
____
Rolle i prosjektet

VEDLEGG 1: MUSKELVEVSPRØVE

Bilde 1 → viser tre arr etter tre muskelprøver på venstre lår (samme sted som denne studien).
Det øverste er 6 måneder gammelt,
de to nederste er 3 måneder gamle.

Bilde 2 under viser to arr etter to muskelprøver på høyre lår (samme sted som denne studien).
Det øverste arret er 7 år gammelt og det nederste er 6 måneder gammelt.





Bilde 3 → viser tre arr etter tre muskelprøver på overarm. Det er over 10 år siden muskelprøvene ble tatt.

Side 8/9

VEDLEGG 2: SÅRSTELL ETTER MUSKELVEVSPRØVE

Du er nå deltager i et forskningsprosjekt hvor vi har tatt muskelprøver (biopsi) fra låret ditt (m. vastus lateralis). Dette er et lite inngrep som ikke skal ha noen negative følger annet enn sår muskulatur noen dager etter inngrepet. Det kan gjøre vondt/være sårt i kveld når bedøvelsen går ut, og i morgen, men det vil gå over i løpet av en dag eller to.

Det er imidlertid en minimal risiko for infeksjon etter slike inngrep. Vi ber deg derfor om å følge rådene under. Om det skulle oppstå noe av medisinsk karakter som du tror kan settes i sammenheng med forsøket, må du ta kontakt med oss uansett tid på døgnet (se kontaktinformasjon nederst i skrivet).

Det er nå viktig at du tar følgende forhåndsregler slik at sårene dine skal gro godt:

- Bandasjen som er surret rundt låret ditt kan tas av i kveld før du legger deg.
- Hvit plasterlapp og strips skal sitte på én uke. Vi anbefaler at stripsene ikke rives av, men tas av når de løsner fra selve såret. Dersom dette skjer før det har gått én uke, ta kontakt slik at vi kan sette på nye.
- Hold sårområdet tørt. Du bør ikke vaske området ved sårene eller dusje slik at tapen rundt såret blir våt. Vann vil øke faren for infeksjon og det vil også medføre at tapen som skal hold sårflatene sammen, løsner. Du kan dusje, men sørg for at du ikke får vann i nærheten av sårene. Dersom du skal dusje, vær forsiktig og bruk plastfolie/"gladpack", vanntette plaster eller lignende for å hindre vann å trenge gjennom plasterlappen.

For å sikre at arrene blir så lite synlige som mulig, anbefaler vi å smøre arrene med høy solfaktor ved soleksponering.

Kontaktpersoner ved Universitetet i Agder:
Truls Raastad: 91 36 88 96
Fredrik Tonstad Vårvik: 928 54 969