Title: The effect of a seven-week strength training intervention using either power clean or loaded hex bar jump for enhancing physical performance.
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By signing this document both members confirms that they both has participated equally in the project and that both is responsible for the content of the report.

Abstract

Purpose: The aim of the present study was to investigate the effect of a seven-week strength training intervention using either the power clean exercise or loaded hex bar jump in enhancing counter movement (CMJ) height, five-, 10-, 25- and 30-meter sprint time, 505 change of direction (COD), power clean 1RM and power output in a loaded hex bar jump.

Method: 40 U17 elite athletes of which 22 were soccer players (height=182.5±5.1 cm, body mass=70±5.2 kg) and 18 were handball players (height=186±7.5 cm, body mass=97.8±10.5 kg) underwent a seven-week strength training intervention with performance tests before and after. The athletes were randomly divided into a hex bar group (HX) or a power clean group (PC) and completed three familiarization sessions and were then all tested for one repetition maximum (1RM) power clean, power output during loaded-hex-bar- jumps at external loads of 21, 41, 61 and 81 kg, CMJ, COD and sprint times for five-, 10-, 25- and 30-meter. The performance tests were conducted on two different days with day one consisting of the loaded hex bar jump test, power clean 1RM and CMJ while day two was sprint and COD test.

Results: The measures obtained from all tests were analyzed using t-tests to compare the pretest and posttest results, as well as the HX group and PC group results. A paired t-test showed a significantly higher CMJ ($p<0.001$), higher power clean 1RM ($p<0.001$), faster COD time ($p=0.03$) for HX group. Lower power output was found in the loaded hex bar jump test for HX group while testing with 21 kg ($p=0.01$) and 41 kg ($p=0.03$). Similarly, a paired t-test revealed a significantly higher CMJ height ($p<0.001$), a higher power clean 1RM ($p<0.001$), a higher power output in 81 kg loaded hex bar jump ($p=0.04$) and a decrease in 41 kg loaded hex bar jump ($p=0.05$) and slower 10- ($p=0.04$) and 25-meter sprint speed ($p=0.034$) for PC group. An unpaired t-test revealed no significant differences in any of the physical performance measures between groups.

Conclusion: In conclusion, it seems that power clean or loaded hex bar jump training were generally equally effective in enhancing physical performance in tested performance measures with no significant difference in performance between HX and PC groups in any of the tests.

Abstract:

The aim of the present study was to investigate the effect of a seven-week strength training intervention using either the power clean exercise or loaded hex bar jump in enhancing counter movement (CMJ) height, five-, 10-, 25- and 30-meter sprint time, 505 change of direction (COD), power clean 1RM and power output in a loaded hex bar jump. 40 U17 elite athletes of which 22 were soccer players (height=182.5±5.1 cm, body mass=70±5.2 kg) and 18 were handball players (height=186±7.5 cm, body mass=97.8±10.5 kg) underwent a seven-week strength training intervention with performance tests before and after. The athletes were randomly divided into a hex bar group (HX) or a power clean group (PC) and completed three familiarization sessions and were then all tested for one repetition maximum (1RM) power clean, power output during loaded-hex-bar- jumps at external loads of 21, 41, 61 and 81 kg, CMJ, COD and sprint times for five-, 10-, 25- and 30-meter. The performance tests were conducted on two different days with day one consisting of the loaded hex bar jump test, power clean 1RM and CMJ while day two was sprint and COD test. The measures obtained from all tests were analyzed using t-tests to compare the pretest and posttest results, as well as the HX group and PC group results. A paired t-test showed a significantly higher CMJ ($p<0.001$), higher power clean 1RM ($p<0.001$), faster COD time ($p=0.03$) for HX group. Lower power output was found in the loaded hex bar jump test for HX group while testing with 21 kg ($p=0.01$) and 41 kg ($p=0.03$). Similarly, a paired t-test revealed a significantly higher CMJ height ($p<0.001$), a higher power clean 1RM ($p<0.001$), a higher power output in 81 kg loaded hex bar jump ($p=0.04$) and a decrease in 41 kg loaded hex bar jump ($p=0.05$) and slower 10- ($p=0.04$) and 25-meter sprint speed ($p=0.034$) for PC group. An unpaired t-test revealed no significant differences in any of the physical performance measures between groups. In conclusion, it seems that power clean or loaded hex bar jump training were generally equally effective in enhancing physical performance in tested performance measures with no significant difference in performance between HX and PC groups in any of the tests.

1.0 Introduction

Maximal- and explosive strength are important physical capabilities for elite athletes to be successful in their respective sport (12,22). These capabilities can be used to enhance key physical performance parameters such as sprint speed, the ability to rapidly change the direction of movement and jumping abilities (6,13,16,20). Recent studies found a difference in explosive and maximal strength between elite and amateur soccer and handball players with the elite players being superior and performing at a higher physical level (4,11). Previous research has investigated effect of strength training for enhancing physical performance in sprint, change of direction (COD) and jumping ability for soccer and handball players by increasing maximal- and explosive strength through heavy strength- and plyometric training as a supplement to the primary sport (2,3,19,23).

Free weight strength training with an intensity above 75% of one repetition max (1RM) and plyometric training has been shown to enhance power output and performance in aforementioned exercises when implemented as a supplement to the primary sport (2,3,19,23). Increased power output can therefore be developed both with the help of heavy strength training, but also with plyometric training (2,3,19,23)). This indicates different training methods can be used to increase power output. However, the Olympic weightlifting exercises, and their derivatives such as the power clean, clean and jerk, hang pull clean, snatch, and hang snatch are more frequently used exercises in strength training for sports used to enhance power output (26,29).

Olympic lifts and their derivatives are a vital part of soccer and handball players' strength training programs to enhance power output and used as physical performance tests (16,27,37). The power clean exercise is often performed with a higher intensity compared to loaded plyometric training exercises such as squat jumps. This will lead to a higher power output for power clean (7). However, the power clean exercise is often performed at a lower load compared to heavy strength training, but at a higher velocity compared to traditional heavy strength training which will also lead to a higher power output based on the force velocity relationship (7,8). Strength training sessions including the power clean exercise has previously led to increased physical performance in team sports athletes, due to the

enhanced power output (34). Furthermore, the power clean is training the triple extension of the ankle, knee, and hip joints that transfers to sprint, change of direction and jumping ability (2,5,19). The power clean has been revealed to be superior compared to heavy resistance training in enhancing sprinting, change of direction and jumping abilities in athletes (2,5,19).

The Olympic weightlifting exercise power clean is complex and technically demanding compared to other similar exercises with a similar movement pattern training the triple extension of the ankle, knee, and hip joint such as the loaded hex bar jump (9,33). To master the power clean exercise the athlete will need expert advice and a lot of technical guidance (15). The athlete will also need to have a high flexibility in the wrist, elbow, and shoulder just to get the barbell in the right position. Furthermore, the high movement velocity of the barbell will make it very difficult to coordinate the lift and catch it correctly. Lastly, the lack of technical skill may lead to a higher force contribution of the upper body muscles instead of the lower body muscles (15). Within this context, it is anecdotally reported from the strength training environment and the authors of the present study, that it may take up to several years for handball players and soccer players to master this exercise and to lift effectively in the exercise so the players can train with an optimal intensity and higher volume. The power clean exercise can therefore be said to be time-consuming to master for both amateurs and elite athletes. Furthermore, it appears that there is a specific body type requirement for performing the power clean easier. This issue is anecdotally common for taller individuals, such as handball- or basketball players, whose natural tall physique may not be fitting for this exercise. So consequently, when aiming to enhance the physical capabilities, it needs to be addressed to explore alternative solutions that can provide an easier and faster method to increase power output.

The power output generated in the power clean exercise is mostly from the triple extension. This shows that the triple extension for the lower limbs, ankle, knee, and hip joint is very important in generating power output (9). It will be of interest to find another method to generate the same amount or higher power output as the power clean but without the possible technical limitation found in the power clean exercise. An alternative exercise could be the loaded hex bar jump as it is a less complex exercise compared to the power clean. The exercise both targets the same muscles, have a similar movement pattern as power clean

focusing on the triple extension of ankle, knee, and hip joint and can be learned during one familiarization trial. Therefore, this exercise could be a great alternative for the power clean as it can be loaded faster and more due to the low technical demand, and it may generate the same or even higher power output (25,33).

The existing literature comparing the Olympic weightlifting exercises to plyometric training with exercises such as loaded hex bar jump and CMJ show conflicting results. A study by Helland (2017) found plyometrics to be superior in enhancing jumping ability, COD, and linear sprint speed (15), while Kaabi (2022) found weightlifting derivatives as the best solution for enhancing these attributes (19). Several studies found no differences between using plyometrics or weightlifting for enhancing physical performance in jumping ability, COD, and linear sprint speed (2,33,35).

Overall, it is important for handball and soccer players to generate high power output in the triple extension of the ankle, knee, and hip joints to increase vertical jumping ability, COD movement and linear sprint speed. Therefore, it is important to determine the most efficient method to enhance performance in these parameters and identify the optimal exercises to achieve this. The existing literature lacks studies investigating the differences between easier and less technically skilled exercises compared to Olympic lifts derivatives with similar performance improvement (33). To the best of the authors knowledge no study so far has compared strength training interventions using a loaded hex bar jump compared to the power clean exercise in enhancing vertical jump height, sprint speed and change of direction for elite youth soccer and handball players.

Therefore, the aim of the present study was to investigate the effect of a seven-week strength training intervention using either the power clean exercise or loaded hex bar jump in enhancing counter movement (CMJ) height, five-, 10-, 25- and 30-meter sprint time, 505 change of direction (COD), increase power clean 1RM and power output in a loaded hex bar jump with 21, 41, 61 and 81 kg and to investigate if the loaded hex bar jump is at minimum as effective as power clean.

3 hypotheses were created based on the different aspects of the introduction.

Hypothesis 1: The seven-week strength training intervention using the loaded hex bar jump exercise will at minimum result in a similar increase in countermovement jump (CMJ) height compared to the power clean intervention group.

Hypothesis 2: The seven-week strength training intervention using the loaded hex bar jump will at minimum result in a similar increase in five-, 10-, 25-, and 30-meter sprint times compared to the power clean intervention group.

Hypothesis 3: The seven-week strength training intervention using the loaded hex bar jump will at minimum result in a similar increase in change of direction (COD) time compared to the power clean intervention group.

2.0 Method

2.1 Experimental approach

This study used a randomized intervention design, which was used to examine various performance parameters after an exercise intervention using either power clean or loaded hex bar jumps. All participants underwent a seven-week exercise intervention. Players from respectively Aalborg handball U17 and Aalborg soccer U17 were divided into groups, of which one group performed power clean at the start of their strength training session, and the other group performed loaded hex bar jump. The study was conducted from the middle to the end of the 2022-2023 season.

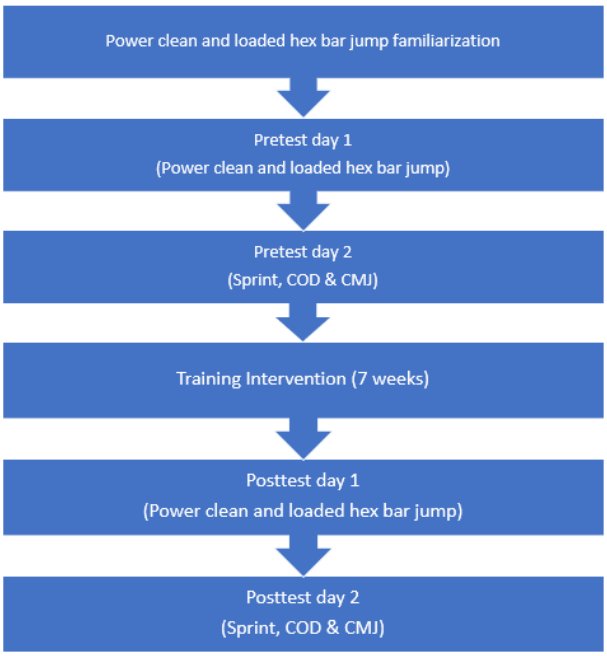

Figure 1: *Shows the experimental process of the study*.

2.2 Participants

The participants who took part in this experiment were U17 elite soccer players and handball players. Data was collected of 22 soccer players (height=182.4±5.0cm, body mass=70±5.1kg) and 18 handball players (height=185.9±7.4cm, body mass=97.8±10.5kg). All the players had a minimum of four to five days of soccer or handball training sessions per week and at least two resistance training sessions per week the latest year. Both handball players and soccer players were divided into groups, of which one group performed power clean (PC group) as the start of their training session, and the other group had to do loaded hex bar jumps (HX group). The players were stratified into groups based on their physical performance test results. To fulfill the inclusion criteria participants had to be injury free and willing to participate in the study. The study conformed to the principles of the World Medical Association's Declaration of Helsinki.

2.3 Procedures

The players went through a test battery before and after the training intervention. The test battery consisted of six exercises, which were supposed to measure different performance parameters and were performed over two separate days. On the first test day,

the body mass and height were found for each player. The height was found using an altimeter, with the subjects standing up straight, with the heel, hip and back of the head in contact with the wall. The participants body mass was then obtained in a private locker room. After the anthropometric measurements the subjects had to go through a preparatory warm-up. Then moving on to the physical performance tests in a randomized order with one third starting at the CMJ, one third starting at loaded hex bar jumps and lastly, one third starting with the 1RM power clean exercise. The second day players performed the sprint and change of direction test starting randomly with one half starting with a sprint, measured by the five-, 10-, 25- and 30-meter mark and the second half starting at 505 changes of direction test. The order of the tests was randomized so that any fatigue effect would not be overrepresented in any exercise. The tests were carried out in the same way for pre- and posttests. Between pretest and posttest, the seven weeks of strength training were conducted. The players trained two times a week with five sets of three reps the first four weeks after which it was five sets of two reps. After the primary exercise was done, the players trained their normal routine exercises.

2.4 Familiarization

All athletes were attending a familiarization protocol to minimize a learning effect and increase reliability for the pre- and posttests. The familiarization consisted of three separate familiarization sessions. These sessions consisted firstly of learning the technique of the power clean, and lastly the hex bar jump. Due to the participants former experience and the high reliability found in the recent literature in the CMJ, linear sprint and COD no further familiarization was performed in these exercises (23,24). The familiarization of the power clean exercise was instructed and progressively learned through five exercises. The first exercise was a stretching exercise, where the participant stood in a squat position under an immovable barbell, where the elbows were turned up and inwards. When the elbows were in position, they were asked to push the barbell up, until a stretch in the elbows was felt and then hold this stretch for three seconds. The second exercise was an elbow rotation exercise, where the participant was standing with a barbell in front of them with relaxed arms. The participants were asked to bring up the barbell and rotate the elbows like in a similar hang power clean movement with a focus on the locking grip. The third exercise was a traditional

hang power clean where the participants pushed the barbell up, with the use of the hip, while leaning back with a shrug and lastly to rotate the elbows learned from the second exercise. Focus was to learn to generate power with the hips. To not perform a horizontal push the participants were asked to lean back with a shrug, so the force of the barbell would be generated in a vertical pathway. The fourth exercise was a power clean starting from the knees, where the participant focused on switching feet position. This means that they moved the feet slightly out at the same time as they went from standing on the toes to grabbing the barbell on the whole foot. The fifth and last exercise was a traditional power clean from the floor. This exercise was to practice the power clean from a full range of motion, with focus on overall technique, with a lot of repetitions. At the last familiarization session, the participants were instructed in the loaded hex bar jump. Participants were told to focus on landing with a slight bend in their knees and to hold their core tightened throughout the exercise. Furthermore, they were told to not bend their back, and look straight forward throughout the trial.

2.5 Tests

The tests were separated into two different days at both pretest and posttest. Test day one consisted of the power clean 1RM, loaded hex bar jump and CMJ tests. Test day two consisted of a sprint test, measured at the five-, 10-, 25- and 30-meter mark and 505 change of direction tests. Test day one and two were separated by 48 hours and each test day was performed a minimum of 24 hours after normal soccer and handball practice.

2.5.1 Test Day 1 Strength tests

Power clean one repetition maximum

At 1RM pretest the participants started with a trial consisting of a total load of 30 kg. They increased the load by adding two point five, five or 10 kg until failure and were told to perform two additional trials at the failure load. If the participants succeeded an additional load of two-point five kg were then added and repeated until three continuously failed trials were found. Same protocol was used at the posttest.

Loaded hex bar jump

Two submaximal jumps respectively, at 60 and 80% of intended maximal force were performed with an unloaded hex bar, before the official loaded hex bar jump test began. All participants were told to jump as high as possible and to land with a slight bend in their knees, and to stand upright at the end of every trial. The test was started in a standing position where they performed a loaded CMJ starting with an eccentric phase before accelerating throughout the concentric phase. They performed one trial with one repetition at each load. The trials were performed with increasing load after every repetition. First trial was a 21 kg hex bar without further load, the second trial consisted of 41 kg, third trial consisted of 61 kg and fourth trial consisted of 81 kg. A linear encoder (ChronoJump, Boscosystems, Spain) was attached to the hex bar (Hex bar 21 kg) and gathered the movement distance of the barbell over time which was later used to calculate power output for all the tests.

Counter movement Jump height (CMJ)

Two submaximal jumps were performed before the official CMJ test began. Firstly, the players were shown the right technique of the CMJ, then they all got the same fixed introduction to the test where participants were asked to place their hands on their hips and keep them there throughout the test. Then they were asked to kneel as far as and fast as they individually preferred, all the time with a focus on jumping as high as possible. Finally, they were made aware that it was not allowed to bend their knees during the flight time to extend the flight time. The players performed two trials of the test at one-minute intervals. The test was conducted on a contact mat (ChronoJump, Boscosystems, Spain). 2.5.2

2.5.2 Test Day 2: Performance tests

Sprint test (0-5m, 0-10m, 0-25m, and 0-30m sprint)

Before the linear sprint test a submaximal sprint with 90% max effort was performed. Witty Photocells (Microgate, Italy) were set up with five- 10-, 25- and 30-meter distances. The players performed two trial runs and were told not to slow down their run prematurely. All photocells stood at a height of approximately 80 cm. The players were stationary with feet pointing forward where the front foot stayed on the ground until "set off".

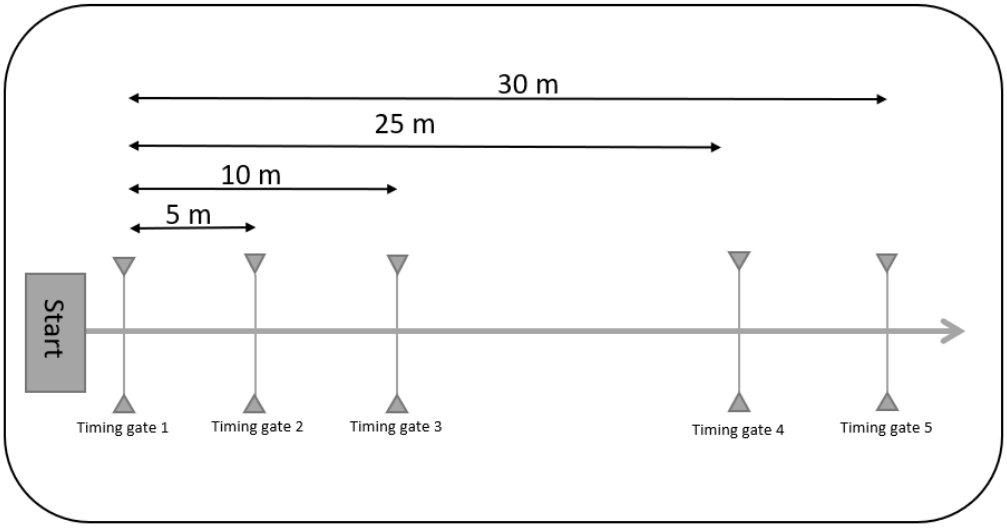

Figure 2. *Illustrates the five-, 10-, 25-, and 30-meter (m) linear sprint test using time gates.*

505 Change of direction

The participants performed the 505 change of direction test at an indoor court and started running 15 meters, then turned 180 degrees and sprinted back to the starting point. 10 meters from the starting line a handheld camera was placed. When the participant passed the camera, the time started and ended when they passed it the second time back to the starting line. All the participants performed two trials with one minute rest between trials.

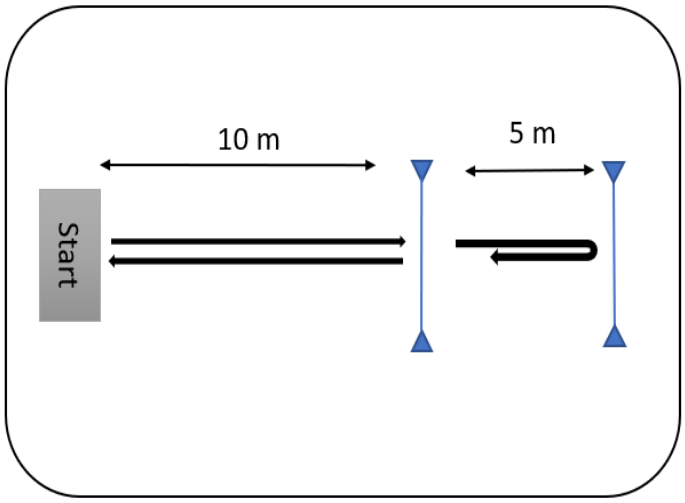

Figure 3. *Illustrates how the 505 change of direction test was performed.*

2.6 Training intervention

The training intervention consisted of seven-weeks of supervised training in power clean or loaded hex bar jump. The training was conducted twice a week performing either power clean or loaded hex bar jumps followed by their normal training routine without any further explosive exercises for the lower body. Throughout the intervention the training intensity increased, this was because the programs were volume equated in terms of the number of sets and reps. The only variable between the two programs was the exercises and load that varied. Before each training session began, the players did a normal warmup routine, consisting of running, dynamic stretching, and injury prevention exercises before starting with either the power clean or the loaded hex bar jump. Three warm-up sets were performed at each session with increasing load until the target load was reached. Hereafter the training session started.

Training program: Power clean and loaded hex bar Jump.

Table 1. *An overview of the seven-week training intervention showing number of sets, repetitions, rest time and intensity over the seven-week period.*

Set	**Repetitions**	**Rest time**	**Intensity**	**Week**
5	3	+2 minutes	79%	1
5	3	+2 minutes	82%	2
5	3	+2 minutes	85%	3
5	3	+2 minutes	88%	4
5	2	+2 minutes	91%	5
5	2	+2 minutes	92%	6
5	2	+2 minutes	94%	7

2.7 Data processing

The CMJ height was measured with a contact mat (chrono jump) and the highest jump height was used for further analysis. The CMJ height was calculated using flight time.

$$Jump\ height = Flight\ time^2 * g/8$$

G is defined as the gravity acceleration, with the eight representing a constant factor.

A linear encoder was used in the present study to access power output in loaded hex bar jumps. The linear encoder was attached to the hex bar and measured the distance traveled and movement time with a sampling rate of 1000 Hz. The distance was calculated from the lowest position before starting the concentric phase of the jump to the highest jump position before the eccentric phase begins. The force calculated was the external mass of the loaded hex bar multiplied with g ($9.82\ m/s^2$). Force and distance were then used to find work performed.

$$Work = Force * distance$$

The calculated work was then applied and divided by the time of the hex bar displacement on the concentric movement to estimate power output.

$$Power = \frac{Work}{Time}$$

This was done for each repetition at 21, 41, 61 and 81 kg loaded hex bar jump.

2.8 Statistical analysis

Normal distribution of all the data was confirmed using the Shapiro wilks test and homogeneity of the data was confirmed through Levene's test of variance where no outliers were found based on excluding any data point above or below an upper (3rd quartile+(interquartile range times by 1.5)) or lower threshold (1st quartile-(interquartile range times 1.5)). An unpaired sample t-test was then conducted to investigate if a significant difference was found between groups at pretest and posttest. Furthermore, a paired t-test was conducted to investigate if a significant difference was found for the power clean group

from pre- to posttest and for loaded hex bar jump group from pre- to posttest in the performance measures (CMJ, five-, 10-, 25- and 30-meter sprint time, COD, power clean 1RM and 21, 41, 61 and 81 kg loaded hex bar jump). Cohen's d was then calculated for finding the effect size (ES) of the difference in each condition Data are presented as mean ± standard deviation. Statistical significance was accepted at $p \leq 0.05$. All calculations were performed in SPSS version 28.0 (IBM Corp: Armonk, NY, YSA)

4.0 Results

All data were normally distributed. The participants included in the HX group used for the analysis have completed the training intervention with a mean compliance of 83.9±7.1% while the PC group have completed the training intervention with a mean compliance of 83.48 ±6.2%. The average training session volume for the HX group was 1000.9±7.1 kg and the average training session volume for the PC group is 695.3±147.8 kg with a significantly higher volume in the HX group ($p<0.001$) (ES=1.841).

4.1 Loaded hex bar jump

A significantly higher mean power output during the 21 kg loaded hex bar jump was revealed for the HX group in pretest compared to posttest ($p=0.01$). Similarly, a significantly higher mean power output during the 41 kg loaded hex bar jump was revealed for HX group in the pretest compared to the posttest ($p=0.03$) (table 2). Furthermore, a significantly higher mean power output for pretest compared to posttest in 21 kg loaded hex bar jump for PC group was observed and a significantly higher mean power output was observed in posttest compared to pretest for 81 kg loaded hex bar jump for PC group ($p=0.04$) (table 2). No significant differences between pre- and posttest for the rest of the loaded hex bar jump tests were observed (table 2).

Table 2: *An overview of the power output for 21-, 41-, 61- and 81 kg loaded hex bar jump and changes in power output from pre- to posttest. * Indicates a significant difference between pre- and posttest power output.*

Test	Pretest	Posttest	p-value	Effect Size
Loaded hex bar jump 21 kg	301.9 ±24.3 W	271.7 ±36.9 W	0.01*	0.83
Loaded hex bar jump 41 kg	484.4 ±41.2 W	454.2 ±38.6 W	0.03*	0.75
Loaded hex bar jump 61 kg	600.0 ±82.6 W	585 ±54.2 W	0.43	0.23
Loaded hex bar jump 81 kg	655.9 ±116.7 W	715.5 ±43.7 W	0.22	0.44
Loaded hex bar jump 21 kg	294.4 ±21.2 W	272.0 ±24.0 W	0.05*	0.73
Loaded hex bar jump 41 kg	461.9 ±54.9 W	459.1 ±26.5 W	0.88	0.05
Loaded hex bar jump 61 kg	563.6 ±93.6 W	582.2 ±51.9 W	0.47	0.22
Loaded hex bar jump 81 kg	607.0 ±75.9 W	705.8 ±52.0 W	0.04*	0.20

When analyzing the soccer and handball players separately a significant increase in power output was revealed for soccer players HX group from pretest (560.7±42.2 W) to post test (727.6±57.7W) at 81 kg loaded hex bar jump (p=0.015) (ES=2.541). No other significant differences between pre- and posttests were revealed for either soccer players or handball players.

An unpaired t-test revealed no significant difference between HX and PC group at any of the loaded hex bar jump tests (table 3).

Table 3: *An overview of the power output for 21-, 41-, 61- and 81 kg loaded hex bar jump and difference in power output between loaded hex bar jump (HX) and power clean group (PC)*

	Pretest			Posttest		
Test	**PC-group**	**HX-group**	**p-value**	**PC-group**	**HX-group**	**p-value**
Loaded hex bar jump 21 kg	283.77 ± 32.15W	307.33 ± 30.30W	p=0.07	274.09 ± 25.46W	271.03 ± 35.15W	p=0.81
Loaded hex bar jump 41 kg	461.98 ± 54.94W	488.42 ± 41.98W	p=0.19	459.16 ± 26.53W	462.30 ± 47.05W	p=0.84
Loaded hex bar jump 61 kg	563.69 ± 93.62W	603.12 ± 79.84W	p=0.27	582.22 ± 51.91W	601.26 ± 78.27W	p=0.49
Loaded hex bar jump 81 kg	617.77 ± 104.57W	632.06 ± 154.12W	p=0.82	657.83 ± 147.69W	731.27 ± 52.12W	p=0.11

4.2 Power clean

A significantly higher power clean 1RM for posttest compared to pretest were revealed for HX group (HX pre=64.6±14.3 kg, post=69.5±13.1 kg) (p<0.001) (ES=1.39) and in

posttest compared to pretest for PC group (PC pre=60.3±14.2 kg, post=67.34±13.4 kg) (p<0.001) (ES=1.28) (figure 4).

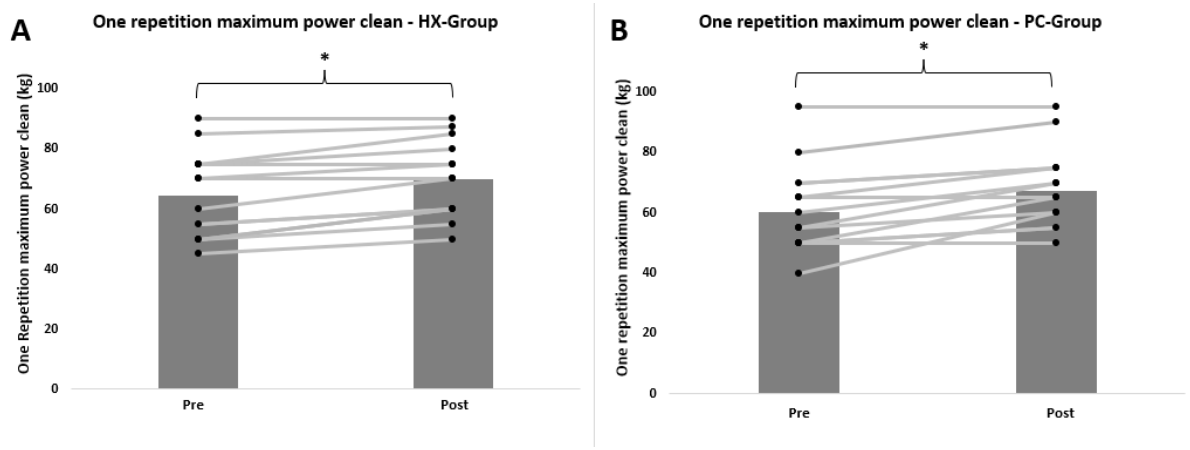

Figure 4: *(A) Shows an overview of the power clean one repetition maximum (1RM) for the loaded hex bar jump group (HX). (B) Shows an overview of the power clean 1RM for the power clean group (PC). Gray lines indicate individual differences from pre- to post test. Black dots indicate individual participants. * Indicates a significant difference between power clean scores p ≤ 0.05.*

An unpaired t-test revealed no significant difference in power clean 1RM between HX and PC group in pre (HX=64.6±14.3 kg, PC=60.3±14.2 kg) (p=0.42) or posttest (HX=69.5±13.1 kg, PC=67.3±13.4 kg) (p=0.67) (Table 4).

Table 4: *An overview of the power clean one repetition max average for each group in pre- and posttest.*

Power Clean 1RM	HX-Group	PC-Group	P-value
Pretest	64.6 ±14.3 kg	60.3 ±14.2 kg	0.42
Posttest	69.5 ±13.1 kg	67.3 ±13.4 kg	0.67

4.3 Countermovement jump

A significantly higher CMJ height for posttest (41.1±5.1 cm) compared to pretest (35.0±4.2 cm) was revealed for HX group (p<0.001) (ES=1.81). The same was revealed for the PC group with a significantly higher posttest (40.7±4.3 cm) compared to pretest (36.1±4.2 cm) (p<0.001) (ES=1.91) (Figure 5).

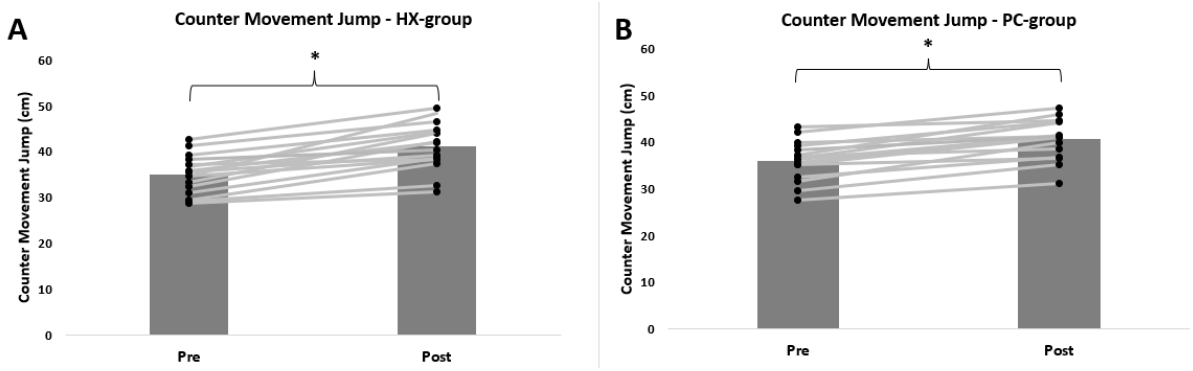

***Figure 5**: A) Shows an overview of the counter movement jump (CMJ) for the loaded hex bar jump group (HX). (B) Shows an overview of the CMJ for the power clean group (PC). Grey lines indicate individual differences from pre to post. Black dots indicate individual participants. * Indicates a significant difference between power clean scores $p \leq 0.05$*

An unpaired t-test revealed no significant difference in CMJ height between HX and PC group in pre- (HX=35±4.2 cm, PC=35.6±3.9 cm) (p=0.68) or posttest (HX=41.1±5.1 cm, PC=40.5±4.3 cm) (p=0.69) (Table 5).

Table 5: An overview of the counter movement jump average for each group in pre and posttest.

Counter Movement jump	HX-Group	PC-Group	P-value
Pretest	35.03 ±4.19 cm	35.64 ±3.88 cm	0.68
Posttest	41.13 ±5.11 cm	40.45 ±4.28 cm	0.69

4.4 Change of Direction

A significant difference in COD test time was revealed from pre (2.37±0.07 s) to post test (2.30±0.12 s) for the HX group (p=0.03) (ES=0.515). However, none was revealed between pre (2.35±0.10 s) and posttest (2.29±0.14 s) for the PC group (p=0.14) (ES=0.49) (Figure 6).

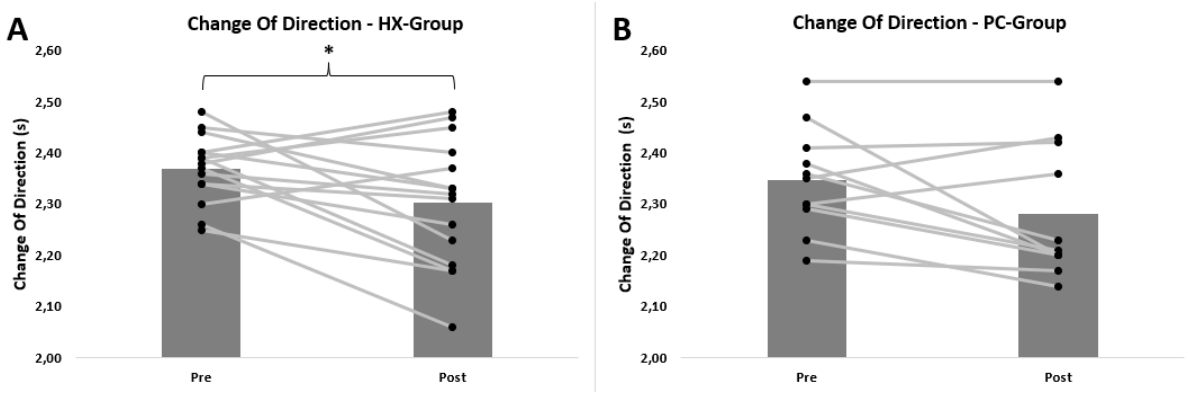

Figure 6: *(A) Shows an overview of the change of direction test data for the loaded hex bar jump group (HX). (B) Shows an overview of the change of direction test data for the power clean group (PC). Gray lines indicate individual differences from pre to post. Black dots indicate individual participants. * Indicates a significant difference between power clean scores p ≤ 0.05.*

An unpaired t-test revealed no significant difference in COD time for HX and PC group in pre (HX=2.37±0.07s, PC=2.35±0.10s) (p=0.49) or posttest (HX=2.31±0.12s, PC=2.30±0.16s) (p=0.86) (table 6).

Table 6*: An overview of the change of direction tests average time for each group in pre and posttest*

Change Of Direction	HX-Group	PC-Group	P-value
Pretest	2.37 ±0.07s	2.35 ±0.10s	0.49
Posttest	2.31 ±0.12s	2.30 ±0.16s	0.86

4.5 Five, 10, 25 and 30-meter sprint.

A paired t-test showed no significantly differences between pre and posttest for HX in any of the sprint measures (table7)

Table 7: *An overview of the sprint speed for five-, 10-, 25- and 30-meter sprint time and changes from pre- to posttest for hex bar group (HX). * Indicates a significant difference between pre- and posttest power output.*

HX-Group	Pretest	Posttest	p-value	ES
Sprint5	1.08 ±0.04	1.12 ±0.10	0.14	0.45
Sprint10	1.80 ±0.08	1.86 ±0.18	0.10	0.46
Sprint25	3.71 ±0.09	3.73 ±0.09	0.46	0.21
Sprint30	4.34 ±0.12	4.31 ±0.09	0.35	0.29

A paired t-test revealed a significantly faster 10-meter sprint time for pretest compared to posttest for PC group (p=0.04) and a significantly faster 25-meter sprint time was revealed for pretest compared to posttest for PC group (p=0.03). However, no significant differences in five- and 30-meter sprint times for the PC group were found (table 8).

Table 8: *An overview of the sprint speed for five-, 10-, 25- and 30-meter sprint time and changes from pretest to posttest* for power clean group (PC)*. * Indicates a significant difference between pre- and posttest sprint speed.*

PC-Group	Pre	Post	p-value	ES
Sprint5	1.06 ±0.03	1.10 ±0.09	0.15	0.40
Sprint10	1.79 ±0.08	1.85 ±0.13	0.04*	0.58
Sprint25	3.66 ±0.11	3.72 ±0.16	0.03*	0.63
Sprint30	4.32 ±0.16	4.27 ±0.14	0.17	0.36

An unpaired t-test revealed no significant differences in sprint time at pretest between HX and PC group for either the five-, 10-, 25- or 30-meter sprint time (table 9).

Table 9: *An overview of the sprint speed for five-, 10-, 25- and 30-meter sprint time and difference in sprint speed between hex bar group (HX) and power clean group (PC)*

	Pretest			Posttest		
Test	**PC-group**	**HX-group**	**p-value**	**PC-group**	**HX-group**	**p-value**
Sprint5	1.07 ±0.05 s	1.08 ±0.04 s	p=0.66	1.11 ±0.10 s	1.13 ±0.09 s	p=0.54
Sprint10	1.79 ±0.08 s	1.80 ±0.09 s	p=0.79	1.86 ±0.13 s	1.83 ±0.14 s	p=0.58
Sprint25	3.67 ±0.11 s	3.70 ±0.12 s	p=0.47	3.74 ±0.16 s	3.70 ±0.14 s	p=0.55
Sprint30	4.32 ±0.16 s	4.33 ±0.15 s	p=0.88	4.28 ±0.15 s	4.30 ±0.16 s	p=0.79

5.0 Discussion

The purpose of this study was to investigate the effect of a seven-week strength training intervention using either the power clean exercise or loaded hex bar jump in enhancing CMJ height, five-, 10-, 25- and 30-meter sprint time, 505 change of direction, power clean 1RM and power output in a loaded hex bar jump.

The primary finding in the present study was that seven-weeks of power clean or loaded hex bar jump training were generally equally effective in enhancing physical performance in tested performance measures. We found an overall significant increase in CMJ height for posttest compared to pretest for PC and HX group, additionally we found an increase in power clean 1RM and faster COD time for HX group. Similarly, we found an increase in power clean 1RM for the PC group, but not for COD time. We found a significantly higher power output in posttest compared to pretest for 81 kg loaded hex bar jump for PC group.

5.1 Comparison with recent literature

For this section we aim to compare and contextualize our study results by examining and contrasting them in relation with previous literature.

The present study`s findings for CMJ was similar to previous literature that also showed an increase in CMJ height after a training intervention included power clean (19,36) or loaded squat jumps (33,38,39). Similar results for increase in power clean 1RM was found in recent literature following a loaded squat jump focused training intervention (15). The outcome of our study`s sprint tests contradict multiple studies on the area (5,8,14,19,28,31,36,39) while other studies are consistent with our findings for sprint speed as neither Hoffman (2004) or Helland (2017) found any increase in sprint time followed by an Olympic weightlifting derivatives training intervention (15,17). Recent research supported our findings in that a loaded hex bar training intervention has a positive impact on COD performance (21,31). However, the present study`s findings showed no effect of a power clean training intervention for COD performance which contradicts the studies by Keller (2020) and Kaabi (2022) but supported by Morris (2022) (19,21,28).

5.2 Performance tests

5.2.1 Loaded hex bar jump power output.

In previous literature it has been suggested that Olympic weightlifting derivatives exercises such as power clean are superior to plyometric training for increasing power output due to the higher load possible while not compromising on the high velocity movement (25). However, the power clean exercise is highly dependent on technical factors such as posture, weight distribution, bar position etc. (28). A less technical loaded plyometric exercise might be more beneficial for inexperienced athletes in weightlifting to increase power output such as the loaded hex bar jump (15). However, the present study`s results did not support this as a decrease in the 21- and the 41 kg loaded hex bar jump was found for HX group from pretest to posttest. The PC group revealed only a decrease in the 21 kg loaded hex bar jump from pretest to posttest. The decrease in power output for the 21- and 41 kg loaded hex bar jump tests was surprising after the increase in CMJ for HX and PC groups was found. A potential reason behind this result might be due to the former experience of the loaded hex bar jump which they are used to perform with higher loads. Several participants performed the 21- and 61 kg loaded hex jump with similar velocity over the same distance traveled. According to the force velocity relationship this would not have been physically possible if the participants performed the 21 kg loaded hex bar jump test with maximal intensity (18). Participants may have under-archived their actual power output for the 21 kg loaded hex bar jump test due to the unfamiliarity of the jump exercise, which seemed difficult to accelerate hard with the low load. The unloaded CMJ test, however, is a more familiar exercise, which they have performed multiple times over the years.

The findings for the 21- and 41 kg loaded hex bar contradict the result from Sáez de Villarreal (2011) who found an increase in power measured by loaded jump squats for 17, 27, and 37 kg (10). A possible explanation for the contradicting results for increased power output might be since the athletes in the present study were used to training with more traditional unloaded plyometric exercises. As the soccer players have trained with unloaded plyometric training and had recently finished a six-week training intervention only consisting of such exercises. They will most likely have a very high physical level in such exercises. The lack of

low loaded plyometric training could be the reasons why a decrease in 21 kg loaded hex bar jump were seen as training intervention from the present study did not include any other ballistic or plyometric exercises than the power clean or loaded hex bar jump. This was not the case for the handball players. However, the majority of HX group consisted of soccer players which could have affected the results. As the present study used a heavy load of an average of 90 kg in the loaded hex bar jump and 65 kg in the power clean exercise within 80-90% of their 1RM the exercises are both focused on the high-force portion of the force velocity curve with a heavy load at lower velocity which may have a low transfer and not being optimal in enhancing performance in the low-force portion of the curve (10). This might explain the decrease in the power output for the 21 kg loaded hex bar jump test. The heavy loaded ballistic exercises should, however, increase power at higher loads similar to the training intervention loads (10). This was supported by our findings that showed improvements in power output for the 81 kg loaded hex bar jump posttest, with increases of 16.2% for PC group and 9% for HX group respectively. Only the PC group showed a significant increase, even though a large and medium effect size for both groups were found. The high standard deviation for the HX group pretest might explain the non-significant findings.

5.2.2 Power clean

The power clean exercise has been recommended throughout the literature to be a very valuable exercise to increase power output, jumping and sprinting performance (2,10). However, the power clean has also been indicated to be a very hard technical exercise for inexperienced athletes and may be more favorable for experienced athletes (15,28). The loaded hex bar jump might be equally as effective as power clean to increase strength as they are biomechanically very similar to each other and are measuring the same capabilities of the neuromuscular system. This was supported by the present study that found an increase from pretest to posttest in power clean 1RM for HX and PC groups. No difference between groups was seen for pretest or posttest. As the PC group focused on the power clean exercise in the seven-week intervention period, it would likely increase their technical skill level and increase power in the intervention period, while the HX group would not increase their technical skill. However, the results from the power clean 1RM test supports this study's hypothesis as both groups increased their 1RM power clean from pretest to posttest.

The similar increase may be due to the HX group trained at a higher volume during the training intervention but did besides familiarization lack the practice in power clean, including the improvement in the technical aspects of the exercise. While the PC group trained the power clean exercise for seven weeks and most likely increased their technique more compared to the HX group. The increase for the PC group seems to be partly due to improved technique as a change in kinematic and kinetics of the bar-path (10) and partly due to overload of the lower body triple extensor ankle, knee and hip and increased intramuscular coordination as effect of the training (10). This will increase the athlete's ability to generate a higher force in a short amount of time (10). Furthermore, an increase in power clean 1RM was found for the HX and PC soccer players while only the PC group of handball players increased power clean 1RM. The lack of increase observed for the handball HX group could be due to the handball players performing power clean at a more advanced level compared to the soccer players, based on the higher loads and former experience in power clean (1). The higher level makes it a challenge for the handball players to make further improvements in this exercise (1). Practice of the technical aspects in power clean at higher loads might be crucial for further improvements. However, as for the soccer players, the improvement in power clean 1RM was seen for both groups. The HX group trained with a higher volume compared to the PC group but lacked the technical aspect. However, it appears when both exercises target the triple extension movement, there is a certain degree of transferability, regardless of whether the soccer players did train power clean or loaded hex bar jump for increase in power clean 1RM. So, while the PC group lacked in volume compared to the HX group, they still have trained the triple extension and might have been compensated with a technical improvement.

5.2.3 CMJ

The present study hypothesized that a seven-week strength training intervention using the loaded hex bar jump exercise will at minimum result in a similar increase in countermovement jump (CMJ) height compared to the power clean intervention group. As expected, this hypothesis was supported by the present study`s result that showed a significant increase in CMJ height for HX and PC group pre to posttest, but no differences were found between groups before or after the intervention. The increase in CMJ height for HX group and PC group is supported by recent literature which revealed that plyometric training

and power clean are equally effective in increasing CMJ height (2,32). However, a study by Morris (2022) suggests that the technical component of the power clean may inhibit the chance to overload the triple extension of the ankle, knee and hip and therefore result in a lower or no increase in CMJ following a power clean training protocol (28). Another study by McBride dismissed this claim and proposed that both the loaded squat jump and power clean can easily overload the triple extension and increase CMJ height (25). This was supported by the present study findings that revealed an increase in CMJ height for both groups with very large effect sizes.

5.2.4 Sprint and change of direction.

The present study result for linear sprint time contradicts the findings of Tricoli et al that showed an increase in sprint speed after seven weeks of weightlifting exercises including the power clean exercise (36). The fact that a decrease in linear sprint speed was found in the 10- and 25-meter sprint for PC group in the present study might be due to the increasing fatigue generated over a season as seen in other studies/ the literature (30). The groups pretests were performed after a recovery winter break mid-season and tested again close to season end when the players have had a lot of matches. Another reason for the decrease in linear sprint speed could be due to the lower recovery period for the soccer players at posttests which were performed 40 hours after the last soccer match compared to pretests that were performed above 72 hours after a soccer match. The negative impact of lack of recovery is supported by the study by Nédélecal (2012) that reveals a recovery period below 72 hours may diminish the performance due to fatigue which will often be detected in a 20-meter run as the average sprint in soccer is 2 seconds around 17-meters which was close to the distance for the decrease in sprint time in the present study (30). This is supported by the present study result as it is only the soccer players that had a significantly slower linear sprint speed in posttest compared to pretest. The handball players' linear sprint speed has either not changed or have increased for both the HX and PC group. However, no difference was found at any of the linear sprint tests for the HX group. This could indicate that the loaded hex bar jump training intervention may have countered the negative effect off in season fatigue. Furthermore, there does not seem to be any differences between HX and PC groups in any of the linear sprint measures based on the test result of the present study which are

supported by recent literature that both exercises are to have a positive impact on sprinting speed training as a consequence of the triple extension overloads of ankle, knee, and hip in an explosive movement (9). Another reason for the decrease in sprint time found in the present study for 10- and 25-meters and the lack of significant increase might be due to a low transfer as the HX group trained at very high intensities compared to a more traditional plyometric training and the power clean being kinematically different from sprint**.** The low transfer seen for the HX group in sprint time are supported by a study from Young (2006) who claims that exercises using only bilateral contractions such as squat jumps may only have minimal transfer to unilateral movement such as sprint despite the positive effect of training the triple extension of hip, knee, and ankle joints (40).

5.2.5 Change of direction test

Additionally, the present study found an increase for COD for HX group, and it seems that a tendency toward an increase was found in PC group with posttest being 0.06 seconds faster than pretest ($p=0.14$) with medium effect sizes for both. However, this was not enough to surpass the significance level for the PC group. As the COD and sprint measures were tested the same day, the same lack of recovery will be present as the post COD tests were performed 40 hours after the latest soccer match were played. This might have inhibited the training response and thereby explain the lack of significance for the PC group. Although the lack of recovery might play a substantial role, the COD test may also be more technical compared to sprint as the athlete changes direction at the turning point, momentum becomes a significant factor to overcome (28). It can be questioned that excessive acceleration prior to turning point might be counterproductive, as the athlete would need to exert greater effort to overcome the resulting momentum. Therefore, optimal decision-making regarding the acceleration rate and timing of deceleration during the first part of the 5-0-5 COD could be a determining factor in COD performance (28). However, when it is a 180-degree turning point in high velocity a high mass will be put on the turning leg demanding a high maximal force which was trained in the HX group as they performed very heavy loads (87.0±15.8) with a higher load and volume compared to PC group ($p<0.001$**)**. This may explain why a faster COD time was found for the HX group and not PC group.

5.3 Limitations

Despite the practically usefulness of these findings, a few limitations should be acknowledged as we faced several limitations that impacted our progress. Firstly, we encountered a lack of supervision for the handball players over the last three weeks. This absence of guidance and oversight may have affected the players' training and performance outcomes. Without the proper supervision in the last three weeks, where the players had their heaviest sets, it has not been possible to know if the desired intensity, volume, and progression of the exercises has been done correctly, which could have led to a decrease in the training effect. Additionally, we were unable to incorporate extra repetitions in the loaded hex bar jump test using a weight of 100 kg. This limitation restricted our ability to fully assess the players' strength and power capabilities. Furthermore, there were instances where the athletes did not have sufficient recovery time of less than 48 hours before certain testing sessions. This lack of adequate rest may have compromised the accuracy and reliability of the test results.

In conclusion, a training intervention including the loaded hex bar jump exercise shows similar improvement in CMJ height and power clean 1RM as the power clean. No differences were found between groups in any of the physical performance measures. However, a training program including loaded hex bar jumps seems to increase COD test time while a training program including the power clean exercise increased the power output for 81 kg loaded hex bar jumps. None of these training interventions increased performance measures from pre to post test in any of the sprint measures with power clean exercise leading to a decrease in 10- and 25-meter sprint performance.

6.0 Practical application

The present study`s result showed an increase in many of the performance measures for the majority of the players from pre to posttest while training with either loaded hex bar jump or power clean. As a result, the present study showed that loaded hex bar jump could be at minimum as effective as the power clean exercise for improving CMJ height and power clean 1RM. The loaded hex bar only requires a few familiarization sessions whereas the power clean is extremely difficult to perform correctly and therefore is a more time-consuming exercise. Strength and conditioning coaches for large teams with many players may have limited time with each athlete and could therefore benefit from using loaded hex bar jumps in their resistance training program as it is more time efficient. Furthermore, it may not be all coaches that have the technical knowledge to teach their athletes the proper technique used in power clean exercise which could lead to even less gains while loaded hex bar jumps have lower technical demands and might be easier for the majority of the athletes to perform correctly.

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