Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Medicine and Health Sciences
Department of Neuromedicine and Movement Science

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The Effect of CrossFit® versus Conventional Training on Maximal and Explosive Strength: A Randomized Controlled Trial

Norsk tittel: Effekten av CrossFit® versus konvensjonell trening på maksimal og eksplosiv styrke: En randomisert kontrollert studie

Master's thesis in Physical Activity and Health
Supervisor: Vegard Moe Iversen
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June 2021

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Kunnskap for en bedre verden

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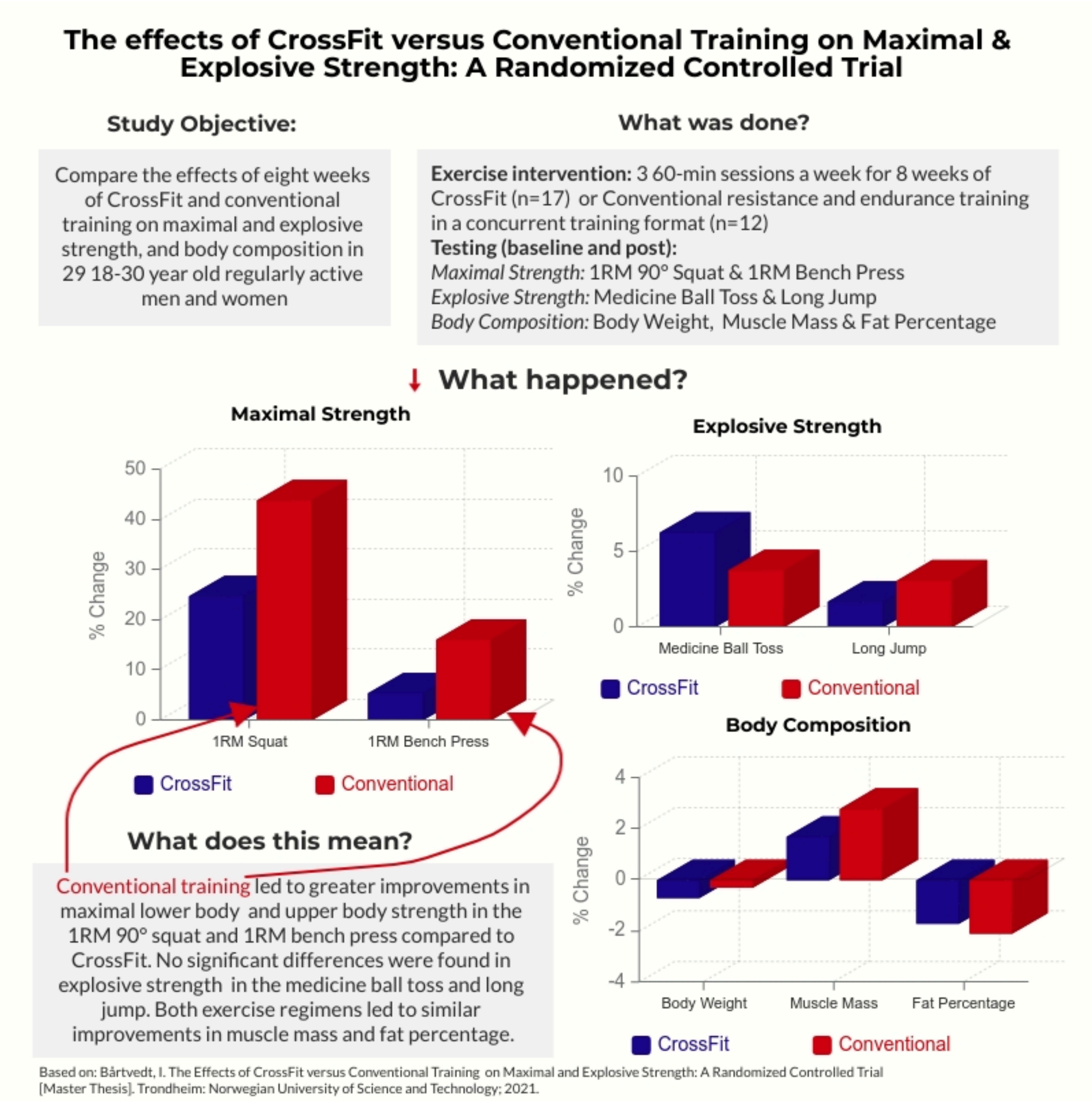
Acknowledgement

Working with this master thesis has definitely offered several challenges, given the situation with Covid-19. All in all, I feel lucky to have gotten to perform the data collection as planned. I would like to give a huge thanks to my fellow master student Rebekka Resell Mauring who has been my partner throughout it all. I would also like to thank my supervisors Vegard Moe Iversen and Marius Steiro Fimland for great guidance through the process, as well as CrossFit® Maxpuls including Ketil Inderberg, Ole Thomas Trobe, Mark Leskó and Esten Heggem for letting us hold the training sessions at their affiliate and for helping with programming the CrossFit® intervention. A thanks to Anders Holmberg for taking the illustration photos. Last but not least I want to give a special thanks to all the volunteers that participated in our project. It would not have been possible without their enormous work and dedication.

Infographic



Abstract English

Background: CrossFit® is a type of high intensity functional training that has spread across the world as both a recreational and competitive sport. By combining aerobic endurance training and resistance training elements in functional multi-joint movements CrossFit® aims to increase work capacity in ten physiological characteristics, including maximal and explosive strength. Previous research comparing the effects of CrossFit® on maximal and explosive strength have mainly focused on the differences compared to resistance training alone. However, research comparing CrossFit to more conventional training methods combining resistance- and endurance training is sparse. **Aim:** The primary aim was to compare the effects of CrossFit® versus conventional resistance and endurance training in a concurrent training format on maximal and explosive strength. A secondary aim was to compare the effects on body composition.

Methods: Twenty-nine healthy men and women were randomly assigned to eight weeks of CrossFit® (n=17) or conventional resistance and endurance training (n=12). Maximal lower body and upper body strength (1RM 90° squat and bench press), upper body and lower body explosive strength (medicine ball toss and long jump), and body composition (body weight, muscle mass and fat percentage) were assessed at baseline and after the eight-week exercise period.

Results: Conventional training improved 19.8 kg more compared to CrossFit® in the 1RM squat (p = 0.006, 95% CI: 6.5 to 33.1) and 4.8 kg more in the 1RM bench press (p = 0.02, CI 95%: 1.93 to 7.74). There were no significant differences between the groups in the medicine ball toss (p= 0.350, CI 95%: -9 to 26), the long jump (p = 0.550, CI 95%: -10 to 5), body weight (p = 0.673, CI 95%: -1.3 to 0.8), muscle mass (p = 0.401, CI 95%: -0.9 to 0.5) or fat percentage (p = 0.461, 95% CI: -0.7 to 1.5).

Conclusion: The conventional training performed in the present study was significantly more effective in improving maximal upper body and lower body strength compared to the CrossFit® performed in this group of healthy 18-to-30-year-old men and women. No differences were found between the groups in explosive strength. Both exercise regimens induced similar positive improvements in body composition.

Abstrakt Norsk

Bakgrunn: CrossFit® er en type høyintensiv funksjonell trening som har spredd seg verden over som både en rekreasjons- og konkurransesport. CrossFit® kombinerer elementer fra aerob utholdenhetstrening og styrketrening ved å utføre funksjonelle flerleddsbevegelser med sikte på å øke arbeidskapasitet i ti fysiologiske egenskaper, deriblant maksimal og eksplosiv styrke. Tidligere forskning har hovedsakelig fokusert på forskjellene mellom CrossFit® og konvensjonell styrketrening. Forskningen som sammenligner effekten av CrossFit® med konvensjonelle treningsmetoder som kombinerer styrke- og utholdenhetstrening er imidlertid mangelfull. **Formål:** Hovedmålet med denne studien var å sammenligne effekten av CrossFit® versus kombinert konvensjonell styrke- og utholdenhetstrening på maksimal og eksplosiv styrke. Et sekundært mål var å sammenligne effekten på kroppssammensetning.

Metode: Tjueni friske menn og kvinner ble tilfeldig plassert i en CrossFit®-gruppe (n=17) og en konvensjonell gruppe (n=12) for åtte ukers trening. Maksimal styrke i underkropp og overkropp (1RM 90° knebøy og 1RM benkpress), eksplosiv styrke i overkropp og underkropp (medisinballkast og stille lengdehopp), samt kroppssammensetning (kroppsvekt, muskelmasse og fettprosent) ble testet ved oppstart og etter de åtte ukene med trening.

Resultat: Konvensjonell trening forbedret seg 19,8 kg mer i 1RM 90° knebøy sammenlignet med CrossFit® (p = 0,006, CI 95%: 6,5 til 33,1) og 4,8 kg mer i 1RM benkpress (p = 0,02, CI 95%: 1,93 til 7,74). Det var ingen signifikante forskjeller mellom gruppene i medisinballkast (p = 0,350, CI 95%: -9 til 26), stille lengdehopp (p = 0,550, CI 95%: -10 til 5), kroppsvekt (p = 0,673, CI 95%: -1,3 til 0,8), muskelmasse (p= 0,401, CI 95%: -0,9 til 0,5) eller fettprosent (p = 0,461, 95% CI: -0,7 til 1,5).

Konklusjon: Denne typen konvensjonell trening økte maksimal styrke i underkropp og overkropp mer effektivt sammenlignet med denne typen CrossFit® blant friske 18-30 år gamle menn og kvinner. Ingen signifikante forskjeller mellom gruppene ble funnet i eksplosivitet. Begge gruppene ledet til forbedret kroppssammensetning.

Table of Content

Abbreviations

ACSM American College of Sports Medicine

AMRAP As many rounds as possible

EMOM Every minute on the minute

RIR Repetitions in Reserve

WOD Workout of the day

Introduction

Improvements in maximal and explosive strength are accompanied by multiple health related benefits and are considered important for several athletic events including throwing, jumping, gymnastics, accelerating and rapid changes of direction (1-3). Conventional approaches for improving maximal and explosive strength typically involves performing resistance training in a systematically and progressively manner to continuously maximize muscle fiber recruitment and muscle hypertrophy (4). Consequently, exercise periodization by systematically manipulating one or more elements in a program sought to keep exercise stimulus challenging trough continuous progression whilst also optimizing recovery and reduce the risk or immensity of overtraining (4, 5). Different periodization models exist including classical (linear) and undulating (non-linear) periodization (4-6). The linear periodization model generally focuses on developing one characteristic at a time and operates with a high initial exercise volume then gradually increasing resistance whilst simultaneously decreasing exercise volume, e.g., 12-15 repetition maximum (RM) to 8-10 RM, and is designed to lead to a peak in performance (5). An undulating model in turn, aims to develop multiple characteristics simultaneously (e.g., maximal and explosive strength) by utilizing variation in intensity, volume and exercise order within the same exercise period (e.g., 3-5 RM, 8-10 RM and 12-15 RM).

Traditionally, resistance training has been performed separately from aerobic endurance training as the improvements following exercise are somewhat different, however, several athletic disciplines highly benefit from athletes who are proficient in both domains (4, 5, 7-9). Thus, concurrent training, which refers to undertaking aerobic endurance training and resistance training within the same session, is gaining interest as a time-efficient approach for optimizing physical competency (3, 7, 8, 10). A non-linear approach to concurrent training is CrossFit® (CrossFit® Inc., Washington, DC, USA) which is a type of high intensity functional training that has become increasingly popular since its inception in the early 2000s and have spread across the world as both a recreational and competitive sport with more than 15,000 affiliated gyms worldwide (9-13). With its promising claims of preparing athletes for any physical challenge imaginable CrossFit® aims to improve work capacity across multiple physiological characteristics simultaneously including maximal and explosive strength, by performing aerobic endurance, gymnastics and weightlifting movements in a circuit format in the so-called workout of the day (WOD) (9, 13, 14). CrossFit® have also been associated with favorable effects on body composition (15-18).

Experimental trials have found significant improvements in maximal and explosive strength following CrossFit® (16, 19-22), but there are only a few studies that have compared the effects of CrossFit® with the ones related to more conventional exercise regimens. Barfield and colleagues (23) found both CrossFit® and conventional group-based resistance training to lead to significant improvements in maximal strength. The CrossFit® performed in this study, however, was a so-called basic instruction program and as details of the CrossFit® intervention were not presented there is uncertainty regarding the consistency with original CrossFit® programming which weakens the generalizability of these findings (14). Barfield and Anderson (24) extended the work of Barfield and colleagues (23) but with a CrossFit® class consistent with CrossFit® programming and found no significant improvements in lower body explosive strength in either groups following 14 weeks of training. However, this study did not provide any insight in the effect on maximal strength.

Furthermore, a master thesis by McWeeny (25) compared six weeks of CrossFit® to conventional resistance training and found significant improvements in maximal strength following CrossFit®, but these improvements were not significantly different from the ones following conventional resistance training. Also, the participants included were allowed to perform uncontrolled endurance training outside of the exercise intervention which increases total exercise volume and potentially affects both exercise stimulus and recovery. Thus, the reliability of these findings is weakened. Özbay (18) compared 16 weeks of CrossFit® to conventional resistance training and found no significant difference in the improvement of maximal strength between the groups, but as the same 20-minute WOD was performed every session which is inconsistent with CrossFit® programming the generalizability of these findings is weakened. Additionally, as the aforementioned studies compared CrossFit® to resistance training alone, they do not provide any insight in the effects of CrossFit® compared to the ones following conventional training performed in another concurrent training format.

There are only one randomized trial, to my knowledge, that have compared CrossFit® to conventional training in a concurrent training format (17). In this study, Bahremand and colleagues (17) found both exercise regimens to lead to significant improvements in maximal strength and body composition, but the improvement in upper body maximal strength was significantly different favoring CrossFit®. However, the conventional training performed in this study was adapted from another study which only utilized lower body exercises using machines (26), and as this study also does not provide any insight in the effects of explosive strength, the need for more research is evident. Therefore, the primary aim of the present study was to compare the effect of eight weeks of CrossFit® to conventional training in a concurrent training format on maximal and explosive strength. A secondary aim was to compare the effects on body composition. It was hypothesized that conventional training would elicit greater improvements in maximal strength, whereas the improvement of explosive strength would be greatest following CrossFit®. Body composition was hypothesized to improve similarly following both CrossFit® and conventional training.

Materials and Methods

Study Design and Setting

This study was a randomized controlled trial (RCT) which investigated the effects of CrossFit® versus conventional training on upper body and lower body maximal strength, upper body and lower body explosive strength, and body composition. The study was a part of a larger RCT including maximal oxygen consumption (Vo_2max), anaerobic capacity, work capacity and degree of satisfaction which are reported in another master thesis (27). The study took place in Trondheim, Norway, and had a total duration of 14 weeks including one week of eligibility screening of participants and randomization, one week of familiarization, an eight-week exercise intervention and four weeks of testing (two weeks at baseline and two weeks post intervention). Figure 1 shows the study timeline. The study was carried out in accordance with the Declaration of Helsinki and the Norwegian Centre for Research Data (NSD) considered the study to be in agreement with the Privacy Act. Results are reported in accordance with the CONSORT statement (28). Maximal strength was assessed at a local CrossFit® affiliate, CrossFit® Maxpuls, which also was the location for familiarization and exercise intervention. Explosive strength was assessed at Ranheimshallen and body composition at St. Olavs Hospital.

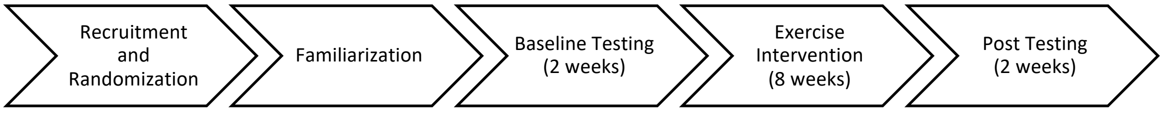


Figure 1. Study timeline.

Participants and Enrollment

Thirty participants were desired for this study, however, due to the prevalence of dropouts in studies like this thirty-six men and women were recruited and randomized. The participants were randomly assigned to two exercise groups: CrossFit® (n=18) or conventional training (n=18). Randomization was performed using a 1:1 block randomization with an unknown block size by a web-based randomization system developed and administered by Clinical Research Unit Central Norway, The faculty of Medicine and Health Sciences, Norwegian University of Science and Technology (NTNU), Trondheim, Norway.

The participants were recruited trough advertisement on social media, visits to lectures at NTNU campus, and posters on campus and student fitness centers. Inclusion criteria were healthy men and women aged 18-30 years, exercising 1-3 times a week the last six months (which included recreational sports or resistance training and/or endurance training), able to meet for scheduled sessions three days a week at daytime at CrossFit® Maxpuls, and were not already engaged in CrossFit®. The ones who showed interest to participate answered an eligibility form covering training background, age, potential injuries and health related problems, to ensure that they were eligible for participation (appendix 1). Participation required participants to refrain from performing CrossFit® and/or structured resistance training and moderate-to-high intensity endurance training outside of the study. Signed informed consent was obtained prior to study start (appendix 2).

Exercise Interventions

Both groups met for scheduled 60-min sessions Mondays, Wednesdays and Fridays for eight weeks. Due to pandemic regulations and practical purposes both groups were divided into two smaller groups (four groups of seven to nine people). All sessions were supervised and led by the two master students, which are certified group instructors and CrossFit® coaches. The participants were requested to not perform any sessions unsupervised if unable to meet for scheduled sessions. In the event of a participant missing a session, a replacement session was scheduled within the same or following week, with a maximum of four sessions a week. Prior to testing and exercise start both groups were given 3.5 hours of familiarization to the most complex exercises included (appendix 3).

CrossFit®

The CrossFit® group completed 24 different WODs programmed based on the "3-1" template (14), developed by the master students in cooperation with three experienced CrossFit® coaches at CrossFit® Maxpuls. The 3-1 template varies by including one, two or three elements in the following pattern: day 1, 5 and 9: single-element days, day 2, 6 and 10: two-element days (couplets) and day 3, 7 and 11: three-element days (triplets) (14). In contrast to the three-days-on-one day-off-template, one day of rest was set between each session to facilitate sufficient recovery. Thus, Mondays were 1-element days, Wednesdays were 2-element days and Fridays were 3-element days. In a single element day, only exercises from one element are included: Metabolic conditioning (M), Gymnastics (G) or Weightlifting (W) (14). E.g., a single M day could involve running and/or rowing longer distances, whereas G days focuses on developing skills in a technically challenging movement of such complexity that it might not yet be suitable for inclusion in a couplet or triplet. W days focuses on lifts with heavy resistance and few repetitions. Couplets involves two elements (e.g., M and G) and are so-called task priority WODs where the task is set and the time varies, typically alternating two exercises three to five rounds as fast as possible (for time). In a triplet all three elements are included (M, G and W) and three or more exercises are repeated for a predetermined number of minutes with the goal to complete as many rounds or repetitions as possible (AMRAP) (14). "EMOMs" (Every Minute On the Minute in x minutes) were also included, where one minute is given to complete a prescribed number of repetitions of an exercise before moving to the next exercise when the next minute starts, e.g., an EMOM30 of rowing and burpees gives 30 minutes of 15 alternating sets of each exercise. "AMRAPs" and "For time" had no prescribed rest periods where the goal was to perform the exercises as fast as possible, whereas "EMOMs" aimed to facilitate 10-15 seconds of rest between each exercise by using a maximum of 45-50 seconds on performing the prescribed repetitions per exercise. "For time" operated with a "time cap" meaning that the maximal time to complete a WOD was predetermined, and that all participants needed to stop exercising at time cap independent of completing the WOD or not. Some WODs were also "team of two" WODs where two participants split the prescribed number of repetitions and worked as a team to complete the WOD. Table 1 gives an overview of the CrossFit® programming.

Each WOD started with a presentation of the WOD, scaling options and recommendations on choice of resistance in the weightlifting exercises, before moving to a warmup. The warmup was comprised of a 10-minute general warmup followed by a 5–10-minute specific warmup reflecting the content of the given WOD. Table 2 and figure 2 show a selection of some of the most used warmup exercises. The WODs were generally split in two parts: a 10-20-minute technique or heavy lifting (skill) part and a 10-30-minute high intensity part. The latter was either an "AMRAP", "For Time" or "EMOM".

Exercises included in the WODs varied depending on the element(s) of focus and are listed in table 3. A sample of these exercises are presented in figure 3. WODs are designed to challenge even the most advanced athletes but still provide an appropriate stimulus for novice (14). Thus, scaling, which refers to altering parts of a WOD (e.g., resistance, time domain or movements) to create a safe and efficient WOD for everyone, is common practice. Therefore, individual scaling was performed when necessary, for example by changing pullups to ring rows or toes to bar to knee raises, with intention to reduce technical difficulty and keep exercise intensity high. The CrossFit® intervention was progressively programmed so that more advanced lifts or high skill movements were gradually implemented, e.g., Clean and Jerk, whereas a hang power clean was implemented initially and by the end of week eight, the full clean and jerk was implemented. Variations of the lift are illustrated in figure 4. Snatch, overhead squats and double unders (double skipping jump ropes), which are commonly included in CrossFit®, were excluded from the programming due to technical complexity. Safe and technically correct form was always of first priority despite the general focus on performing exercises fast. To reduce the opportunity to practice or prepare before a session, the participants were unaware of the details of each session beforehand, except which elements were in focus (e.g., G and W).

Table 1. CrossFit® Programming Overview

	Session 1 M	Session 2 GW	Session 3 MGW
Week 1	Rowing, 4x4-intervals	Front Squat, build to heavy complex *3RFT (TC: 10 min)* 15 Front Squats (approx. 60% of 1RM) 25 Pushups	*AMRAP20* 10 Burpees 15 Box Jumps 20 Ground to Overhead 200 m Run
	Session 4 G	**Session 5 WM**	**Session 6 GWM**
Week 2	Kipping practice Toes to bar *EMOM6* 4-7 Toes to bar 16-20 Overhead lunges	*E2MOM10* 3-6 Hang Power Cleans *For time* 21-15-9 Hang Power Cleans (Rep) Assault Bike (Cal)	Push Press, build to 5RM *AMRAP20* 20 Air Squats 10 Push Presses (approx. 50% of 1RM) 12/15 Cal Row
	Session 7 W	**Session 8 MG**	**Session 9 WMG**
Week 3	5x5 Deadlift *EMOM8* 8-12 Burpees *Tabata* 20 sec x8 Sit Ups Toe touches Tuck ups Bicycle Sit Ups	Kipping pullups practice *For Time* 400 m Run 21-15-9 Kipping Pullups	*AMRAP20* 20 Wall Balls 20 Sit-Ups 20 Db Hang Power Clean & Press 20 Lunges 20 Cal Assault Bike
	Session 10 M	**Session 11 GW**	**Session 12 MGW**
Week 4	*"Fortitude"* *EMOM30* 10/12 Cal Row 8-10 Burpees	4x4 Front Squats 80-90% of 1RM *5RFT (TC: 15 min)* 24 Overhead Lunges 10 Toes to bar	Deadlift practice, build to 5RM *AMRAP20* 200 m Run 15 Pushups 15 Deadlifts
	Session 13 G	**Session 14 WM**	**Session 15 GWM**
Week 5	Handstand Practice Death by Burpee	*E2MOM10* 3-6 Power Cleans 5RFT 10 Power Cleans 10 Burpees	*"Jackie"* (scaled version) 800 m Row 35 Thrusters 20 Pull Ups
	Session 16 W	**Session 17 MG**	**Session 18 WMG**

Week 6	Push Jerk and Clean and Jerk Practice *Big Clean Complex* On Every 5 x6 3-Position Squat Clean 1 Push Press 3-Position Squat Clean 1 Push Jerk 3-Position Squat Clean 1 Push Jerk	*"Bert"* (Modified) Team of two 50 Burpees 500 m Row 100 Pushups 500 m Row 150 Walking Lunges 500 m Row 200 Air Squats 500 m Row 150 Walking Lunges 500 m Row 100 Pushups 500 m Row 50 Burpees	Buy in: 600 m Run *EMOM18* 10 Deadlifts 15 KB Swings 10-12 Toes to Bar Cash Out: 600 m Run
	Session 19 M	Session 20 GW	Session 21 MGW
Week 7	*Trisprint* Team of two AMRAP 4x5 30 Shuttle runs (10 m) 22/16 Cal Row Max Cal Assault Bike	*"Fran"* 21-15-9 Thrusters Pullups	*AMRAP30* *Team of two* 40 Cal Assault Bike 40 Wall Balls 40 Burpee Box Jumps 40 Single arm Db Push Press
	Session 22 G	Session 23 WM	Session 24 GWM
Week 8	Muscle Up Practice *EMOM12* 3-5 Ring Dips 3-5 Ring Pull-Ups 8-10 Box Jumps	Clean and Jerk, build to 3RM *EMOM10* 6-8 Clean and Jerk 8-12 Cal Row Handstand Practice	*"Lumberjack 20"* (modified) 20 Deadlifts 500 m Row 20 KB Swings 500 m Row 20 Front Squats 500 m Row 20 Burpees 500 m Row 20 Pull-Ups 500 m Row 20 Box Jumps 500 m Row 20 Dumbbell Squat Cleans 500 m Row

AMRAP, As Many Rounds As Possible; Cal, Calories; EMOM, Every Minute On the Minute; E2MOM, Every Second Minute On the Minute in x minutes; G, Gymnastics; KB, Kettlebell; M: Metabolic conditioning; 3RFT, Three Rounds For Time; Sec, Seconds; TC, Time Cap; W, Weightlifting.

Table 2. CrossFit® Warmup Exercises

General Warmup Exercises	Specific Barbell Warmup Exercises
Active Samson	Deadlifts
Active Spiderman	Good Mornings
Childs Pose	Front Squats
Hip Stretch	Shoulder Presses
Pidgeon Pose	Push Presses
Wall Stretch	Back Squats
Jumping Jacks	Elbow Rotations
Climb outs	
Mountain Climbers	
Shuttle Runs	
Squat to Stand	
Side Lunges	
Front Rack Stretch	
Bird dog	

Figure 2. CrossFit® General Warmup Exercises. A. Active Samsons, B. Mountain Climbers, C. and D. PVC Pass Troughs, E. Active Spidermans, top position, F. Active Spidermans, bottom position, G. Squat to stand, H. Wall Stretch

Table 3. CrossFit® exercises categorized by element

Metabolic conditioning (M)	Gymnastics (G)	Weightlifting (W)
Run	Pushups (box pushups)	Kettlebell swings
Row	Pullups (Ring Rows)	Wall balls
Assault bike	Handstands (Pike position)	Deadlifts
	Air squats	Front squats
	Box jumps (Box step ups)	Thrusters
	Lunges	Cleans:
	Situps	*Hang power cleans*
	Burpees	*Power cleans*
	Burpee Box jump overs	*Squat cleans*
	Toes to bar (Knees to chest, knee raises, tuck ups)	*Clean and Jerk*
		Shoulder press
		Push press
		Push Jerk
		Weighted lunges
		Ground to overhead

(x) = Scaling options

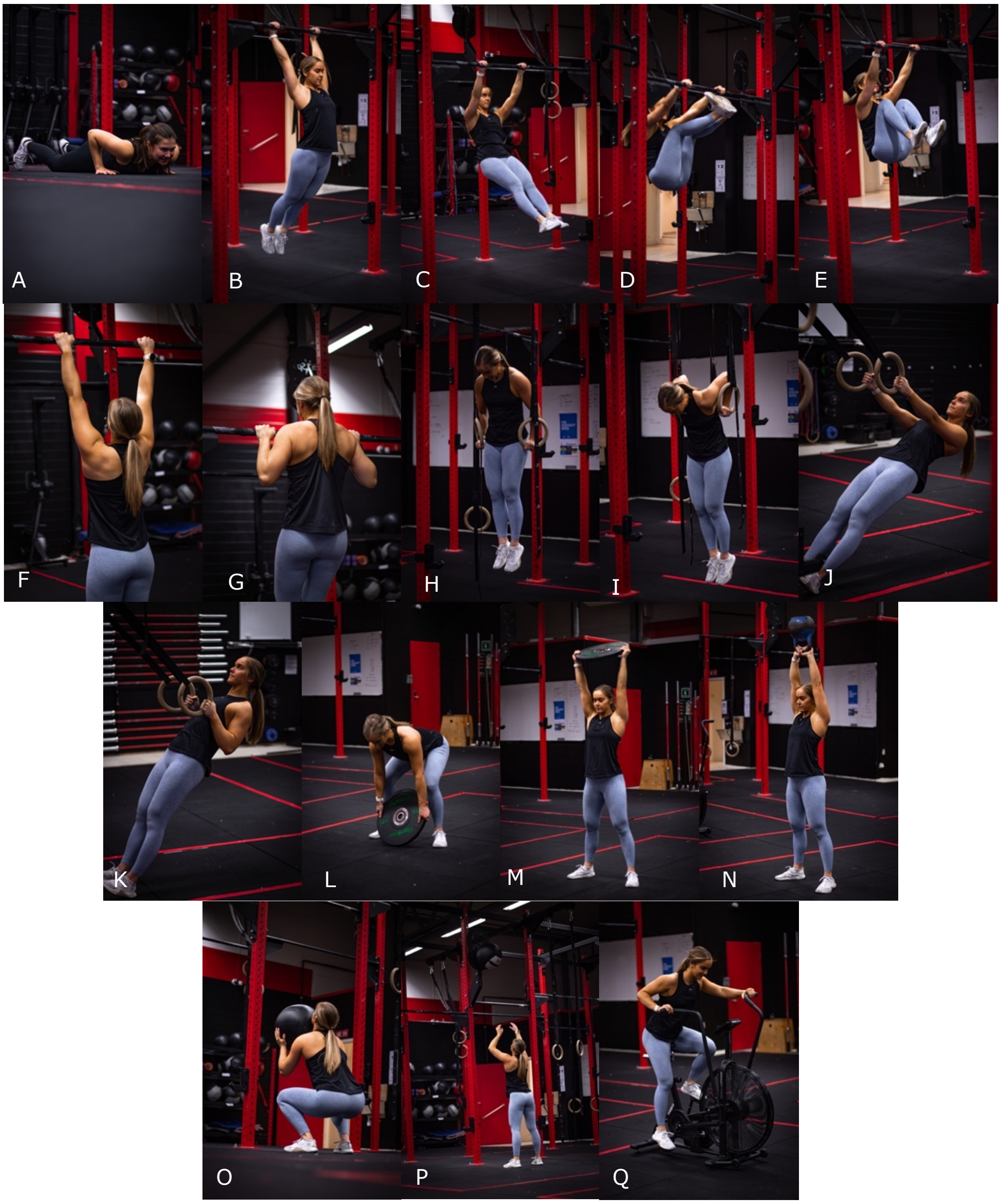


Figure 3. Examples of CrossFit exercises. A. Burpees, B. Arch, Kipping movement, C. Hollow, Kipping movement, D. Toes to bar, E. Knees to chest, scaling option for toes to bar, F. Pullups, bottom position, G. Pullups, top position, H. Ring dips, top position, I. Ring dips, bottom position, J. Ring rows, start position, scaling option for pullups, K. Ring rows, top position, scaling option for pullups, L. Ground to overhead, bottom position, M. Ground to overhead, top position, N. Kettlebell Swing, O. Wall Balls, bottom position, P. Wall Balls, top position, Q. Assault Bike.

Figure 4. Olympic Clean variations. A: Hang clean, starting position, B. Clean, starting position, C: Moving/Pulling position in hang power clean/clean, D. Power Clean, receiving position E. Squat clean, receiving position, F. Push jerk

Conventional Training

The conventional group did 35 minutes of resistance training and 25 minutes of high intensity interval training (HIIT, 4x3 minutes treadmill running at 85-95% of maximal heart rate) each session and alternated starting the session with resistance training or HIIT. The resistance training was based on the American College of Sports Medicine (ACSM) recommendations for resistance training progression for novice to intermediately trained (4) and composed of three barbell exercises in the following order: back squats, bench presses and standing bent over rows. The resistance training followed a linear periodization format: week 1-4: 3 sets of 10-12 repetitions at 70-75% of one repetition maximum (1RM), 1.5-2-minute breaks between sets, and week 5-8: 3 sets of 8-10 repetitions at 75-80% of 1RM, 2-minute breaks between sets. Each exercise was initiated with 1-3 warm up sets with progressively increased resistance at 35-60% of 1RM. Percentage of 1RM for each exercise was estimated from the familiarization sessions and maximal testing for each participant. As muscular strength can vary from day-to-day and be influenced by performing HIIT prior to resistance training a repetition-in-reserve (RIR) approach in combination with desired percentage of 1RM was utilized to ensure appropriate resistance intensity (29). The participants were instructed to have a maximum of 1-2 RIR on each set. This was determined by the subjective feeling of the participant and visual observation by the master students whereas a reduction in lift velocity or a loss of range of motion in the last 2-3 repetitions was considered an indication for reaching desired intensity (29, 30). The following equipment was used for all exercises: A 20 kg barbell for men and a 15 kg barbell for women (Play Sport AS), a barbell rack to place the bar in (Gym Sport AS), weight plates ranging from 0.5-25 kg (Gymleco, Gym Sport AS) and an adjustable bench (Hammer Strength).

The exercises were performed in the following order: back squats, bench presses and bent over rows. The back squats were performed by placing the barbell in a high-bar position (on the top of the trapezius muscles across the shoulders), supported by placing a narrow grip on the bar (slightly outside of the shoulders), and standing with the feet in a shoulder width position with toes pointing slightly outwards. Thereafter, the participants were instructed to squat to the point where the hip joint reached the same position or lower than the knee joint before extending the hip and reach starting position again. Participants with mobility restrictions preventing them from reaching desired squat depth were instructed to squat as far down as possible.

In the bench press, participants were instructed to lie on the bench with eyes located directly under the barbell, gather the shoulder blades together and arch the back so that the lower back raised from the bench, whilst ensuring that both shoulder blades and glutes still stayed in contact with the bench. The grip was placed approximately a thumb length from the shoulders and feet were to be in contact with the floor at all times. The bench press was then performed by un-racking the bar, lowering the bar towards the lower part of the chest, slightly touching the chest with the bar, before pressing back to starting position. The bent over rows were performed by placing an overhand grip on the bar, feet approximately shoulder width apart, letting the hip back with a slight bend in the knees and lowering the upper body in front of the lower extremity, before pulling the bar upwards towards the belly button, squeezing the shoulder blades together and then lowering the bar back to starting position. Technical feedback was provided in all exercises after each set. Figure 5 shows an illustration of all three exercises.

Figure 5. Conventional training exercises. A. Barbell Back Squats, B. Barbell Bench Presses, and C. Barbell Bent Over Rows

Experimental Testing

Two weeks of testing were performed at baseline and post intervention. The initial test week was used to test Vo_2max and body composition. The second week was comprised of three days of testing; Day 1: Explosive strength and anaerobic capacity, Day 2: Maximal strength and Day 3: Work Capacity, ensuring approximately 48 hours of rest between each test. The participants were also requested to avoid strenuous physical activity 48 hours prior to testing. The test procedures and results for Vo_2max, anaerobic capacity and work capacity are reported in another master thesis (27).

Lower Body Maximal Strength

The lower body maximal strength was assessed by performing a 1RM 90° barbell squat. The familiarization session revealed that mobility restrictions in a majority of the participants made full squats unapplicable, which was originally chosen for testing lower body strength. Thus, a squat to a 90° knee angle was chosen instead (figure 6). Prior to the test a 5-minute general warm up consisting of squat to stands, lateral lunges, active spidermans (both sides) (figure 2E and 2F), ankle stretches, and a hip flexor stretch (both sides) was performed. The participants also practiced performing the 90° squat movement 3-5 times before performing a specific warm up with submaximal loading (starting at approximately 50% of 1RM) and gradually increasing resistance until 1RM was reached (see table 4). Warm up weights were based upon training weights for the full squat recorded in the familiarization sessions. The same equipment as in the conventional training was used for testing. The participants were instructed to perform the squat in the same format as the full squat but lower themselves to the point where the knee joint reached a 90° angle (signaled by a verbal cue by the master students), before extending the hip and re-racking the bar. For security reasons, each lift was spotted by one person standing behind the participant or two people standing at each side of the bar. If a lift was failed the participant was given 5 minutes of rest before a second trial at the same or lower weight was performed.

Table 4. 1RM 90° Squat and Bench Press test protocol

Warm up	
Set 1	1x6 50% of 1RM
Rest	2 min
Set 2	1x3 70% 1RM
Rest	3 min
Set 3	1x2 85% 1RM
Rest	3.5 min
Set 4	1x1 90% 1RM
Rest	4 min
Set 5	1x1 95% 1RM
Rest	5 min
Test set	
Set 6	1x1 100% 1RM
If 1RM was not reached after set 6, a 5-minute break was given. This was continued until 1RM was reached within a maximum of 10 sets	

1RM; One repetition maximum

Figure 6. 90° squat

Upper Body Maximal Strength

Upper body maximal strength was assessed by performing a 1RM barbell bench press in the same format as the bench presses in the conventional training. This test have shown to be a reliable measure of maximal upper body strength (31). The test was performed directly after the 1RM squat with the same equipment. A specific warm up protocol was used in a similar build up as for the 1RM Squat (table 4). For safety reasons, a spotter stood behind the bench and grabbed the bar if a participant was to fail a lift. Lifts were unapproved if the bar did not touch the chest, arms were not fully extended at top or if the glutes or feet raised from the bench/floor. If a lift was failed, the participant was given a 5-minute break before a second try on the same or lower weight.

Upper Body Explosive Strength

Upper body explosive strength was assessed by performing a standing medicine ball toss based on the Norwegian Armed Forces test protocol (32). Medicine ball tests are valid measures of upper body explosiveness and this medicine ball toss was chosen due to the low cost and practical feasibility (33). The test was initiated with a warmup consisting of thirty seconds of each of the following movements: arm swings, wall pushups, wall chest stretch and air squats. Next, participants practiced the tossing movement eight times without the ball, before two submaximal practice trials with the 9 kg medicine ball (Nordic Sportsmaster AS). The test consisted of three trials separated by a three-minute break where the best of three was recorded. The toss was performed by standing behind a marked line, feet slightly apart, holding the medicine ball with both hands in front of the chest and tossing the ball forward as far as possible. Both feet needed to be in contact with the floor, but the participants were allowed to lift the heels from the floor during the toss and use their upper body and legs actively if preferred. In order to get the toss approved the participant needed to regain balance and stand with feet still after the toss. Stepping over the marked line or slipping backwards with one or both legs led to an unapproved toss. Distance in cm was measured with a measuring tape. Figure 7 illustrates how to perform the toss.

Figure 7. Medicine ball toss. A. Start position, B. Tossing position

Lower Body Explosive Strength

Lower body explosive strength was assessed by performing a long jump based on the Norwegian Armed Forces test protocol (32), which is a viable test for assessing lower body explosiveness whilst also being low-cost and feasible (34). The jump was performed directly after the medicine ball toss and started with a specific warmup of ten jumping squats and three submaximal trial jumps on the floor. The jump was performed landing in a sandpit and scored according to distance in meters jumped from starting position to landing position of the back of the heels, measured in cm with a measuring tape. If a participant fell backwards after landing the length of the jump was registered at the rearmost landing position (i.e., the position of the hand or glutes). Three trials were given where best of three was recorded. Figure 8 shows how to perform the long jump.

Figure 8. Standing Long Jump. A. Start position, B. Jump position, C. Landing position

Anthropometric Measures and Body Composition

A multi-frequency bioelectrical impedance analysis (BIA, Inbody 770, BIOSPACE, Seoul, Korea) was performed to assess body composition. The measures of interest were body weight in kg, muscle mass in kg, and fat mass in percent. The test was performed in accordance with the InBody user manual (35). Body height was measured with a wall mounted height measuring rod (Seca 222, Deutschland) prior to analysis and manually plotted. Age and sex were also manually plotted before analysis. Participants were instructed to not eat, drink or exercise prior to testing and wear light clothing (big clothing like jackets were removed prior to analysis) (35).

Statistical Analysis

The software program Statistical Package for the Social Sciences version 27.0 (IBM SPSS, Chicago IL, USA) was used for the statistical analysis. The data was visually inspected for normality using quantile-quantile (QQ) plots and histograms and assessed for normality with a Shapiro-Wilk test. Normal distribution could not be confirmed in the 1RM Squat or body weight, probably due to the small sample size. However, these variables are expected to be normal in the general population and parametric tests were therefore performed for all variables. Differences from baseline to post testing were calculated for each variable as absolute values and in percentage. Between-group differences in mean change from baseline to post testing were assessed using independent sample t-tests. Within-group differences in mean change from baseline to post testing were assessed using paired sample t-tests. The statistical level of significance was set to $p < 0.05$. Results are presented as mean ± SD and confidence intervals of 95% (CI 95%). Cohen´s d effect sizes (ES) are presented for the primary outcome variables. The cut-off values for ES were 0.2 = small effect, 0.5 = medium effect and 0.8 = large effect. Graphs were made using GraphPad Prism 9.

Considerations Associated with the Covid-19 Pandemic

Due to Covid-19 Pandemic regulations, participants were instructed to keep at least one meter distance to each other at all times. Equipment sharing was kept to a minimum, and all equipment was disinfected both when sharing was unavoidable and after each session. If a participant experienced Covid-19-like symptoms he or she was instructed to follow national COVID-19 recommendations.

Results

Participant Characteristics

Of the 36 participants randomized, six participants dropped out prior to study start due to personal reasons (dissatisfied with intervention group n = 2, work n = 2, school n = 1 and injury unrelated to study n = 1) and one participant dropped out in exercise week seven due to lack of time. Thus, 29 participants (24 women and 5 men) were included in the final analyses (figure 9). All participants completed more than 80% of the exercise intervention (88% in the CrossFit® group and 100% in the conventional group). Participants´ characteristics are presented in table 5.

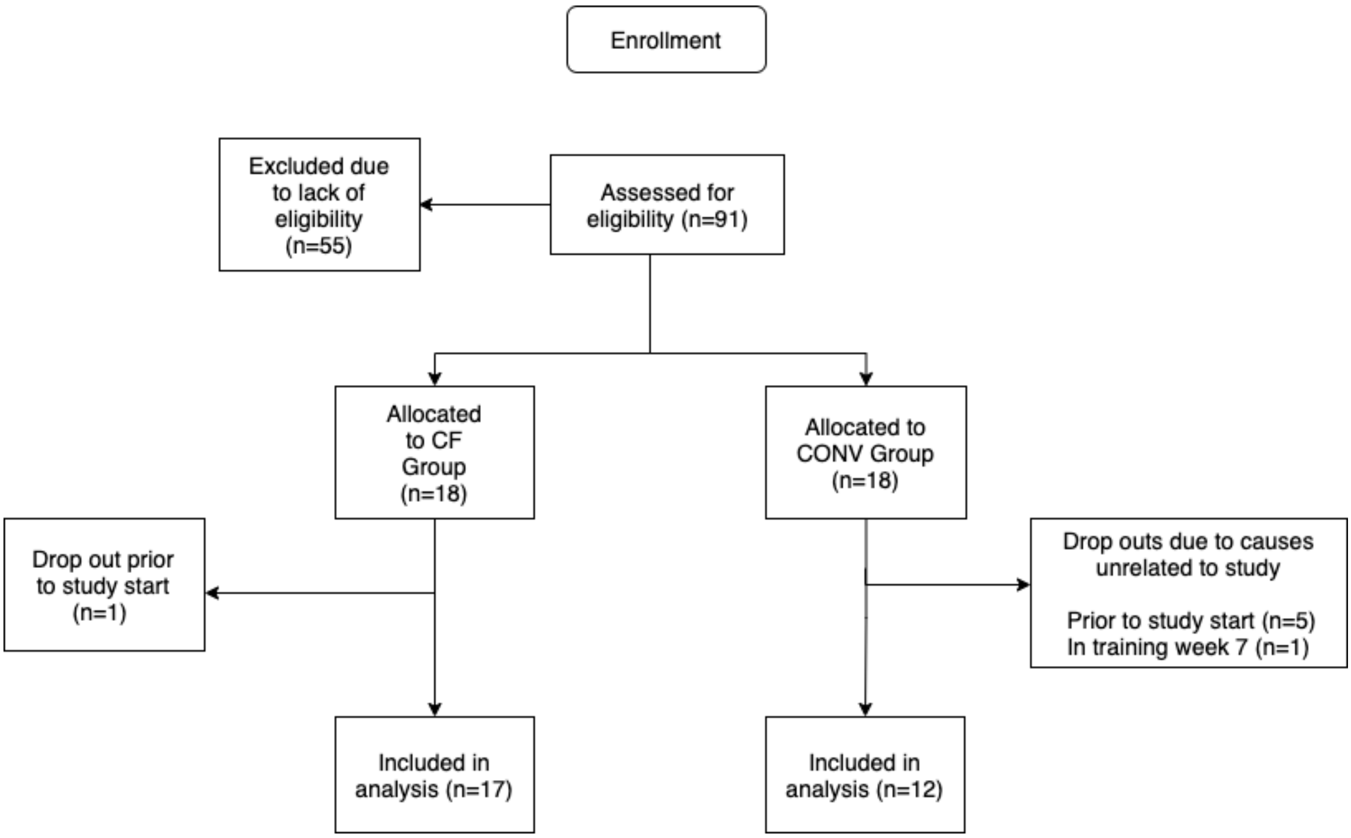


Figure 9. Flow diagram of the study design. CF, CrossFit®; CONV, Conventional

Table 5. Participant's characteristics at baseline

	CrossFit® (n=17)	Conventional (n=12)
Age (years)	23 ± 3	23 ± 2
Height (cm)	174.0 ± 7.1	171.9 ± 6.5
Body Weight (kg)	68.6 ± 9.5	74.6 ± 18.3
Women %	82%	83%
Men %	18%	17%

Data are presented as mean ± SD.

Maximal Lower Body and Upper Body Strength

Maximal lower body strength in the 1RM 90° squat improved significantly for both groups by an average of 26.3 kg in the CrossFit® group and 46.1 kg in the conventional group from baseline to post testing (p = 0.000, 95% CI: 19.7 to 32.9, ES: 2.0 and p = 0.000, 95% CI: 32.1 to 60.0, ES: 2.1, respectively). The conventional group experienced a significantly greater improvement in the 1RM squat compared to the CrossFit® group with a mean difference of 19.8 kg between the groups (p = 0.006, 95% CI: 6.5 to 33.1, ES: 1.2). In maximal upper body strength in the 1RM bench press, the CrossFit® group did not experience a significant increase with an average improvement of 1.4 kg from baseline to post testing (p = 0.191, CI 95%: -0.77 to 3.60, ES: 1.3). The conventional group experienced a significant improvement by an average of 6.3 kg (p = 0.000, CI 95%: 4.4 to 8.1, ES: 2.2), and the mean difference of 4.8 kg between the groups was significantly different favoring the conventional group (p = 0.02, CI 95%: 1.93 to 7.74 to, ES: 1.3). All data are presented in table 6 and figure 10A.

Table 6. Changes in mean absolute values from baseline to post testing after eight weeks of training

	CrossFit® (n=17)		Conventional training (n=12)	
Performance data	Baseline	Posttest	Baseline	Posttest
1RM Squat (kg)	113.7 ± 25.7	140.0 ± 25.2**	105.6 ± 22.5	151.7 ± 38.1*** [a]
1RM Bench Press (kg)	45.7 ± 20.4	47.1 ± 17.7	44.3 ± 16.5	50.6 ± 15.7***[a]
Medicine Ball Toss (cm)	360 ± 83.6	380 ± 80.1*	360 ± 58.7	370 ± 51.1
Long Jump (cm)	220 ± 32.6	220 ± 32.4	210 ± 25.8	220 ± 24.3
Body Weight (kg)	68.7 ± 9.8	68.2 ± 9.3	74.6 ± 18.3	74.3 ± 18.2
Fat Percentage (%)	23.7 ± 8.5	22.0. ± 8.0***	29.6 ± 8.2	27.5 ± 8.4***
Muscle Mass (kg)	29.2 ± 5.8	29.6 ± 5.4**	29.0 ± 6.1	29.7 ± 5.6**

Data are presented as means ± SD. *Significant differences ($p < 0.05$) within groups from baseline to post training; ** Significant differences ($p < 0.01$) within groups from pre to post training; *** Significant differences ($p < 0.001$) within groups from pre to post training; [a] Significant difference ($p < 0.001$) between groups from pre to post training

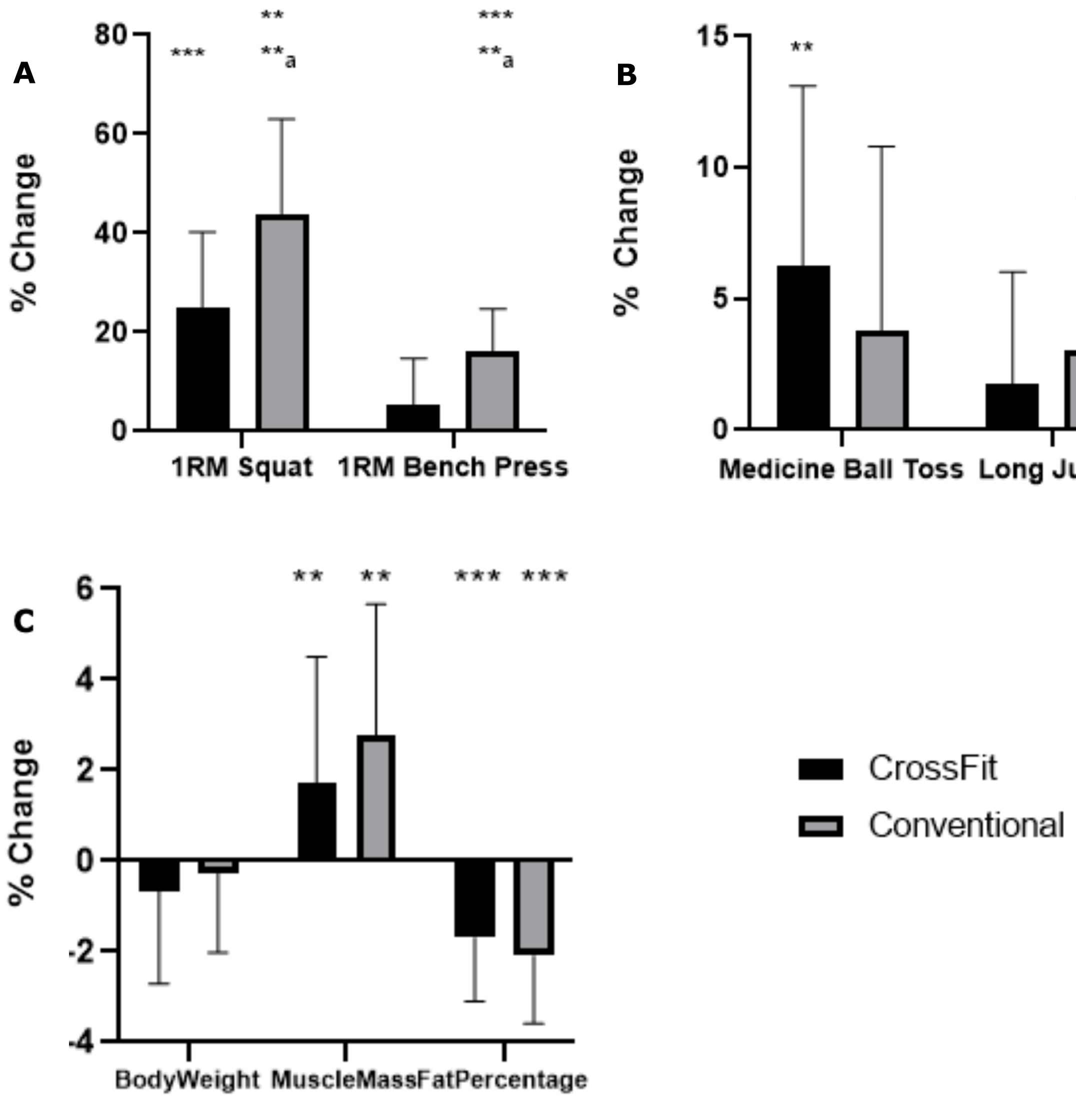


Figure 10. Percentage change from baseline to post testing. A. Maximal Strength, B. Explosive Strength, C. Body Composition. Data are presented as mean ± SD.** Significant difference within group ($p<0.01$); *** Significant difference within group ($p<0.001$) [a] Significant difference between groups

Upper Body and Lower Body Explosive Strength

The CrossFit® group experienced a significant improvement in the medicine ball toss by an average of 20 cm baseline to post testing (p= 0.001, CI 95%: 9 to 31, ES: 0.9) whereas the conventional group had an average improvement of 10 cm which was not significant (p = 0.125, CI 95%: -3 to 27, ES: 0.5). The mean difference of 8 cm between the groups was not significant (p= 0.350, CI 95%: -9 to 26, ES: 0.4). In the long jump, the average difference of 2 cm between the groups from baseline to post testing was not significant (p = 0.550, CI 95%: -10 to 5, ES: 0.3) and the average improvements within the CrossFit® group and the conventional group from baseline to post testing of 3 cm (p= 0.134, CI 95%: -12 to 8, ES: 0.4) and 6 cm (p= 0.117 and CI 95%: -1 to 13, ES: 0.5), respectively, were not significant either. All data are presented in table 6 and figure 10B.

Body Composition

Neither the CrossFit® group or the conventional group experienced a significant difference in body weight with an average difference of 0.5 kg (p = 0.201, CI 95%: -1.2 to 0.6) and 0.3 kg (p = 0.814, CI 95%: -1.1 to 0.06), respectively, from baseline to post testing. The difference of 0.2 kg between the groups was not significant either (p = 0.673, CI 95%: -1.3 to 0.8). Both groups experienced significant improvements in muscle mass from baseline to post testing whereas the CrossFit® group experienced an average increase of 0.4 kg (p= 0.045, CI 95%: 0.01 to 0.8), and the conventional group an average increase of 0.7 kg (p = 0.013, CI 95%: 0.2 to 1.2). The difference in increased muscle mass between the groups of 0.2 kg was not significant (p = 0.401, CI 95%: -0.9 to 0.5). Fat percentage also decreased significantly in both groups by -1.7% (p=0.000, CI 95%: -1.0 to -2.4) and -2.1% (p=0.000, 95% CI: -1.2 to -3.0, respectively). The average difference of 0.4% decrease in fat percentage between the groups was not significant (p=0.461, 95% CI: -0.7 to 1.5). All data are presented in table 6 and figure 10C.

Discussion

The aim of this study was to compare the effects of eight weeks of CrossFit® and conventional training on maximal and explosive strength, and body composition. The major findings were that maximal lower body and upper body strength in the 1RM 90° squat and 1RM bench press, respectively, improved significantly more in the conventional group compared to the CrossFit® group. Both groups experienced significant improvements in the 1RM 90° squat but only the conventional group experienced a significant improvement in the 1RM bench press. There were no differences between the groups in upper body and lower body explosive strength in the medicine ball toss and long jump, respectively, despite the CrossFit® group experiencing a significant improvement in the medicine ball toss. None of the groups experienced a significant improvement in the long jump. No differences were found in body weight, muscle mass and fat percentage between the groups, but both groups experienced significant within-group improvements in muscle mass and fat percentage.

Maximal Lower Body and Upper Body Strength

The improvement in the 1RM 90° squat was significantly greater in the conventional group compared to the one seen in the CrossFit® group (43.9% versus 24.8%, respectively), however; both groups experienced a significant within-group improvement suggesting that both the CrossFit® and conventional training performed in this study are viable approaches for improving maximal lower body 90° squat strength but that the conventional training regimen seem to be significantly more effective. The between-group ES of 2.1 and within-group ES of 2.0 and 2.1 in the CrossFit® group and the conventional group, respectively, indicate that the improvements observed are strong and supports this suggestion. Some of the magnitude of improvement, however, could partially be attributed to a learning effect as none of the groups were familiarized to the 90° squat prior to baseline testing because of having to switch tests from a 1RM full squat to a 90° squat after familiarization.

Nevertheless, this effect was in such case apparent in both groups and is therefore not likely to have affected the main findings of this study.

The present findings are consistent with our hypothesis. Both exercise regimens included heavy squat and lower extremity exercises which probably resulted in improved maximal 90° squat strength, however, the specific, repetitive and systematical approach of the conventional training seem to have been superior to the CrossFit® programming, at least in an initial exercise stage. Technically complex exercises were included in both exercise interventions but as the exercises in CrossFit® varied a lot more and were not repeated as regularly as in the conventional training technical proficiency after only eight weeks of training might not be fully obtainable amongst novice individuals which also likely affects the opportunity to induce improvements in maximal strength.

In the conventional training, exercise intensity and volume were controlled by the master students by logging resistance, providing technical feedback and aiming to increase weights at least once a week which continuously increased resistance training intensity and led to progressive overloading. Guidance of resistance intensity in the CrossFit® group was attempted as well but was mostly applicable in the weightlifting parts in the beginning of a WOD as the high aerobic intensity and focus on moving quickly through the exercises in the circuit parts made it difficult to predict resistance intensity. It is possible that the CrossFit® participants would have been able to improve more if they were more familiarized to CrossFit® prior to intervention start, as technical difficulty might have been reduced and thus appropriate workload would have been easier to determine. Utilizing scaling in the CrossFit® programming was intended to reduce technical difficulty and adjust the exercise stimulus to fit the desired stimuli of the given WOD but as a consequence it potentially also reduced resistance intensity for the benefit of being able to e.g., perform the exercises faster and complete more rounds in an AMRAP. Thus, it is likely that adaptations following CrossFit® were more related to aerobic and muscular endurance adaptations rather than maximal strength (4).

A study by Alcaraz and colleagues (36) found high intensity circuit training utilizing heavy loading to lead to similar improvements in maximal strength as conventional resistance training in a group of resistance trained men when exercises were performed regularly in a systematical manner with controlled rest periods (36). These findings support the previous suggestion that the general variation of exercises, sets and repetitions in the CrossFit® programming, specifically within the high intensity circuit parts of a WOD where rest periods are almost nonexciting, might attenuate the opportunity for improving maximal strength. The interference effect, which refers to high volume or high frequency endurance training possibly attenuating improvements in muscular strength and hypertrophy in concurrent training like the exercise interventions performed in the present study (7, 8), might also contribute to the explanation of the present findings. The interference effect has been found to be less dominating when endurance training is performed at high intensity, like in HIIT (8), however; a relatively new study by Vechin and colleagues (3) proposed that even HIIT of longer durations seem to attenuate improvements in muscular strength to a larger degree than e.g., short sprint intervals. The 4x3-intervals performed in the conventional training were not sprint intervals but were still of a shorter duration than the CrossFit® WODs circuits which might have made a considerable difference in interference effect.

The observed improvements in maximal lower body strength are partly consistent with previous findings like the ones of Bahremand and colleagues (17) who found improvements of 24% and 34.5% in the 1RM full squat following eight weeks of CrossFit® and conventional concurrent training, respectively. McWeeny (25) also found significant improvements in the 1RM full squat following six weeks of CrossFit® and conventional resistance training. However, none of the aforementioned studies found a significant difference between the groups which differ from present findings. Paine and colleagues (22) and Crawford and colleagues (20) also found significant improvements in the 1RM full squat of 13.4% and 9.8%, respectively, following six weeks of CrossFit®. Our findings are of a greater magnitude compared to the aforementioned findings, but as these studies did not include a comparison group the magnitude of improvement following CrossFit® compared to other exercise regimens is unknown. Comparison with other studies is not straight forward due to differences in e.g., range of motion in the 90° squat and full squat specifically, general differences in CrossFit® programming which largely varies, and baseline strength and training background, which all are likely to affect the magnitude of observed improvement (4). Nevertheless, these findings support lower body maximal squat strength improvements following both CrossFit® and conventional training.

In the 1RM bench press, only the conventional group experienced a significant improvement from baseline to post testing which was significantly greater compared to the CrossFit® group (16.1% versus 5.5%, respectively). The between-group ES of 1.3 and within-group ES of 1.3 and 2.2 for the CrossFit® group and the conventional group, respectively, indicate that differences observed are strong and also suggest that the CrossFit® performed might lead to a significant improvement in bench press strength with a bigger sample size. The present findings are somewhat consistent with our hypothesis; however, it was expected that the CrossFit® group would experience a significant improvement in the 1RM bench press. These findings could partially be explained by the resistance training principle of specificity, as improvements following resistance training are most evident in exercises and movements that are performed regularly (4), and the conventional group performed bench presses each session in the same format as the 1RM test whereas the CrossFit® group did not perform bench presses at all. The CrossFit® group performed pushups, which have been found to produce similar muscle activity patterns as the bench press (37), however, pushups were only performed three out of twenty-four sessions and involved a lot of repetitions without scheduled rest periods which might not be optimal to elicit improvements in maximal bench press strength but rather improve characteristics more related to e.g., muscular endurance (4). This suggest that the conventional group had an exercise specific advantage in the 1RM bench press test, but the general differences in exercise programming and exercise stimulus between the groups are also of consideration. It is possible that the CrossFit® performed would have led to a greater improvement in another test of maximal upper body strength, e.g., a 1RM shoulder press, as the CrossFit programming involved several variations of push exercises like push presses and push jerks of heavier loads.

In the study of Bahremand and colleagues (17) a 19.7% and 24% improvement in maximal bench press strength was found in the conventional group and the CrossFit® group, respectively, and the improvement in the CrossFit® group was significantly greater than the one following conventional training which contrasts present findings (17). Neither the CrossFit® programming nor conventional training in Bahremand´s study involved bench presses but still led to improved bench press strength. McWeeny (25) also found significant improvements in the 1RM bench press following both CrossFit® and conventional training, but the improvement did not significantly differ between the groups which also contrasts present findings. These findings, however, suggest that utilization of other push exercises have the potential to lead to improved bench press strength and supports the speculation proposed previously that the CrossFit® performed in the present study potentially could have led to a significant improvement in maximal bench press strength with a bigger sample size.

Explosive Upper Body and Lower Body Strength

There was no significant difference observed in upper body explosive strength in the medicine ball toss between the CrossFit® group and the conventional group (6.3% and 3.8%, respectively), but the CrossFit® group did experience a significant within-group improvement from baseline to post testing. Nevertheless, the between-group ES of 0.4 indicate that the difference between the groups was small to medium and implies that there was no practical difference in the medicine ball toss between the groups. The within-groups ES of 0.9 in the CrossFit® group and 0.5 in the conventional group indicate a strong and medium strength, respectively. This suggest that despite the CrossFit® group experiencing a significant improvement in the medicine ball toss, the improvement is not of significance when compared to the improvement following conventional training. Moreover, none of the groups experienced a significant improvement in the long jump. The between-group ES of 0.3 and the within-group ES of 0.4 and 0.5 for the CrossFit® group and the conventional group, respectively, indicate that the differences are of small to medium strength. This indicates that the included exercise regimens might not be effective in improving maximal lower body explosive strength in the standing long jump.

The present findings are inconsistent with the hypotheses as the CrossFit® group was expected to experience a significantly greater improvement in explosive strength, primarily due to the utilization of Olympic weightlifting, wall balls, jumping movements and general explosiveness of CrossFit®. However, if comparing CrossFit® programming to explosive strength training principles, CrossFit® does not directly utilize specific explosive strength training in terms of e.g., repetition range, sets or breaks (1). This also applies for the conventional training in this study, which could explain the lack of improvement observed in explosive strength in general. Novice individuals have the potential to gain improvements in explosive strength following less specific training, however, more specific explosive strength training might be necessary to induce significant improvements in explosive strength for this group of novice-to-intermediate (4). It is also possible that the technical complexity of CrossFit® exercises attenuate the possible improvements following CrossFit®, and that a greater improvement would have been observed if technical proficiency had been greater. However, these assumptions are mostly speculations. Moreover, cannot be ruled out, however, that the interference effect potentially attenuated improvements in explosive strength as well, as overall explosiveness is one of the major variables that are negatively affected by concurrent training (8).

No other studies investigating CrossFit® have assessed upper body explosive strength in the standing medicine ball toss previously. However, McWeeny (25) assessed the seated medicine ball toss and did not find any significant improvement following CrossFit® or conventional resistance training after six weeks of training, which are consistent with present findings. With regards to the lower body explosive strength in the long jump, Barfield and colleagues (23) found conventional resistance training to lead to a significantly greater improvement in lower body explosive strength in the long jump compared to CrossFit® (7.5% versus -0.5%) after ten weeks of training. Eather and colleagues (38) also found significant improvements in the long jump in male adolescents but not female adolescents following eight weeks of CrossFit®. Yüksel and colleagues (21) also found significant improvements in lower body explosive strength in the vertical jump among wrestlers following eight weeks of CrossFit®. The majority of these findings contrast the findings of the present study. Barfield and Anderson (24) did not find any significant improvement in a vertical jump following 14 weeks of CrossFit® and conventional training, which are consistent with present findings. The vertical jump is not directly comparable to the standing long jump; however, the aforementioned studies assessing lower body explosive strength indicate a great variability in the observed effects following CrossFit®.

Body Composition

There were no significant differences between the CrossFit® group and the conventional group in body weight, muscle mass or fat percentage. Body weight did not significantly change for any of the groups from baseline to post testing. In the conventional group, body weight was not normally distributed at any measurement point due to one of the participant's body weight of 128.4 kg and 128.7 at baseline and post testing, respectively, differing from the rest of the group. Secondary analyses excluding this participant´s body weight made the variable normally distributed at both measurement points, as expected, but did not significantly change the results (data not shown). Muscle mass significantly improved by an average of 1.7% for the CrossFit® group and 2.8% for the conventional group, whereas fat percentage significantly improved for both groups with a reduction of 1.7% for the CrossFit® group and 2.1% for the conventional group. Our findings indicate that both exercise regimens led to positive changes in body composition. This is consistent with our hypothesis, however, as our study did not involve any dietary control, which is likely to influence body composition (39), the potential effects of dieting cannot be ruled out. Our findings are also consistent with the ones of Bahremand and colleagues (17) who found significant improvements in muscle mass of 5.5% and 3% and significant decrements of 10.7% and 8.5% following CrossFit® and conventional training, respectively. Özbay (18) also reported significant decrements in fat percentage in male wrestlers after 16 weeks of CrossFit® and conventional resistance training. Differences in baseline body composition, population and evaluation methods could affect the magnitude of improvement and should be taken into account when comparing results.

Strengths and Limitations

One of the strengths of this study was the RCT study design which is considered a gold standard for assessing the effects of an intervention (40). Performing randomization by a third party (the Unit for Applied Clinical Research, NTNU) with an unknown block size reduces the risk of selection bias. However, a self-selection bias could have been apparent as a majority of the participants that showed interest in participating did so because of their interest in CrossFit®. Thus, the present findings might not be generalizable outside of this population. In general, exercise intensity and volume between CrossFit® and conventional training are difficult to match due to the great variety in CrossFit® programming, however, comparing CrossFit® to time-matched conventional concurrent training contributes to filling a knowledge gap as previous studies have mainly focused on CrossFit® alone or compared CrossFit® to conventional resistance training only. All exercise and testing were controlled and supervised by the master students which reduces performance bias related to differences in interpretation of protocols and strengthens the internal validity. However, not blinding the test or exercise settings could potentially lead to another performance and detection bias but neither single- or double-blinding were applicable within the budget or design of this study. Thus, scheduled workouts including standardized exercise protocols, warmups and test procedures, was intended to reduce the magnitude of these biases. The high adherence after intervention start strengthens the external validity and as no serious short-term or long-term injuries were reported, both exercise interventions were safely implemented.

As there were five more dropouts in the conventional group than the CrossFit® group the groups were uneven at baseline which potentially affect the differences in magnitude of improvement between the groups. Furthermore, the difference in control and administration of resistance training intensity between the CrossFit® group and the conventional group could potentially lead to a performance bias as well, as each individual in the conventional group was more closely administered. However, controlling resistance training intensity more closely in the CrossFit® group would require more personnel which would have led to an even larger performance bias as the resources provided to each group would have become uneven. Thus, the resources available were considered correctly distributed. Considering the training-specific advantage the conventional group had in the 1RM bench press test, other less training-specific tests for assessing upper body maximal strength or other exercises included in the conventional training could be considered in future studies. Also, as the nature of CrossFit® is complex and broadly aims to develop multiple physiological characteristics simultaneously, traditional measures like included in this study might not be optimal for revealing the full effects of CrossFit®.

Further studies are warranted including longer study durations to increase participants technical proficiency in CrossFit® and bigger sample sizes to better understand the effects of CrossFit® on maximal and explosive strength. More complex tests for assessing maximal and explosive strength could also be considered.

Conclusion

The present study suggest that the conventional training performed was superior to the CrossFit® performed in improving maximal lower body 90° squat strength and maximal upper body bench press strength in a group of healthy 18-to-30-year-old men and women, but that the CrossFit® performed was effective enough to be considered as a viable alternative to conventional training in improving maximal lower body 90° squat strength. Only the CrossFit® performed led to an improvement in upper body explosive strength in the medicine ball toss, but this improvement was not greater than the one following conventional training and can therefore not be considered more effective than conventional training in improving explosive upper body strength in the medicine ball toss. None of the exercise regimens were effective in improving lower body explosive strength in the long jump. Both exercise regimens induced positive changes in muscle mass and fat percentage and can be considered effective in improving body composition.

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Appendices

Appendix 1. Eligibility form

Generell informasjon	
Navn	
Fødselsdato	
Høyde (cm)	
Vekt (kg)	
Email	
Telefonnummer	
Har du skader eller andre helserelaterte utfordringer? hvis ja, utdyp.	
Treningsbakgrunn	
Hvor mange økter i uka har hatt de siste 6 mnd?	
Beskriv kort innholdet i disse øktene (varighet, type trening, intensitet, type øvelser etc., ca. antall sett og reps)	

På en skala fra 1-10, hvor motivert er du for trening? (1 = ikke motivert i det hele tatt, 10 = kunne ikke vært mer motivert)	

Jeg bekrefter at informasjonen over er korrekt og at jeg kan trenes basert på dette. Hvis min helsestatus eller treningsstatus endrer seg i løpet av studien er jeg pliktig å informere trenerne så fort som mulig.

Dato   Signatur

Appendix 2. Consent form

Har du lyst til å delta i masterprosjektet 'Effekten av CrossFit versus konvensjonell trening på maksimalt oksygenopptak, anaerob kapasitet, muskulær styrke, muskulær kraft, arbeidskapasitet og kroppssammensetning''?

Hensikten med studien

Du er invitert til å delta i et masterprosjekt i samarbeid med NTNU hvor formålet er å undersøke de fysiologiske effektene av CrossFit sammenlignet med konvensjonell styrke- og utholdenhetstrening. CrossFit er en gruppebasert treningsform som innebærer konstant varierte, funksjonelle bevegelser utført med høy intensitet. CrossFit-økter er dermed sjeldent like da ulike øvelser settes sammen på ulike måter for hver økt for å skape variasjon og uforutsigbarhet. Konvensjonell trening defineres som en form for mer tradisjonell trening hvor man trener styrketrening med frivekter og høyintensiv intervalltrening på tredemølle i samme økt. De konvensjonelle treningsøktene er like hver gang hvor målet er å øke belastningen (kilo/motstand og gjerne hastighet på intervalldragene) for å stimulere kroppen. For å kunne sammenligne effektene av de to ulike treningsmetodene (CrossFit og konvensjonell trening) vil fysiske tester bli gjennomført før og etter treningsperioden. Dette informasjonsskrivet vil gi mer informasjon om detaljene knyttet til studien og hva deltakelse vil innebære for deg.

Hvem er ansvarlig for studien?

Masterprosjektet vil bli gjennomført i samarbeid med NTNU (Norges tekniske naturvitenskapelige universitet) og er en del av den internasjonale mastergraden Physical Activity and Health ved det medisinske fakultet, institutt for nevrovitenskap og bevegelsesvitenskap.

Hvem kan delta i studien?

I studien ønsker vi å inkludere friske menn og kvinner i alderen 18-30 år som trener 1-3 ganger i uka. Deltakelse i idrett på lavt nivå er også tillat. Vi ønsker å rekruttere 30 deltakere og da du møter disse kriteriene inviterer vi deg til å delta i dette masterprosjektet.

Hva innebærer deltakelse?

Deltakelse i studiet innebærer 8 uker trening, 1 uke opplæring og 4 uker testing (2 uker før og 2 uker etter treningsperioden). Studieoppstart er 7. september og studien har en total varighet på 13 uker. Opplæringen vil bestå av totalt 3,5 timer fordelt over to dager. Testing vil bestå av totalt 6 timer fordelt over tre dager før treningsperioden og tre dager etter treningsperioden. Siste uke med testing og avsluttende uke av studien vil være 30. november – 6. desember. Treningsøktene og majoriteten av testene vil foregå på CrossFit Maxpuls Lade. Maksimalt oksygenopptak og kroppssammensetning vil testes på St. Olavs Hospital. Du som deltaker blir tilfeldig plassert i CrossFit-gruppen eller den konvensjonelle treningsgruppen. Disse gruppene deles igjen i to slik at det totalt er 4 treningsgrupper. I hver gruppe vil det være 7-8 deltakere som skal trene sammen hver mandag, onsdag og fredag gjennom den 8 ukers lange treningsperioden. Før og etter treningsperioden vil din fysiske form bli testet gjennom en rekke fysiske tester (disse testene er forklart i detalj i påfølgende avsnitt). Deltakelse i studien innebærer også at man ikke kan trene systematisk styrke og/eller utholdenhetstrening utenfor prosjektet.

Treningsintervensjon

Som deltaker i studien vil du bli randomisert (tilfeldig plassert) i CrossFit-gruppen eller den konvensjonelle gruppen (tradisjonell styrke- og utholdenhetstrening). Det vil si at du ikke kan velge treningsform selv. CrossFit-gruppen kommer til å trene 24 ulike økter i løpet av de 8 ukene. Den konvensjonelle treningsgruppen kommer til å trene det samme hver økt: 4x3-intervaller på tredemølle (fire treminuttersdrag) og styrkeøvelsene knebøy, benkpress og stående roing.

Hvilke tester skal gjennomføres?

Maksimalt oksygenopptak (Vo_2maks) refererer til den maksimale mengden oksygen kroppen din klarer å ta opp og er ansett som det beste målet på kondisjon. Vo_2maks måles ved å utføre en maksimal løpetest på tredemølle med oksygenmaske. Belastningen i form av hastighet eller stigning øker hvert minutt til man når utmattelse eller til andre tegn tilsier at man skal avslutte testen. Hvis du skulle oppleve et overveldende ubehag før dette har du mulighet til å stoppe testen når du måtte ønske. Målet med testen er å gå eller løpe til man ikke klarer å fortsette lengre grunnet utmattelse.

Muskulær kraft testes ved utføre et stille lengdehopp hvor målet er å hoppe så langt som mulig, og ved å kaste en medisinball så langt som mulig i stående posisjon.

Maksimal muskulær styrke referer til den største kraften en muskel eller muskelgruppe kan utvikle i en bevegelse. Dette måles ved å utføre en 1-repetisjon-maksimum (1RM) test i knebøy med stang og benkpress. 1RM er den maksimale vekta man klarer å løfte én gang.

Kroppssammensetning vil måles ved bruk av en analysemaskin og kroppsvekt i kilogram, andel fettmasse og andel muskelmasse vil bli registrert.

Anaerob kapasitet (hurtighet) vil testes ved å utføre en 200 m sprint.

Arbeidskapasitet vil bli testet ved å gjennomføre en treningsøkt bestående av tre runder thrusters og burpees med synkende repetisjoner hvor målet er å fullføre på kortest mulig tid.

Et spørreskjema knyttet til grad av tilfredshet vil også fylles ut tre ganger i løpet av studieforløpet: ved start, midtveis og ved slutten av de 8 ukene.

Smittevernstiltak

All trening og testing vil gjennomføres i henhold til smittevernsanbefalingene. Dersom du som deltaker skulle oppleve symptomer som feber, sår hals, hoste, pustevansker og muskelsmerter skal du ikke møte opp for trening og/eller testing. Ta kontakt med en av masterstudentene så fort som mulig dersom dette skulle forekomme (listet under kontaktinformasjon).

Risiko og ubehag

Du kan oppleve noe ubehag knyttet til $V_{O}2$maks-testen da det er en test som presser deg til du har nådd maksimal kapasitet. Til tross for dette er det en helt trygg og normal reaksjon på en slik test. All trening og testing i denne studien gjennomføres på en trygg måte og vil bli veiledet av kvalifisert personell for å sørge for at du som deltaker er komfortabel til enhver tid. Styrketrening kan også potensielt føre til forbigående ubehag og/eller muskelstivhet. All trening kan medføre en moderat risiko for muskel- og seneskade, men det er godt dokumentert at fordelene knyttet til å være fysisk aktiv veier opp for denne risikoen. Skulle du likevel oppleve økt smerte under trening eller utførelsen av en øvelse vil en 4-stegs tilnærming utføres: 1) redusere vekt/motstand i øvelsen, 2) redusere bevegelseshastigheten, 3) redusere bevegelsesutslaget og 4) unngå å utføre den spesifikke bevegelsen i minst én uke.

Potensielle fordeler ved å delta i studiet

Deltakelse i denne studien gir deg 8 uker gratis veiledet trening av kvalifiserte trenere samt gratis fysiologisk testing som gir en verdifull indikator på din fysiske form. Du vil potensielt lære mye om generelle treningsprinsipper da du vil få en detaljert opplæring i treningsteknikk og utførelse. Andre potensielle fordeler knyttet til deltakelse er økt Vo2maks, økt muskulær kraft og styrke, økt hurtighet, forbedret kroppssammensetning og økt arbeidskapasitet.

Samtykkefrihet

Du har rett til å trekke deg fra studiet når som helst uten å måtte oppgi en grunn. Vær vennlig å kontakte en masterstudentene listet under «kontaktinformasjon» hvis du bestemmer deg for å trekke deg fra studien før den er ferdig. Hvis du velger å fortelle de prosjektansvarlige hvorfor du forlater studien vil grunnen potensielt oppbevares som en del av prosjekts datamateriale. Informasjonen om deg som deltaker vil oppbevares og inkluderes i dataanalysen med mindre du ber oss om å fjerne informasjonen fra våre arkiver. Hvis de prosjektansvarlige allerede har brukt informasjonen om deg i dataanalyser vil det ikke være mulig å fjerne denne informasjonen i ettertid.

Personvern

Informasjonen om deg som registreres vil være navn, adresse, telefonnummer, epost, fødselsdato, vekt, høyde og treningsbakgrunn. Fysiske tester vil utføres for å kartlegge fysisk kapasitet. Disse dataene og informasjonen som registreres på deg vil bare brukes som beskrevet i henhold til formålet med denne studien. All informasjon og testresultater vil behandles uten navn og fødselsdato eller annen direkte gjenkjennbar informasjon. Et id-nummer kobler deg og informasjonen din til testresultatene via en navneliste. Dette betyr at informasjonen om deg er deidentifisert. Bare autorisert personell knyttet til masterprosjektet vil ha tilgang til navnelisten og kan koble informasjonen til deg. Det vil ikke være mulig å identifisere deg i studiens resultater når den er publisert. Til kontrollformål vil data uten personlig informasjon trygt oppbevares på en harddisk hos NTNU til 15.06.2026. Etter denne datoen vil disse dataene bli slettet. Byråer som muligens kan kontrollere datamaterialet er eksempelvis forskningsansvarlig eller etiske komiteer.

Deltakers rettigheter

Som deltaker har du rett til å be om tilgang til personlig data, inkludert sletting, retting eller begrensning av data. Dette inkluderer også dataportabilitet som tillater deg å få og bruke personlig data til egne formål. Du har også rett til å sende en klage til personvernombudet hos NTNU eller norsk senter for forskningsdata hvis ønskelig (listet under kontaktinformasjon).

Forsikring

Som universitet er NTNU selvforsikret og ansvarlig for å forsikre at det vi gjør er i samsvar med lover og regler til enhver tid. Dette betyr at når et prosjekt er godkjent hos NTNU er NTNU ansvarlig for forsikring om en deltaker skulle bli skadet på grunnlag av det vi ber dem om å gjøre.

Informasjon om utfallet av studiet

Som deltaker i denne studien har du rett til å få informasjon om studiens resultater. Du vil få tilgang til denne informasjonen etter at resultatene er publisert.

Kontaktinformasjon

Ved spørsmål relatert til deltakelse eller ønske om å ta i bruk dine rettigheter som deltaker, ta kontakt med en av personene listet her:

Masterstudent: Rebekka Resell Mauring (+47 41 46 75 16, rebekkrm@stud.ntnu.no)

Masterstudent: Ingrid Bårtvedt (+47 92 80 20 96, ingridtb@stud.ntnu.no)

Veileder: Vegard Moe Iversen (+47 95 91 61 88, vegard.m.i@ntnu.no)

Personvernombud: Thomas Helgesen (personvernombud@ntnu.no)

NSD – Norsk senter for forskningsdata AS (55 58 21 17, personverntjenester@nsd.no)

Med vennlig hilsen,

Studenter

Appendix 3. Familiarization session

General comments:

This is an introduction to the exercises included in the training program. We do not expect anyone to get skilled at any of the exercises after this session, the focus lies on learning the technique and this will be repeated each session

CrossFit Group

Day 1: 1.5 hours

Whiteboard: 5 min go trough of the session

Exercise: Air Squats

Feet shoulder width apart, lift and extend arms over head, sit down (like sitting on a chair).

3x4-5, The instructors walk around and correct technique (8 min)

Exercise: Squat to medicine ball

Same as air squats but sitting down touching the medicine ball with the glutes. 1-2x4-5 (2-3 min)

Exercise: Air Squats

Repeat of air squats. 1x4-5 slowly down, 1x4-5 stop mid-way, 1x4-5 normal tempo (2-3 min)

Exercise: Front Squats w/ medicine ball

Hold ball with both hands, supporting on top of the chest. Do the same as air squats but keep the ball at chest level, 2x4-5 (2-3 min)

Exercise: PVC Front Squats

"Zombie" Squats (placing the bar under the chin resting on the front of the shoulders and lifting arms up in front of the body parallel to the floor like a "zombie walk"). Squatting like this to learn where to place the bar when doing front squats. 1x4-5. (2-3 min).

Exercise: Barbell Front Squats

The same as PVC Front Squats but supporting the bar with hands instead of zombie-squats. 3-4x4-5 (12 min).

Exercise: PVC and Barbell Strict Press

Strict shoulder press, first with the PVC pipe, then with the barbell. 2-3x4-5 sets for both (5 min).

Exercise: PVC and Barbell Push Press

The same as strict shoulder press but driving/pushing with the legs (dipping down and extending the hips to generate force) to push the barbell over the head. 3x4-5 (5 min).

Exercise: PVC and Barbell Push Jerk

Still using the legs to generate force but sitting under the bar instead of pressing the bar overhead. 3x4-5 (5 min).

Exercise: Strict Press + Push Press + Push Jerk

Combining the three exercises to understand the difference. 2 Strict Press + 2 Push Press + 2 Push Jerk x3 (5-6 min).

Exercise: Barbell Thrusters

A Front Squat combined with a Push Press. 4x4-5 (10 min).

Exercise: Wall Balls

Based on the medicine ball squat and adding a medicine ball strict press, then a thruster and then a thruster with a vertical toss before performing the actual wall balls. A couple of reps of each (10 min).

Exercise: Rowing Machine Technique

Focus on using the legs to generate force: start by pressing heels against foot plate, extending knees and hips before pulling handle back, do the row, extending the arms back before letting legs go back again (15 min).

Exercise: Burpees

Split in different stages: lay down, press chest up, jump with legs to a low squat position, extend hips. Jump to target. 2x5 reps (5 min).

Day 2: 2 hours

Whiteboard: 5 min go through of the exercises

Exercise: Medicine Ball Deadlift

Practicing the deadlift movement with a medicine ball. 2x5 (5 min).

Exercise: PVC Deadlift + Barbell Deadlift

Practicing the deadlift with the PVC and the barbell. 2x5 + 3x5 (20 min).

Exercise: Olympic lift: Power Cleans

Split into different stages: w/ medicine ball: Ground to overhead, deadlift + front squat, sumo deadlift high pull, hang power clean. W/ barbell: Deadlift, deadlift + calf raises, deadlift + calf raises + shoulder shrugs, deadlift + calf raises + shoulder shrugs + high pulls. Then putting it all together and performing the actual hang power clean. (45 min).

Exercise: Pushups

Practicing the pushups and scaling options (using wooden boxes to elevate the participant from the ground). (10 min).

Exercise: Pullups and Ring Rows

Practicing the pullup and ring rows (5 min).

Exercise: Barbell Squats

Practicing the barbell squats (15 min).

Exercise: Barbell Bench Presses

Practicing the barbell bench presses (15 min).

Conventional Group

Day 1: 1.5 hours

Whiteboard: 5 min go through of the exercises

Exercise: Air Squats

Feet shoulder width apart, lift and extend arms over head, sit down (like sitting on a chair). 3x4-5. The instructors walk around and correct technique (10 min).

Exercise: Squat to medicine ball

Same as air squats but sitting down touching the medicine ball with the glutes. 1-2x4-5 (2-3 min)

Exercise: PVC Back Squats

Practicing the back squat with a PVC. 3x5-6 (10 min).

Exercise: Front Squats w/ medicine ball

Hold ball with both hands, supporting on top of the chest. Do the same as air squats but keep the ball at chest level, 2x4-5 (7,5 min)

Exercise: PVC Front Squats

"Zombie" Squats (placing the bar under the chin resting on the front of the shoulders and lifting arms up in front of the body parallel to the floor like a "zombie walk"). Squatting like this to learn where to place the bar when doing front squats. 1x4-5. (7,5 min).

Exercise: Barbell Front Squats

The same as PVC Front Squats but supporting the bar with hands instead of zombie-squats. 3-4x4-5 (12 min).

Exercise: PVC and Barbell Strict Press

Strict shoulder press, first with the PVC pipe, then with the barbell. 2-3x4-5 sets for both (5 min).

Exercise: PVC and Barbell Push Press

The same as strict shoulder press but driving/pushing with the legs (dipping down and extending the hips to generate force) to push the barbell over the head. 3x4-5 (5 min).

Exercise: PVC and Barbell Strict Press + Push Press

Combining the two exercises to learn the difference. 4x2 Strict Press + 2 Push Press (10 min).

Exercise: Barbell Thrusters

A Front Squat combined with a Push Press. 4x4-5 (10 min).

Exercise: Burpees

Split in different stages: lay down, press chest up, jump with legs to a low squat position, extend hips. Jump to target. 2x5 reps (5 min).

Exercise: Treadmill Running

Get familiar with how to use the treadmill in terms of adjusting speed, inclination, hopping off between intervals etc. Also practicing running technique.

Light stretching afterwards. (10 min).

Day 2: 2 hours

Whiteboard: 5 min go through of the exercises

Exercise: Treadmill Running

Repeat of the treadmill running and practice of running technique (10 min).

Exercise: Barbell Back Squats

Learn the technique before building to a squat around 75-80% of 1RM (40 min).

Exercise: Barbell Bench Press

Learn the technique before building to a squat around 75-80% of 1RM (35 min).

Exercise: Standing Bent Over Barbell Rows

Learn the technique before building to a squat around 75-80% of 1RM (30 min)

Appendix 4. CrossFit® Equipment

Barbells (15 kg & 20 kg): Play, Play Sport AS

Weight plates (0,5-25 kg): Gymleco, Gym Sport AS

PVC Pipes: Made by K-Lund

Bench: Hammer Strength

Rack: Gym Sport AS

Wooden box: Made by Brundalen High School

Medicine ball: Nordic Sportsmaster AS

Assault bike: Nordic Sportsmaster AS

Rowers: Concept 2

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