Master's thesis

NTNU
Norwegian University of Science and Technology

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The effects of deep squats versus half squats in resistance trained men - A randomized controlled trial

Master's thesis in Physical Activity and Health - Exercise Physiology
Supervisor: Marius S. Fimland
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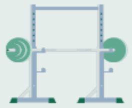
DOES SQUAT DEPTH ACTUALLY MATTER?

The effects of deep squats versus half squats in resistance trained men
- A randomized controlled trial by Anders Gjellan

We performed a **randomized study** to see how **squat depth** would affect overall leg strength in well trained men aged 19-30 years by comparing two different squat depths.



WHY

IS THIS INTERESTING?

Exercise **range of motion** is not well researched as a training variable, and more studies should examine the effects of different ranges of motion on **maximal strength**.

- Research is inconclusive.
- How will well trained participants respond to training at different ranges of motion?
- Does training specificity matter?
- Higher training load versus range of motion?
- How does it affect pain?

DURATION

- 2 Week Familiarization
- 8 Weeks Training

HOW?

- Deep Squats vs Half Squats
- 2 weekly supervised training sessions
- Testing at week 2 and 10

TESTS!

- 1RM 90-Degree Squat
- 1RM Parallel Squat
- Maximal isometric knee extension at different angles
- Pain questionnaire

WHAT WE FOUND!

- The **Deep Squat group** improved slightly more at both depths than the Half Squat Group
- **Both groups improved** significantly compared to baseline at the squat 1RM at both depths
- **Neither group** changed notably in isometric knee extensions for any of the three tested angles
- **No changes in pain** for either group

PRACTICAL APPLICATIONS

Deep squats can be more effective, although **both** depths can be used to improve squat strength and elicit **no pain** in **well trained** participants.

Abstract

Objective: This study aimed to investigate the effects of deep squats versus half squats on maximal low limb strength in resistance trained men, with a secondary aim to assess musculoskeletal pain.

Methods: Through an open label randomized controlled trial design, participants with more than six months of resistance training experience were voluntarily recruited and randomized to train with squats to a tibiofemoral angle of 90-degrees (Half Squats) or to parallel depth (Deep Squats). Under supervision, participants performed two weeks of familiarization followed by an eight week periodized squat training program. Maximal strength tests, including a one repetition maximum (1RM) for both squat depths and an isometric knee extension test for three different angles were performed at baseline and upon completion of the training program. Participants also filled out a customized pain questionnaire during week 3, 4, 9 and 10.

Results: A total of 17 participants completed all tests and training sessions in the study (N=17). The Deep Squat group increased their 1RM squat at both depths slightly more than the Half Squat group, although no significant difference between the groups were reported (p=0.211-0.528). Neither group saw any notable changes in isometric knee extension strength for any of the three tested angles, and neither group reported any notable changes in pain perception throughout the study.

Conclusion: These findings suggest that Deep Squats can elicit larger increases in maximal squat strength than Half Squat, although squat exclusive training might be insufficient for improving isolated knee extension strength. Additionally, both deep- and half squats can be well tolerated and not elicit pain in trained participants.

Abstrakt

Objektiv: Denne studien har hatt som mål å undersøke effektene av to forskjellige knebøydybder på maksimal styrke i nedre ekstremiteter hos veltrente menn, med et sekundært mål om å undersøke muskel-skjelett smerte.

Metode: Gjennom et åpent randomisert kontrollert studiedesign ble deltakere med mer enn 6 måneders styrketreningserfaring frivillig rekruttert randomisert til å enten trene med knebøy til en tibiofemoral vinkel på 90 grader (Half Squats), eller knebøy til parallell dybde (Deep Squats). Under monitorering av trenere gjennomgikk deltakerne først en to-ukers tilvenningsperiode etterfulgt av åtte-uker periodisert knebøytrening. Maksimale styrketester,

inkludert en knebøy èn repetisjon maksimum (1RM) for begge knebøydybdene og en isometrisk kneekstensjonstest for ulike vinkler ble gjennomført ved studiestart og på slutten av studien. Deltakerne fylte også ut et spørreskjema om smerte i uke 3,4, 9 og 10.
Resultater: Totalt 17 deltakere gjennomførte alle testene og treningsøktene for studien (N=17). Gruppen som trente med dype knebøy økte sin 1RM i begge knebøydybdene litt mer enn gruppen som trente halve knebøy, men ingen statistisk signifikante forskjeller ble rapportert (p=0.211-0.528). Ingen av gruppene opplevde noen signifikante endringer i isometrisk kneekstensjonsstyrke for de tre testede vinklene, eller smerte i løpet av studien.
Konklusjon: Funnene fra denne studien antyder at dype knebøy kan være mer effektive for økninger i maksimal knebøystyrke enn halve knebøy. Det kan derimot hende at knebøytrening alene, uavhengig av dybde, ikke har en sterk overførbarhet til isolert isometriske kneekstensjonsstyrke. Funnene indikerer også at trente deltakere godt tolererer, og opplever ikke smerte med noen av knebøydybdene.

Acknowledgements

I would like to express gratitude to all the study participants and my co-worker throughout this project Anna K. Dale for their contributions to the study. I would also like to express gratitude to my supervisor Marius S. Fimland from the Faculty of Medicine and Health Sciences for helping me structure the project throughout its entirety, and I want to thank those who instructed testing at the St. Olavs hospital prior to the study; Xiangchun Tan and Ane Øvreness from the Institute of Neuromedicine and Movement Science, Trondheim, Norway.

Introduction

Maintaining sufficient maximal strength is valuable for facilitating movement and general physical health. Resistance training (RT) is an adaptable training mode used to improve athletic performance and physical capacity through modified exercises and training variables (1). Low limb focused RT in particular plays a large role for improving physical function, as it targets muscle groups which are essential in daily physical movement and play a major role in sports involving the legs (2–7). The barbell squat is thereby one of the most prevalent RT exercises used to improve maximal low limb strength, given its ability to effectively load the hip- and knee extensors in a safe manner (8).

The barbell squat is normally performed to a measurable depth that can be visually assessed (2), of which, there are two common depths. Squatting to a tibiofemoral angle of 90-degrees is often called a “half squat”, while squats to parallel depth where the inguinal fold is parallel to the top of the knee are called parallel- or “deep squats” (2,9,10). Traditionally, for improving maximal strength within specific parts of movement for sprinting and jumping, half squats have been recommended as they allow for higher training loads compared to deep squats, and have a less challenging movement pattern (2,3,9,11,12). However, because of the shorter moment arm, half squats are reported to produce similar levels of knee extensor muscle activity and force to deep squats when similar training effort is achieved, even with substantially higher training loads (13–15). Moreover, studies have reported more mechanical tension on the knee- and hip extensors during deep squats (8,16), suggesting deep squats might produce larger neuromuscular adaptations from RT. Anyhow, the optimal squat depth, and the effects of exercise range of motion (ROM) on maximal strength are still topics of debate (2–4,8,10).

There are a few studies who have investigated the effects of squat depth on maximal strength. Most recently, a study by Pallares and colleagues (2) compared half squats, parallel squats, and “full” squats (past parallel) over 10 weeks, and found that training with squats to-, and past parallel depth induced greater increases in maximal strength across all squat depths compared to half squats, a result which has only been reported in one other similar study by Weiss and colleagues in 2000, which did not focus exclusively on maximizing squat strength (17). Pallares and colleagues (2) also conducted measures on pain perception, which reported half squats to cause significantly more pain and stiffness than deeper squats, particularly of the neck (2), in accordance with hypotheses on compressive forces and intervertebral stress (8,12,14,18). Moreover, a similar study from 2019 by Kubo and colleagues (19) reported that squats to- and past parallel induced significantly larger improvements than half squats in the parallel squat 1RM, while showing no significant difference between groups in the 90-degree squat 1RM. Other studies have also reported similar changes in maximal strength when training with full ROM exercises compared to partial ROM exercises in participants without RT experience (20–22).

On the contrary, other studies have reported that adaptations to different squat depths are specific, in accordance with hypotheses regarding the specificity of training stimuli in relation to test performance (23,24). A study by Hartmann and colleagues (9), which researched the influence of maximal squatting strength on rate of force development by comparing deep- and half squats, reported that each group saw the largest improvements at their trained depth. Furthermore, a study by Bloomquist and colleagues (15) compared two groups squatting to a tibiofemoral angle of either 60- (shallow squats) or 120 degrees (deep squats), and reported that the deep squat group increased 1RM strength similarly for both depths (~20%), although the shallow squat group improved significantly more at 60 degrees comparatively (~36%), with smaller improvements at 120 degrees (~9%). The same study also reported that increases in squat strength at specific depths carried over to improved maximal isometric knee extension strength at the corresponding knee angles, in line with the principle of specificity. Moreover, a study from Rhea and colleagues (10) which studied the effects of squat depth on maximal strength and rate of force development in resistance trained participants, reported that groups improved their squat 1RM far more at their trained depth. However, this study also included other low limb exercises in the training program besides squats, which could affect results. Finally, a study by Graves and colleagues (24) compared partial- and full ROM leg extension strength over 10 weeks, and reported that each group improved more at their assigned ROM.

In light of the presented research, there is no clear consensus regarding the effects of squat depth for maximal low limb strength, as similar protocols report different results. Moreover, there is little data exploring how different squat depths affect maximal knee extension torque at different angles. Clear protocols for measuring the effects of specific ROM training have not been well established, and studies investigating the effects of squat depth differ in methodologies for RT programming and periodization, using different relative training loads, rest times, intensities and occasionally following different standards for what is considered a half squat and a deep squat. Furthermore, only three of the aforementioned studies utilized resistance trained participants in their sample size (2,9,10), and only one utilized angle specific measures of isometric knee extension force (15). Lastly, only the study by Pallares and colleagues (2) prospectively investigated squat depth and musculoskeletal pain, suggesting a need for more research on the matter. Therefore, the goal of this study was to examine the effects of two different squat depths on maximal squat- and knee extension strength at different ranges of motion in resistance trained men, with a secondary aim to assess musculoskeletal pain. It was hypothesized that participants would improve more at their assigned squat depth and corresponding knee angles during maximal knee extension.

Methods

Study design and participants

For the primary goal of comparing maximal low limb strength and musculoskeletal pain using two squat based training interventions differing in squat depth, an open label randomized controlled trial design was chosen. Two experimental groups underwent a two-week technique and test familiarization before being randomized to one of two squat based training groups, one training with squats to 90-degrees (Half Squat group) and one training with parallel depth (Deep Squat group). Tests for measuring leg strength, including a 1RM test for both squat depths, followed by an isometric knee extension test at different angles, were performed once after the familiarization, and once again following the completion of the squat training program. All participants were asked to discontinue any strenuous low limb RT throughout the study, alongside intensive running, cycling and deadlifting. Participants were randomized in a 1:1 ratio via the unit of applied clinical research at the Norwegian University of Science and Technology following the familiarization and 1RM- and isometric knee extension baseline tests and were stratified by 1RM strength in the parallel squat to ensure balanced groups.

Upon inclusion, participants had to meet the following criteria; (i) be a male aged between 18-30 years old, (ii) have more than six months of RT experience, (iii) be able to perform a parallel squat, (iiii) have no physical limitations related to strength training - including severe health problems or existing musculoskeletal injuries. Additionally, participants were required to have a membership at a local student training facility. Prior to the study, all participants signed up to appropriate training times to ensure they met the attendance criteria of two weekly supervised training sessions with a minimum of 48 hours between each session. If participants were unable to meet for the assigned session, a replacement session was scheduled.

Both groups were trained and tested by two experienced powerlifting trainers and given a periodized and progressive barbell squat based strength training program lasting for eight weeks, training only at their assigned squat depth for 30-45 minutes, twice per week, at a local training facility. With that, the project had a total follow up period of ten weeks. Additionally, during the third, fourth, ninth and tenth week of training, participants would fill out a pain questionnaire following their second workout of the week.

All participants were provided written and oral information regarding the project, and signed a written form of consent regarding data safety alongside information regarding the study, training and testing. All personal participant data was kept safe in a code dependent memory chip. The project was approved by the Norwegian Centre of Scientific Data (ID 923833) (NSD) and conducted in accordance with the Declaration of Helsinki.

Familiarization

Prior to randomization, participants underwent a two-week familiarization consisting of two technique-focused squat training sessions and one familiarization session on the Biodex System 4 Pro dynamometer (Biodex, Shirley, USA). Clear instructions regarding how to perform both squat variations were given by the trainers, alongside continuous feedback regarding squat depth and knee angles. In addition, participants were familiarized with the intensity scale used throughout the study, repetitions in reserve (RIR) which refers to the number of repetitions a participant would theoretically be able to perform at the end of a working set (25). Each squat familiarization session consisted of two warm up sets with feedback and depth measurements from the trainers, followed by two working sets on each respective depth. For the first session, participants performed two sets of parallel squats followed by two sets of 90-degree squats at low intensity (8-10 RIR). For the second familiarization session, the order was reversed, and the training load slightly increased (RIR 6-8).

90-degree and parallel squat technical execution

In both squat variations, participants were instructed to start the movement in a standing position with extended knees and hips, using a high bar placement (defined as bar placement above the spina scapula). Prior to the actual squat, participants would lift the weight off the squat rack and move two steps back to avoid hitting the rack during working repetitions. Participants were asked to find a comfortable hand- and foot placement around shoulder width, with a slight external rotation of the ankle suitable for achieving both squat depths. All repetitions were instructed to be “controlled” on the eccentric descent, and as rapidly as comfortably possible during the ascent. To assess the 90-degree knee angle, a two-sided 90-degree ruler was used during the familiarization and 1RM testing without making contact with the participants. The ruler would be placed beside the lateral condyle of the left knee during squats, from which the position of the femur and tibia would be assessed. Participants could decide to pause at the intended depth during the familiarization, but were intended to reach the desired depth in a fluent motion during training and testing. To assess parallel squat depth, two experienced powerlifters with competitive- and judging experience would visually confirm whether a participant reached the required depth or not. Moreover, whether or not participants chose to utilize a lifting belt or specific shoes during the pretest was noted and replicated for the post-test. Participants who opted to use a belt or specific shoes were also instructed to use said equipment during training.

Isometric Unilateral Leg Extension

Measurements on leg extension strength were taken using the Biodex System 4 Pro dynamometer (Biodex, Shirley, USA), and performed on the right leg exclusively, without shoes. Each participant underwent a 5-10 minute ergometer cycle warmup after taking measures of their body mass and height. Participants then completed five isokinetic warm up repetitions on the dynamometer before initiating the test. During these trial repetitions, participants were instructed to extend their knee at around 50-70% of their max force throughout a full range of motion. Following the warm up, three repetitions of five-second maximal isometric knee extensions were performed for each of the angles; 45, 75 and 105 degrees (0 degrees fully extended). Participants were instructed to brace and extend their knee as hard as possible upon test initiation, while keeping their neck and arms in a fixed position to avoid the use of momentum. Following each repetition, participants would rest for 25 seconds, and an additional 30 seconds between angles. The order of which angle would be performed first was randomized for each participant prior to the pre-test, and replicated for the post-test. Finally, measures regarding seat- and leg position for each participant were taken during the pre-test and later replicated. Strict protocols regarding knee- ankle- and seat position were upheld to ensure a high test reliability and properly adjust the machine for each participant.

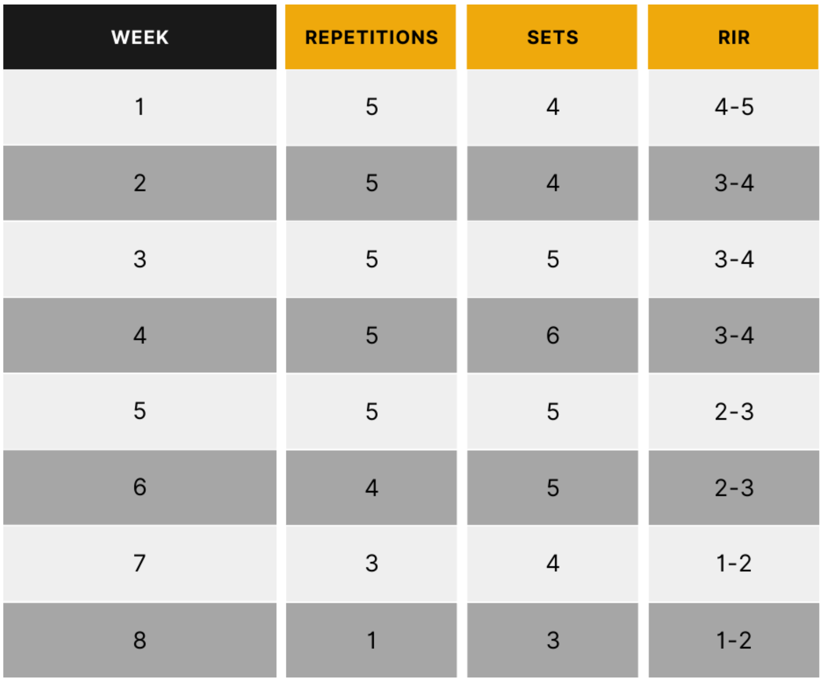
Pain questionnaire

Throughout the study, participants would fill out a custom made pain questionnaire, scaling pain perception from the last 24 hours using an unnumbered scale with five points (1-5) ranging from “no pain” to “a lot of pain” for the neck (bar placement), low back, knees, hips and ankles. The questionnaire was filled out immediately following the second weekly training session during week three, four, nine and ten for both training groups.

Squat training program

The squat training program consisted of 15 supervised training sessions dispersed over eight weeks (see ***Table 1***). Both experimental groups trained using the same relative intensity, which was determined using the RIR scale. The first eight training sessions focused on training volume accumulation, while the latter seven followed a strength peak with a slight decrease in training volume, and increased resistance and intensity (26,27). The number of repetitions per set varied between one to five, and the total number of sets varied between three to six. Following each training session, a note regarding each participants' training load was made. Additionally, participants would adequately warm up with increasing weight increments for three to four sets before reaching their workload. When using an external load >160 kilograms, participants performed an additional warmup set to avoid large jumps in load. For each warmup, all participants performed ten repetitions with a 20kg barbell, then increased the weight in increments to align with their working sets based on percentage estimates of their 1RM. To ensure an adequate training load was chosen, participants and trainers had an ongoing dialogue during the warm up regarding training load, sleep, nutrition, and anything that could affect performance. If the chosen load was deemed too light or heavy for the RIR on the first working set, the weight would be adjusted for the following sets. Ideally, the RIR would remain the same for every working set.

Table 1. Details about the squat training program performed by both groups.



WEEK	REPETITIONS	SETS	RIR
1	5	4	4-5
2	5	4	3-4
3	5	5	3-4
4	5	6	3-4
5	5	5	2-3
6	4	5	2-3
7	3	4	1-2
8	1	3	1-2

Note: The final week (8) consisted of only one training session. RIR: Repetitions in reserve.

Sample size

The required total sample size for the project was estimated using a power analysis with a statistical power of 0.8 (β=0.2) and a p-value of 0.05 for the primary variable, being the parallel squat 1RM. Based on similar studies, a mean difference of ~14% could be expected between groups (2). Expecting a loss of follow up of 20% (2,9), the required sample size was estimated to be 32 total participants (N=32), using the MedCalc Statistical Software version 20.106.

Statistical analysis

Assumptions of normality were verified using the Shapiro-Wilk test, and visually confirmed with a qq-plot and histogram for both groups across all strength outcomes. Following the intervention, the mean differences in 1RM for both squat depths and isometric knee extension for all angles between both groups were compared using an independent sample t-test using a p-value of 0.05. Groups were also compared to their baseline results to assess strength progress for all strength tests using a paired sample t-test and a p-value of 0.05. Effect Sizes (ES) for each group and outcome were determined with Cohen's D and classified as either "small" at 0.2, "medium" above 0.5 or "large" if higher than 0.8. All values in the results of the study were expressed as means ± standard deviation.

Results

19 healthy men (age 22.4 ± 2.0 years, body weight 86.0 ± 8.3kg, height 182.1 ± 4.8cm) were voluntarily recruited and randomly assigned to either a "Half Squat", or "Deep Squat" training group following a two week squat technique- and test familiarization. Three participants dropped out during the study; one participant withdrew following a series of low back pain during the familiarization and was not randomized. Two others, one from each group, resigned due to illness and events which occurred outside of training. A total of eight participants from the Half Squat group (N=8) and nine from the Deep Squat group (N=9) completed all the required tests and training sessions (total N=17).

Strength Tests

At baseline, the Half Squat group had a mean 1RM of 157.9kg (± 38.5) and 200.0kg (± 37.8) in the parallel squat and 90-degree squat respectively, while the Deep Squat group had a mean 1RM of 143.7kg (± 42.4) and 176.7kg (± 44.8) (see ***Table 2***). The Half Squat group significantly increased the 1RM for the 90-degree squat by 22.9kg (p=0.009, ES=1.261) and parallel squat by 11.1kg (p=0.035, ES=0.924). The Deep Squat group also significantly increased their 1RM for both squat variations compared to baseline measures with 17.5kg in the parallel squat (p<0.001, ES=2.085) and 27.8kg in the 90-degree squat (p<0.001, ES=2.134) respectively. Comparatively, no significant differences in strength increases between groups were measured. The Deep Squat group performed slightly better than the Half Squat group in both the parallel squat 1RM (p=0.211) and 90-degree squat 1RM (p=0.528) (see ***Figure 1***).

In the isometric knee extension test, no significant changes were measured for either group compared to baseline for any of the three angles (see ***Table 2***). The Half Squat group showed small improvements at 45 degrees (p=0.510, ES=0.245), negligible improvements at 105 degrees (p=0.798, ES=0.094), and a small decrease in peak torque at 75 degrees (p=0.210, ES=-0.488). The Deep Squat group showed medium improvements in peak torque at 45 degrees (p=0.135, ES=0.554), a medium decrease at 75 degrees (p=0.167, ES=-0.506) and a small decrease at 105 degrees (p=0.554, ES=-0.206). No significant differences in peak torque were observed between groups for any angle (p=0.528-0.977).

Table 2. Strength test results

Outcome	Half Squat Group		Cohen's D	Deep Squat Group		Cohen's D
	PRE	POST	ES	PRE	POST	ES
1RM 90-Degree Squat (Kg)	200.0 ± 37.8	222.9 ± 44.5*	1.261	176.7 ± 44.8	204.4 ± 41.1*	2.134
1RM Parallel Squat (Kg)	157.9 ± 38.5	168.9 ± 45.0*	0.924	143.7 ± 42.4	161.1 ± 44.0*	2.085
45 Degree Knee Extension (Nm)	223.44 ± 44.4	229.08 ± 36.1	0.245	205.07 ± 34.7	213.60 ± 41.4	0.554
75 Degree Knee Extension (Nm)	331.44 ± 64.4	318.18 ± 76.1	-0.488	315.43 ± 57.9	301.78 ± 57.1	-0.506
105 Degree Knee Extension (Nm)	256.26 ± 52.3	258.58 ± 65.2	0.094	273.64 ± 92.5	264.36 ± 67.3	-0.206

Data are mean ± standard deviation. 1RM: One repetition maximum; kg: kilograms; Nm: Newton-meters; ES: Effect Size. * = statistically significant compared to baseline (PRE) with $p<0.05$.

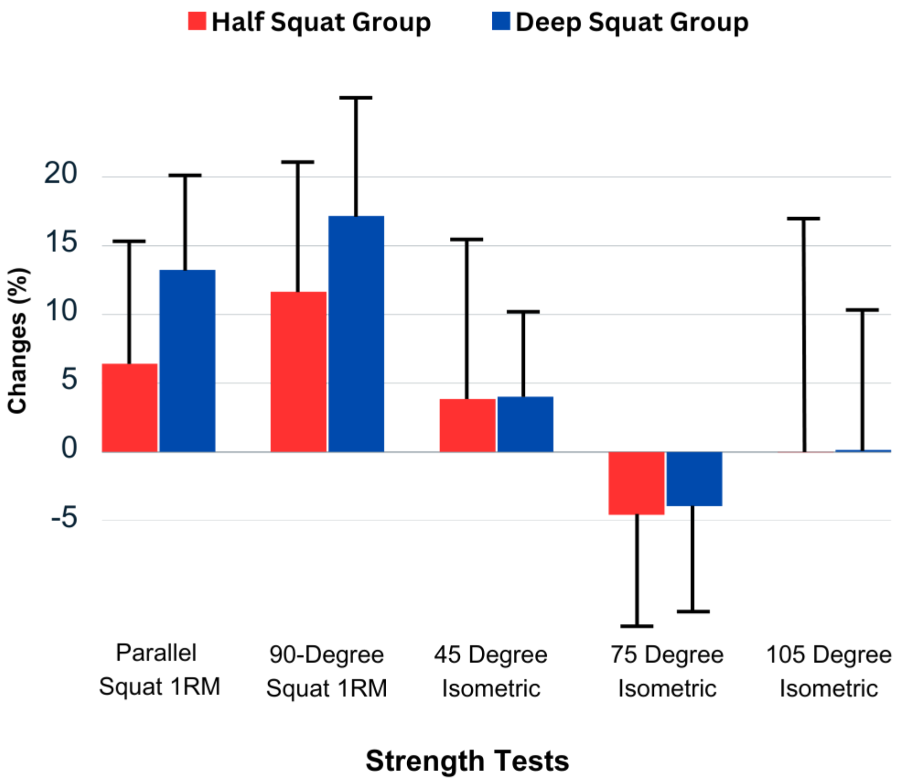
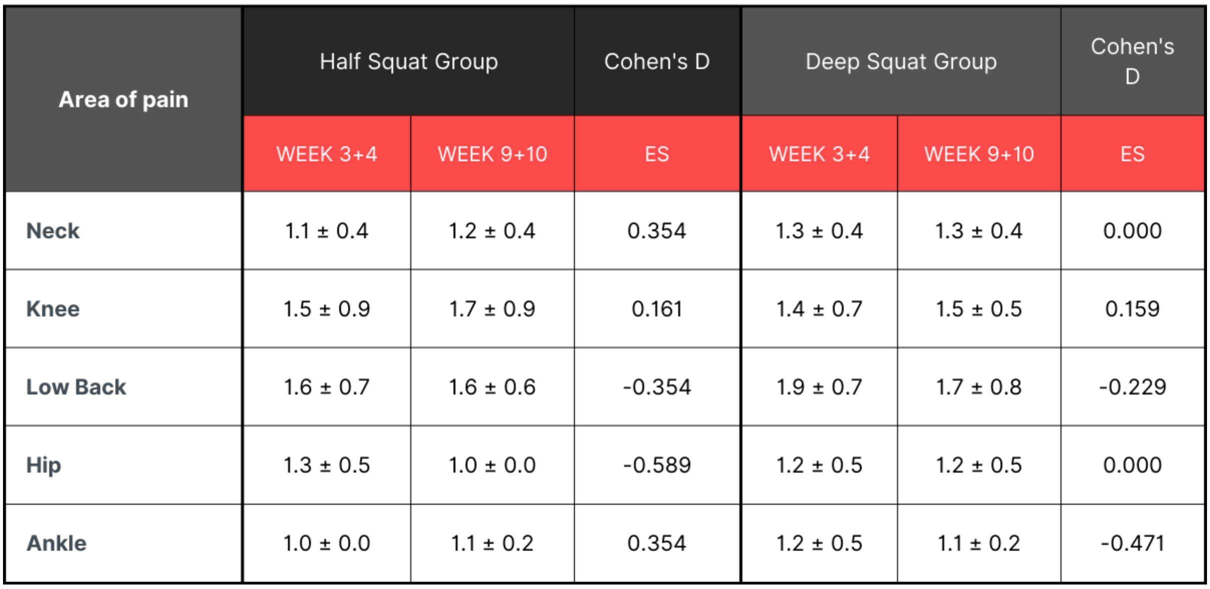


Figure 1. Mean changes across strength tests between groups. Error bars = standard deviation of mean.

Musculoskeletal pain

Both groups reported very small changes in pain throughout the study (see ***Table 3)***. None of the reported changes between week 3-4 and 9-10 were statistically significant for either group, or between groups (p=0.119-0.870). The Half Squat group saw a small increase in neck and ankle pain, a negligible increase in knee pain, a small reduction in low back pain, and a medium reduction in hip pain (p=0.140-0.662). The Deep Squat group reported similar pain perception: Neck and hip pain did not change; a negligible increase in knee pain; and a small reduction in low back and ankle pain (p=0.195-1.000).

Table 3. Changes in musculoskeletal pain



Area of pain	Half Squat Group		Cohen's D	Deep Squat Group		Cohen's D
	WEEK 3+4	WEEK 9+10	ES	WEEK 3+4	WEEK 9+10	ES
Neck	1.1 ± 0.4	1.2 ± 0.4	0.354	1.3 ± 0.4	1.3 ± 0.4	0.000
Knee	1.5 ± 0.9	1.7 ± 0.9	0.161	1.4 ± 0.7	1.5 ± 0.5	0.159
Low Back	1.6 ± 0.7	1.6 ± 0.6	-0.354	1.9 ± 0.7	1.7 ± 0.8	-0.229
Hip	1.3 ± 0.5	1.0 ± 0.0	-0.589	1.2 ± 0.5	1.2 ± 0.5	0.000
Ankle	1.0 ± 0.0	1.1 ± 0.2	0.354	1.2 ± 0.5	1.1 ± 0.2	-0.471

Data are mean ± standard deviation. ES = Effect size, scale of pain perception from 1-5.

Discussion

The primary finding from this study was that although no significant differences between groups were found, the Deep Squat group experienced larger improvements in 1RM squatting strength than the Half Squat group at both parallel- and 90-degree depth, indicated by a contrast in effect sizes. (ES=2.085 vs ES=0.924 & ES=2.134 vs ES=1.261). Both groups saw significant increases in strength compared to baseline measures for both squat depths over eight weeks of periodized and supervised squat RT. No significant differences were measured for isometric knee extension strength compared to baseline, or between groups across all three angles. Finally, no notable differences in musculoskeletal pain were measured between week 3-4 and 9-10 for either group, suggesting that each group tolerated the training.

Most research regarding the effects of squat depth and maximal strength suggests that neuromuscular adaptations are specific to the trained depth, in line with theories on the specificity of training stimulus and test performance (23,28). Several studies have reported that groups training with a specific squat depth tend to improve more at their trained depth (9,10,15,19,24). Despite this, results from the current study contrast these findings and are more in line with studies which reported that deep squats can elicit larger neuromuscular adaptations throughout the entire squat ROM (2,17,20). There are a few possible explanations for why the Deep Squat group improved more than the Half Squat group. For one, deep squats cause greater mechanical tension to the knee- and hip extensor muscles than half squats by being placed in a more lengthened position, which might elicit greater neuromuscular adaptations (8,29–33). However, this hypothesis is contrasted by the studies which reported larger adaptations at specific training ROM, both in untrained and resistance trained participants (10,15,19). Moreover, results might have been affected by the fact that all participants were required to walk with the full weight for two steps before and after a working set to avoid hitting the rack when squatting. As such, the Half Squat group may have experienced more central fatigue from carrying the high loads than the Deep Squat group, and require longer intra-set recovery times which could affect performance (34). Similar studies have on occasion prompted the use of a smith machine squat variation for this reason, and for participants' safety (2,9). However, the "walk out" part of the lift has not been described in similar studies, and it is therefore uncertain whether or not this affected results. Interestingly, the participants in this study were notably stronger than in similar studies for both squat depths at baseline, which could affect their response to ROM specific exercise (24,29). Moreover, the most comparable sample size in terms of maximal squat strength at baseline was found in the study by Rhea and colleagues (10), who suggested that angle-specific strength improvements might be more pronounced in higher trained participants, although our findings contrast this statement. Lastly, all the aforementioned studies investigating squat depth had the same approaches to training effort and load, using percentages of participants 1RM results at baseline to estimate training load, leaving room for individualized progression. In our study, the utilization of the RIR intensity scale meant that loads were adapted for each participant during each training session respectively.

Although both training groups improved their maximal squatting strength, there was no clear transfer to the maximal isometric knee extension measures for any of the angles; 45-, 75- and 105 degrees respectively, as neither group changed notably compared to baseline measures. There are a couple potential explanations for why neither group saw any transfer of squatting strength to isometric knee extension strength. For one, all participants in this study were required to have a minimum of six months of RT experience and they were notably stronger at baseline than in similar studies using trained participants (2,9,10). Therefore, it could be that squat exclusive training lacked the required specificity for adaptations to occur in isolated knee extensions, as trained participants are believed to require more specific training stimuli to improve at specific tasks than untrained participants (10,35). Moreover, although not accounted for in the inclusion of participants, it could be that some participants were already using specific and isolated knee extension exercises in their regular RT, which they were asked to avoid during this study. Furthermore, it cannot be excluded that changes in squat strength may have been mostly driven by increased hip extensor strength, as the m. gluteus maximus in particular becomes notably increasingly active until parallel depth is reached (15,19,36). Although small differences in isometric knee extension strength were measured, both groups increased mean peak torque at 45-degrees, suggesting that knee extension strength might be of more importance during the upper portion of the squat, in accordance with the suggestions from Bryanton and colleagues regarding increased knee extensor relative muscular effort at higher squat depths (16). Finally, results in the isometric knee extension test might have been affected by the fact that participants performed a test familiarization on the dynamometer one week before the actual baseline test, while a familiarization session was not scheduled prior to the post-testing.

The finding of no changes in pain throughout the study indicates that all participants tolerated the training loads regardless of squat depth, which opposes the hypothesis of partial squat depth and high training loads to cause more knee- and spinal joint pain (8,12,14,18). According to Hartmann and colleagues (8,12), due to high levels of intervertebral- and patellofemoral compressive forces caused by high training loads during a half squat, degenerative changes to knee- and spinal joint morphology could occur, increasing pain perception for those areas. Interestingly, in the only study measuring pain in relation to squat depth prospectively, Pallares and colleagues (2) reported a higher degree of pain in participants training with half squats, especially cervical pain, which also differs from our findings. However, in the aforementioned study, participants were instructed to perform the ascending part of the squat as rapidly as possible, suggesting that rapid squats with high loads can elicit elevations in pain and discomfort. In the current study, participants were asked to ascend as fast as comfortably possible, implying that, in well trained participants, high loads during half squats might not elicit more pain than deep squats if the lifting tempo is not vigorous. Finally, since our participants were notably stronger than the participants in Pallares and colleagues' study (2), it could also be that their threshold for exercise-related pain was higher because they were more accustomed to similar training, and were more self-adapted to technical execution of the lifts (12,37).

This study has several notable limitations which could have affected results throughout. For one, the sample size was small compared to the suggested sample based on expected results from previous studies (N=32) (2), making statistically significant changes difficult to detect. Secondly, the total training duration in this study was short compared to similar studies (2,9,10,19), lasting only for eight weeks and containing only 15 training sessions. Rhea and colleagues (10) reported that, during their 16-week study comparing different squat depths, that improvements in strength were insignificant at eight weeks, and that longer study durations should be utilized to assess maximal strength in trained participants. Despite this, both our training groups improved significantly compared to baseline, similarly to longer studies (2,9,19). Moreover, these improvements in squat strength may have arised by increased hip extensor strength, which was not specifically measured in this study. Another limiting factor could be that assessments of squat depth were not adapted to each participant's biomechanical structure, resulting in large technique deviations within groups, even when the required squat depth was achieved. For example, one person's half squat could come close to parallel depth if there was little ankle dorsiflexion, and much hip flexion, while another person's half squat could be comparatively “high” with more extended hips, achieving the same knee angle while having a much larger overall ROM, which could affect relative muscular effort of specific muscles during the squat (16). Moreover, squat depth at 90-degrees was sometimes difficult to assess, as the knee angle was based on positioning of the tibia and femur (2), which were difficult to visually spot on occasion, especially with muscular participants. Finally, measurements of pain during the study were only taken following completion of the second squat training sessions during week 3,4, 9 and 10, but not immediately following 1RM testing. Therefore, it could be that important measurements of pain from the 1RM testing were omitted, as the 1RM loads were much higher than those used in training, and could therefore theoretically produce more knee- and intervertebral joint stress.

Conclusion

In summary, this study presents some evidence indicating that deep squats may elicit larger improvements in maximal squat strength compared to half squats at both 90-degrees and parallel depth in resistance trained men. However, squats at either depth alone may not provide sufficient stimuli to improve maximal isometric knee extension strength in well trained participants. Additionally, neither deep- and half squats may elicit pain when technique and lifting tempo are controlled in trained participants. Although this intervention indicates greater squat ROM to elicit greater neuromuscular adaptations from RT, further research is needed to examine the effects of exercise ROM and maximal strength for the purpose of optimizing individualized training strategies.

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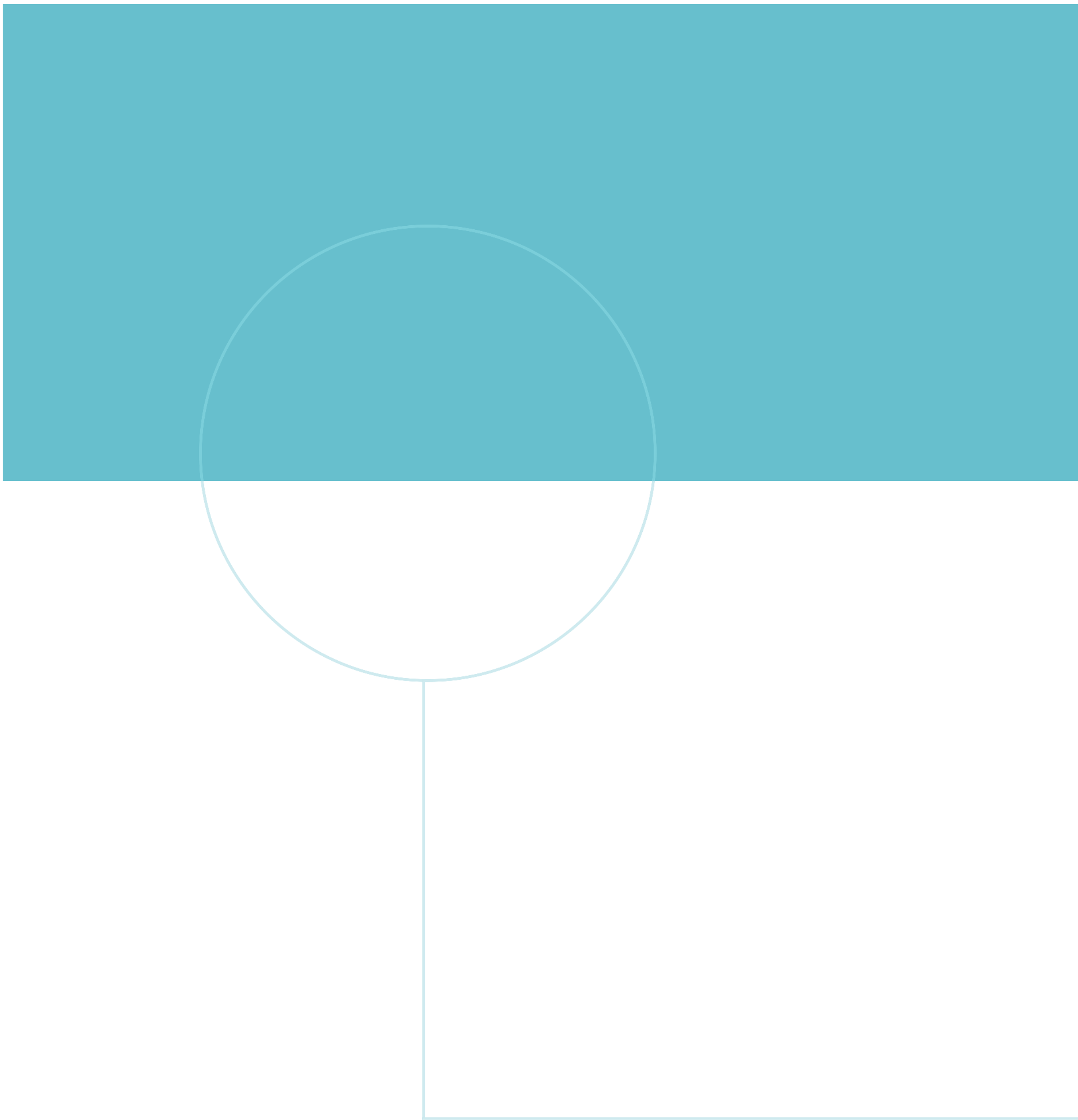

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