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# Asymmetry in strength training: investigating the impact of offset training on the deep stabilisation system, strength/performance, and maximal power in Female Softball Players



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ABSTRACT
**Purpose.** This study aims to fill a significant gap in sports science research by examining the underexplored effects of asymmetric load training on the deep stabilisation system (DSS), strength, and maximal power in female softball players.
**Methods.** Fourteen participants were divided into two groups: a control group (CON), which exercised with a symmetrically weighted bar, and an experimental group (EXP), which used a bar with asymmetrically distributed weight. The asymmetric load with a distribution of weight that was gradually increased during the 8-week intervention program. The assessment included a 1 repetition maximum (1RM) test for deadlift, flat bench press, front squat, and 4RM tests for single-leg leg press for both legs, along with evaluations of DSS and strength/performance, before and after a resistance training program. A two-way ANOVA was used to compare pre- and post-intervention performance on the DSS and 1RM strength tests.
**Results.** The results showed significant improvements in all 1RM and 4RM tests for both groups in all exercises ($p > 0.001$), with no significant differences between the groups ($p < 0.05$). However, a dependent *t*-test in the EXP group revealed significant improvements in DSS strength/performance from pre- to post-measurements in all tests, with large effect sizes. In contrast, the CON group showed significant improvements only in trunk extension, side plank, and prone tests.
**Conclusions.** These findings indicate that asymmetric training may provide superior benefits in strengthening the DSS, while still achieving comparable gains in maximal strength.
**Key words:** asymmetry training, deep stabilisation system, offset training

## Introduction

Resistance training (RT) with external loads is widely used by both professional and amateur athletes to enhance their performance and reduce injury risk [1]. This training focuses on developing key physical skills like muscle coordination, strength, and endurance. However, these aspects are just part of the overall movement pattern. An athlete's success is often reliant on their ability to efficiently transfer forces between different body parts, minimising energy loss [2]. Consequently, building and maintaining a strong deep stabilisation system (DSS) is crucial for athletes to effectively create and channel forces to their extremities. Without proper force transmission, athletic performance in activities like running, jumping, or throwing can be adversely impacted. The significance of a robust core in boosting athletic performance is well-documented in current research [3].

Asymmetric training, often referred to as offset training, has not been extensively explored in the scientific literature [4]. Most studies have centred around muscle activation during the bench press (BP) exercise, with findings showing increased activity in the external oblique muscle on the side bearing more weight [4–6]. Moreover, asymmetric loading has been recognised as an effective way to enhance BP performance and address muscle imbalances [4]. Nevertheless, this technique is frequently employed by strongmen in exercises like the One-Hand Suitcase Carry or asymmetric kettlebell carry. These exercises uniquely challenge the lateral core muscles, including the quadratus

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lumborum and oblique abdominal wall, in ways that squats cannot [7]. Despite its practical use, there appears to be a lack of focused research on the effects of asymmetric training on the core muscles of athletes.

The DSS is comprised of 29 pairs of muscles, essential for supporting the lumbar-hip complex and stabilising the spine, pelvis, and kinetic chain during functional movements [8]. The DSS is vital for efficient and strong body movements. It involves trunk and pelvic muscles that maintain spinal and pelvic stability, helping to generate and transfer energy from larger to smaller body parts. Postural stability, the body's ability to distribute and control forces impacting the skeleton, is crucial not only during static standing but also in dynamic movements. This stability is achieved through coordinated muscle tension of the trunk, pelvis, and lower limbs' agonist and antagonist muscles, ensuring stability in complex movements [9]. There is a variation in the current understanding and practices among coaches for strengthening these muscles. For instance, the significance of fortifying the quadratus lumborum is often underestimated, even though its importance in core stability is well-established [10]. A common recommendation is to contract the abdominal muscles inward, but this approach actually diminishes stability [11]. The most effective strategy for DSS strengthening is to focus on the overall stiffening of the entire core musculature. Isolating and targeting just one muscle typically does not improve stability and can lead to patterns that reduce stability when measured [10]. Hence, it's crucial to employ exercises that engage and challenge all core muscles in maintaining balance.

Incorporating DSS training is essential for enhancing athlete performance. However, adding more training sessions increases the overall training volume, which can raise the risk of injury. This presents a challenge for coaches, especially in managing training for university sports that span an entire season, in balancing training volumes accurately. Focusing on training that boosts maximal strength and core power can effectively reduce the total training volume, thereby lowering injury risk. Thus, the primary objective of this study is to investigate whether asymmetric training improves not only the core strength but also increases 1RM scores in traditional exercises in female softball players.

We hypothesise that asymmetric load training will lead to significantly greater improvements in the strength and performance of the DSS in female softball players compared to symmetric load training. Furthermore, we expect that both asymmetric and symmetric load training will result in comparable gains in maximal power. This hypothesis is based on the potential of asymmetric training to uniquely challenge and enhance DSS muscle activation, which is crucial for effective force transmission and overall athletic performance.

## Materials and methods

### Experimental approach to the problem

The study employed a randomised parallel design to assess the impact of offset training on DSS performance and maximal strength in deadlift (DL), flat BP, front squat (FSQ), and 4RM tests for single-leg leg press (LP) for both legs. Participants underwent a familiarisation session followed by an 8-week RT regimen, exercising three times a week. They took a 24-hour rest before training different muscle groups and a 48-hour rest for the same muscle group. The familiarisation session involved determining the one-repetition maximum (1RM) load for exercises such as single-leg LP, flat BP, DL, and FSQ. The experimental (EXP) group performed these exercises with an asymmetrically loaded bar, while the control (CON) group trained with symmetrically distributed weights. To measure the effects of asymmetric training on core strength, various tests were conducted, including Pronation, Supination, Diaphragm, Trunk Flexion, Trunk Extension, Hip Flexion, Intra-abdominal Pressure, and Side Plank Tests.

### Subjects

The study involved sixteen professional Czech softball players, including members of the national team and top division clubs. Of these, fourteen (*n* = 14) completed the intervention, as detailed in Table 1. Two participants were unable to finish due to injuries unrelated to the study. The study participants were divided into two groups. Seven participants formed the CON group, performing exercises with a symmetrical weight distribution. The other group, also consisting of seven participants, was designated as the EXP group, and they exercised with an asymmetrical weight distribution on the bar. Recruitment criteria required the athletes to be healthy and free from injury. The measurements were in parallel groups taken during the off-season, a period when only practice sessions were conducted. Participants had the freedom to withdraw from the study at any time. The sample size was determined using the statistical software GPower (Dusseldorf, Germany), with power calculations indicating a minimum

Table 1. Descriptive statistics for age, body height, body mass, experience in softball, 1RM for bench press (BP), deadlift (DL), ftont squat (FSQ), and leg press for the right (LP_P) and left leg (LP_L)

| Group | *N* | Age (years) mean ± *SD* | Height (cm) mean ± *SD* | Body mass (kg) mean ± *SD* | Softball experience (years) mean ± *SD* |
|---|---|---|---|---|---|
| Experimental | 7 | 20.4 ± 2.9 | 170.4 ± 4.5 | 68.4 ± 10.4 | 9.9 ± 4.1 |
| Control | 7 | 21.9 ± 3.6 | 168.6 ± 5.2 | 66 ± 9 | 9.3 ± 5.0 |

of 12 participants was needed to detect an effect size of 0.832. This effect size was based on the findings reported in Barrio's meta-analysis [12], with specified parameters (power = 0.8, alpha = 0.05, correlation among repeated measures = 0.8; GPower 3.1.9.4). The participants were randomly assigned to either the CON or EXP groups.

Experimental procedures

Familiarization session and 1RM measurements

Before and after the experimental protocol, the 1RM for flat BP, DL, and FSQ, and the 4RM for single-leg LP was recorded on different occasions. Each participant started with a standardised warm-up, which included 5 min of treadmill running at a steady speed of 6 km/h and dynamic stretching. Participants were exposed to three different measurements: BP with DL on one occasion, FSQ and LP on the second, and DSS tests on the third. The order of measurements was random. For BP, the focus was on chest muscles, while for DL, LP, and FSQ, the emphasis was on the lower body muscles. All 1RM tests were scheduled at least 48 hours apart, and participants were advised to refrain from RT 24 hours before the tests. Following the warm-up, participants performed sets of 10 with 6 repetitions of each exercise, using weights recommended by the national team's conditioning coach, who worked with them regularly. The initial test load was approximately 80% of the estimated 1RM, incrementally increased by 2.5–5 kg until the participant could no longer maintain proper lifting technique, for BP loads increased by 1–2.5 kg. Conversely, if the initial attempt at the self-reported 1RM was unsuccessful, the weight was reduced by 1–2.5 kg for BP and 2.5–5 kg for the rest of the exercises. To mitigate the potential impact of fatigue, rest periods of at least 5 minutes were mandated between each attempt [13]. The duration of each repetition was synchronised with a metronome, set to 2 s for the eccentric phase and at maximum velocity for the concentric phase for BP, FSQ, and single-leg LP. For DL, participants were instructed to perform the lift from the ground without tempo requirements. For all exercises, the highest load performed without the assistance of spotters was defined as 1RM. Participants were not allowed to use a belt during 1RM measurements or the intervention. Tests were performed in a randomised order.

Front squat

For the FSQ, participants began the exercise standing, with their knees and hips fully extended. Their foot stance was approximately shoulder-width apart, and the foot positioning (flat on the ground, either parallel or slightly outwardly rotated) was individually customised and consistently replicated for each repetition. The barbell was set with a width that matched or was slightly wider than shoulder width. Participants were instructed to keep their upper arms roughly parallel to the floor. The barbell was positioned just above and slightly behind the anterior deltoids and upper clavicle area [14]. In cases where athletes experienced difficulty with this technique, they were permitted to use a cross grip to hold the bar. Starting from this position, participants were required to lower themselves until their knees reached 90° of flexion. This angle was accurately measured by an assistant using a goniometer.

Deadlift

For the DL, the positioning of the feet is similar to that in the FSQ with a double overhand grip. They were instructed to keep their scapulae retracted and to maintain the natural S-shaped curvature of the spine, including both the cervical and lumbar regions, throughout the entire lift [15]. For the DL, an open trap bar was utilised. Participants were guided to execute a hip hinge by bending at the hips and knees until they could firmly grasp the bar, ensuring their spine remained in a neutral position throughout. They were then instructed to lift the bar by initiating a driving force through their feet against the ground. Upon reaching a standing position, participants were advised to push their hips forward, mirroring the motion performed during the concentric phase of the hip hinge [16].

Single-leg leg press

For the LP, participants started the measurements with the non-dominant limb and, after reaching its 4RM, had a 5-minute break and proceeded to measure the 4RM of the dominant leg. LP was measured in the sited position on the LAX fitness systems device, heels were set at the middle of the foot pedal. The LP involved a countermovement, with participants initiating the movement from the top position, descending to their maximum reach, and then returning to the starting position. Participants were directed to follow precise technique guidelines: exerting force through their heel, avoiding active downward movement of the foot, ensuring the knee stays aligned with the hip and ankle on the same side, keeping the lower back in contact with the backrest, and breathing out during the upward or effort phase of the exercise [17].

Bench press

For BP, participants laid flat on the bench with their knees bent and their feet flat on the floor. The hand placement on the barbell was at a width that was 1.5 times the width of the shoulders [18]. A research assistant was designated as a spotter and positioned behind the bench to assist if the subject struggled to lift the weight. The subject gripped the bar at an equal distance from the middle, unracked it, and fully extended their arms to hold the bar at the sternum's midpoint for one second. Subsequently, the subject smoothly and carefully lowered the bar to touch the chest at approximately nipple level and then pressed the bar upward until both elbows were completely extended. It was emphasised that the vertebral column should not be hyperextended during the lift. The principal investigator also visually confirmed the completion of the barbell press at full elbow extension.

Experimental sessions

During all measurements, the resistance level remained constant for both groups. The only difference was in the weight distribution on the barbell: the EXP group had asymmetrical loading, while the CON group worked out with a symmetrical load on both sides. The total resistance and the degree of asymmetry were progressively increased throughout the training phase, calculated based on the initial 1RM measurements. The training spanned 8 weeks under licensed strength and conditioning coaches, with the first two weeks comprising of two sessions per week and the remaining six weeks including three sessions each, spaced at least 48 hours apart. In the first week, the resistance was set at 50% of 1RM, increasing to 60% from the 2nd to 4$^{th}$ week, 70% from the 5$^{th}$ to 7$^{th}$ week, and 80% in the 8$^{th}$ week. Each session began with a standardised warm-up specific to each training protocol, followed by two warm-up supersets at 30% and 20% lower resistances than the main session. Three distinct training protocols were consistently followed each week. The warm-up and training protocols were identical for both groups. Exercises performed during the sessions included DL, flat BP, Romanian DL, FSQ, Bulgarian split squats, and barbell rows. The distribution of asymmetry for the EXP group is detailed in Table 2. The tempo for all main exercises was set at 2-1-1-1, with a total time under tension (TUT) of 50–60 s, and each repetition consisted of one inhale and one exhale. Participants were introduced during the familiarisation session to the exercises with the tempo regulated by a metronome, in addition, the coach always monitored the participants, and if there was a case of losing the tempo, he motivated and corrected the participant. The asymmetric load was switched between the dominant and non-dominant sides for each set, and coaches closely monitored to ensure that the barbell was lifted perpendicular to the floor during asymmetric loading, avoiding any uneven lifts.

Additionally, both groups were instructed to grip the barbell in the same position to prevent compensation by altering the grip during exercise. Participants performed the exercises in a circuit format, moving from one station to another with a 15-second transition period. After completing the entire circuit, they had a 180-second break before starting the next round. In the first week, they began with two sets per exercise at 50% of their 1RM. In the second week, they increased to three sets per exercise at 60% 1RM. Starting in the third week, the number of sets increased to four, and the load began at 60% of 1RM, moving to 70% of 1RM starting in the fifth week. In the final eighth week, they continued with four sets per exercise, increasing the weight to 80% 1RM. Rest between workouts was at least 48 hours.

DSS testing

The DSS testing, according to Kolář [19], was performed by inspection and palpation by one certified physical therapist who was blinded to the type of intervention of the subjects.

The physical therapist utilised a five-point scale to evaluate core strength: 1 = sufficient activity, 2 = ac-

Table 2. Overview of the training protocol, including asymmetry calculation

| Week | Training session | Exercise | Resistance | Asymmetry %* | Sets | Repetitions |
|---|---|---|---|---|---|---|
| I | 1 | Deadlift<br>Flat bench press<br>Romanian deadlift | 50% 1RM | 5% | 2 | 10<br>10<br>5 each leg** |
| I | 2 | Front squat<br>Bench press with legs in 90°<br>Barbell row | 50% 1RM | 5% | 2 | 10<br>10<br>10 |
| II | 1 | Deadlift<br>Flat bench press<br>Romanian deadlift | 60% 1RM | 5% | 3 | 8<br>8<br>4 each leg** |
| II | 2 | Front squat<br>Bench press with legs in 90°<br>Barbell row | 60% 1RM | 5% | 3 | 8<br>8<br>4 each leg** |
| III | 1 | Deadlift<br>Flat bench press | 60% 1RM | 7.5% 1RM | 4 | 16<br>16 |
| III | 2 | Bulgarian split squat<br>Barbell row | 60% 1RM | 7.5% 1RM | 4 | 8 each leg**<br>16 |
| III | 3 | Front squat<br>Romanian deadlift | 60% 1RM | 7.5% 1RM | 4 | 16<br>8 each leg** |
| IV | 1 | Deadlift<br>Flat bench press | 60% 1RM | 10% 1RM | 4 | 16<br>16 |
| IV | 2 | Bulgarian spilt squat<br>Barbell row | 60% 1RM | 10% 1RM | 4 | 8 each leg**<br>16 |
| IV | 3 | Front squat<br>Romanian deadlift | 60% 1RM | 10% 1RM | 4 | 16<br>8 each leg** |
| V | 1 | Deadlift<br>Flat bench press | 70% 1RM | 5% 1RM | 4 | 12<br>12 |
| V | 2 | Bulgarian spilt squat<br>Barbell row | 70% 1RM | 5% 1RM | 4 | 6 each leg**<br>12 |
| V | 3 | Front squat<br>Romanian deadlift | 70% 1RM | 5% 1RM | 4 | 12<br>6 each leg** |
| VI | 1 | Deadlift<br>Flat bench press | 70% 1RM | 7.5% 1RM | 4 | 12<br>12 |
| VI | 2 | Bulgarian spilt squat<br>Barbell row | 70% 1RM | 7.5% 1RM | 4 | 6 each leg**<br>12 |
| VI | 3 | Front squat<br>Romanian deadlift | 70% 1RM | 7.5% 1RM | 4 | 12<br>6 each leg** |
| VII | 1 | Deadlift<br>Flat bench press | 70% 1RM | 10% 1RM | 4 | 12<br>12 |
| VII | 2 | Bulgarian spilt squat<br>Barbell row | 70% 1RM | 10% 1RM | 4 | 6 each leg**<br>12 |
| VII | 3 | Front squat<br>Romanian deadlift | 70% 1RM | 10% 1RM | 4 | 12<br>6 each leg** |
| VIII | 1 | Deadlift<br>Flat bench press | 80% 1RM | 10% 1RM | 4 | 8<br>8 |
| VIII | 2 | Bulgarian spilt squat<br>Barbell row | 80% 1RM | 10% 1RM | 4 | 4 each leg**<br>8 |
| VIII | 3 | Front squat<br>Romanian deadlift | 80% 1RM | 10% 1RM | 4 | 8<br>4 each leg** |

* only applicable to the experimental group, ** the exercise started on the non-dominant leg

tivity with a single functional deficiency, 3 = activity with multiple functional deficiencies, 4 = inadequate postural maintenance, and 5 = core strength insufficiency. The reliability of this assessment method was consistent with other comparable physiotherapy approaches. The evaluation was comprised of six tests based on Kolář work [20], along with two tests focused on diagnosing spinal segment stabilisation, specifically emphasising transversus abdominis muscle function using a Pressure Biofeedback Unit (PBU), in accordance with Richardson [21]. The testing protocol employed a five-point scale, where 1 represented optimal performance (lack of spinal or pelvic movement) and 5 indicated suboptimal performance.

Pronation test (PRONE)

To assess the stabilising function of the transversus abdominis and internal oblique muscles while in a prone position (referred to as the PRONE test), the subject lies down with their upper limbs alongside the body. A PBU is positioned beneath the abdominal wall, aligning the distal edge of the pad with the junction of the right and left spina iliaca anterior superior, and placing the umbilicus at the centre. The PBU is then inflated to 70 mm Hg, allowing a brief pause to stabilise the pressure. The subject is instructed to relax their abdominal muscles before beginning the test. Following this, they inhale and exhale, engaging the abdominal muscles without breathing. The instruction given to the subject is: “Activate the abdominal wall without moving the back and pelvis.” A decrease in pressure of 6 to 10 mm Hg is expected. To effectively activate the transversus abdominis, the subject is guided to focus on engaging the lower abdominal wall [21].

Supination test (SUPINE)

To evaluate the stabilising function of the transversus abdominis muscle in the supine position (known as the SUPINE test), the subject lies on their back on a recliner, with their upper limbs resting alongside the body and lower limbs flexed. This positioning offers advantages, making it easier to observe and palpate the abdominal wall or simultaneously monitor it through ultrasound. Moreover, this position benefits the subject by facilitating easier activation of the transversus abdominis muscle. A PBU is positioned under the lumbar spine and inflated to 40 mm Hg. The breathing instructions are consistent with those for the physical therapy examination. The subject then activates the transversus abdominis muscle without moving their back and pelvis, aiming to maintain the pressure on the manometer at a steady 40 mm Hg, following the original authors’ guidelines [21]. However, in 2013, research was conducted to refine the target pressure change during the activation of the transversus abdominis muscle during the SUPINE test. The findings indicated that an appropriate target value was an increase in pressure ranging from 0 to 2 mm Hg [22].

Diaphragm test (DT)

The individual is seated in an upright posture with the arms and legs in a relaxed position. The chest is positioned in a downward or expiratory orientation. The examiner positions their fingers between the patient’s lower ribs and below them, instructing the individual to take a deep breath and exert counter-pressure against the examiner’s fingers to engage the lateral and dorsal parts of the abdominal wall. The examiner assesses any lateral movement of the lower ribs, as well as evaluates the extent and symmetry of activation in the lateral and dorsal sections of the abdominal wall through visual observation and palpation [19, 20].

Trunk flexion test (TF)

The individual is lying in a supine position with arms resting comfortably by their sides. The examiner directs the person to gradually flex the neck and then the trunk until the lower edges of the shoulder blades lift off the surface. The examiner then visually evaluates the engagement of the thoracic muscles [19, 20].

Trunk extension test (TE)

The evaluation occurs with the subject lying face down (prone) and arms resting naturally by their sides. The examiner guides the subject to gradually lift the head and smoothly extend the spine while sliding over the table. The examiner visually examines the stabilisation pattern, focusing on the dorsal and lateral abdominal muscle groups, from both a side view and a top view. Additionally, palpation of the laterodorsal abdominal wall may be performed to assess muscle engagement [19, 20].

Hip flexion test (HF)

The evaluation takes place while the subject is seated upright at the table’s edge, with arms and legs in a relaxed position and feet not touching the ground. The examiner directs the subject to slowly lift one flexed lower limb at a time, performing alternating hip flexion of approximately 10–20 cm over the table. During this movement, the examiner visually monitors for any spinal and pelvic movements and palpates the laterodorsal segments of the abdominal wall to assess the coordination of abdominal muscle activity [19, 20].

Intra-abdominal pressure test (IAP)

The individual is evaluated while sitting upright, with arms and legs in a relaxed position. The examiner palpates the lower abdominal section above the groin, specifically the area between the anterior superior iliac spine and the femoral heads of the hip joints. The subject is then guided to engage the abdominal wall and generate intra-abdominal pressure by pushing against the examiner's fingers positioned above the inguinal ligaments. The assessment involves observing the symmetry of activation, visually assessing the abdominal contour, and simultaneously monitoring any movement of the umbilicus [19, 20].

Side plank test (SP)

The individual is evaluated while in a side plank position: the lower arm is supported on the forearm, and the upper arm is positioned in a relaxed manner on the same side's hip. The assessment focuses on observing the engagement of the abdominal and thoracic muscles, while also considering the coordinated action of the shoulder girdle muscles [23].

Statistical analysis

All statistics have been performed using IBM SPSS Statistics Version 29.0. A two-way mixed ANOVA was conducted to explore the differences in 1RM and DSS performance within and between the groups. If the sphericity assumption was violated, *p*-values were adjusted using the Greenhouse-Geisser correction. Bonferroni post hoc tests were used for further analysis. Additionally, paired *t*-tests were employed to determine the effect size for DSS and 1RM results. An ES of < 0.2 was considered trivial, 0.2–0.5 small, 0.5–0.8 medium, and > 0.8 large [24]. The significant level was set to a *p*-value of < 0.05. Magnitudes of mean changes were assessed by standardisation (i.e., an effect size; the mean difference divided by the appropriate *SD*). For between-group comparisons, Cohen's *d* effect sizes were calculated as (M1 minus M2) / $SD_{pooled}$, where M1 and M2 are the mean differences (post minus pre) for each group, and $SD_{pooled}$ is the pooled standard deviation of the changes from each group. Within-group mean changes are presented as mean ± *SD*, 95% confidence intervals, and with Cohen's d effect size (*ES*).

## Results

Fourteen female softball players from the Czech National Team participated in this study, 7 in each intervention.

1RM results

Two-way ANOVA revealed significant improvement in BP among all participants ($p > 0.001$) when comparing pre- and post-measurements; however, no significant difference between groups was shown ($F_{(1,12)} = 0.172$, $p = 0.685$). Similarly, for DL, a significant improvement was found between pre- and post-measurements ($F_{(1,12)} = 78.6$, $p > 0.001$), but no significant difference between interventions ($p = 0.64$). For FSQ significant improvement was observed between pre- and post-measurements in both groups ($F_{(1,12)} = 157.38$, $p > 0.001$), with no difference between groups. For 4RM LP in the right leg there was a main effect on pre- and post-measurement ($F_{(1,12)} = 40.55$, $p > 0.001$), but no significant difference between groups ($p = 0.27$), the left leg also showed significant improvement from pre- and post-measurements ($F_{(1,12)} = 56.14$, p > 0.001), where no difference was observed between the groups ($p = 0.27$, Table 3, Figures 1 and 2).

Table 3. Comparison of 1RM values before and after intervention

| Treatment group | Phase | BP 1RM (kg) mean ± *SD* | DL 1RM (kg) mean ± *SD* | FSQ 1RM (kg) mean ± *SD* | LP_P (kg) mean ± *SD* | LP_L (kg) mean ± *SD* |
|---|---|---|---|---|---|---|
| Experimental | Pre | 37.6 ± 5.9 | 78.9 ± 16.2 | 58.9 ± 7.5 | 41.8 ± 13.7 | 41.1 ± 16.9 |
| | Post | 40.5 ± 6.8* | 92.9 ± 17* | 73.2 ± 6.6* | 60.7 ± 18.6* | 62.1 ± 21.4* |
| Control | Pre | 35.9 ± 7.1 | 76.8 ± 16.2 | 53.6 ± 6.7 | 36.1 ± 13.9 | 33.6 ± 12.4 |
| | Post | 39.3 ± 7.5* | 89.3 ± 13.4* | 67.9 ± 6.4* | 48.6 ± 14.1* | 50 ± 15.3* |

* significant differences between pre- and post-measurements

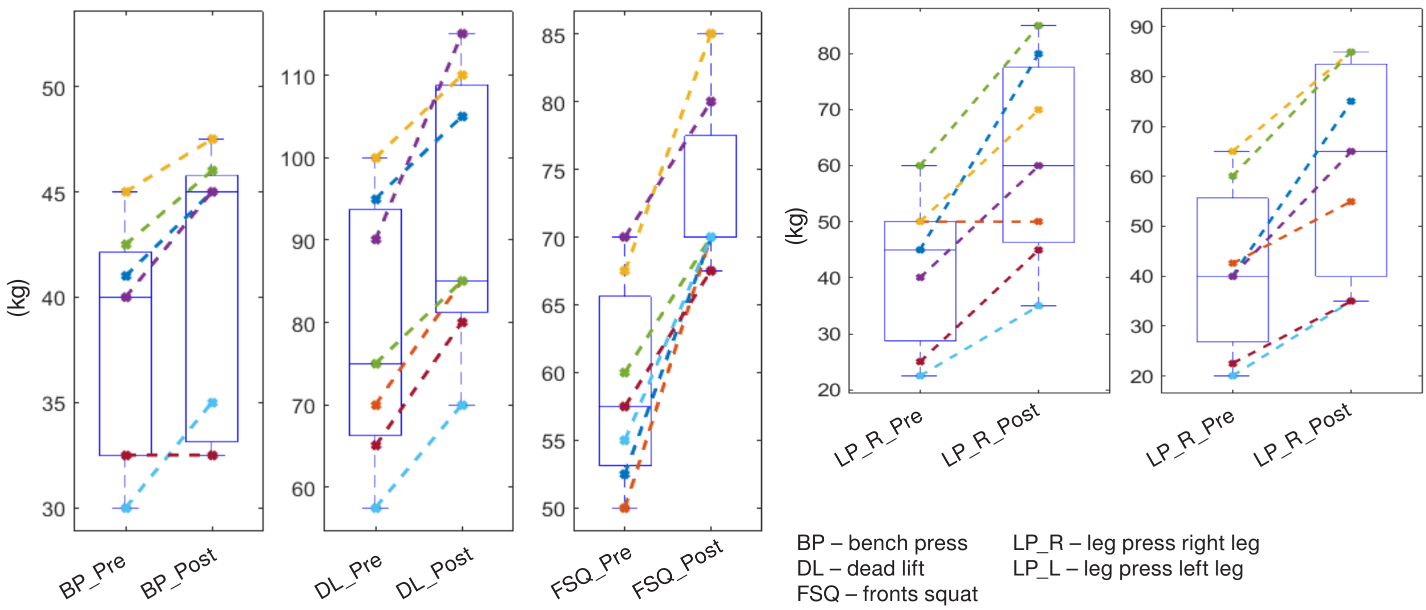


Figure 1. Individual 1RM comparison from pre- to post-measurements for bench press, deadlift, front squat, and single leg press performance for the experimental group

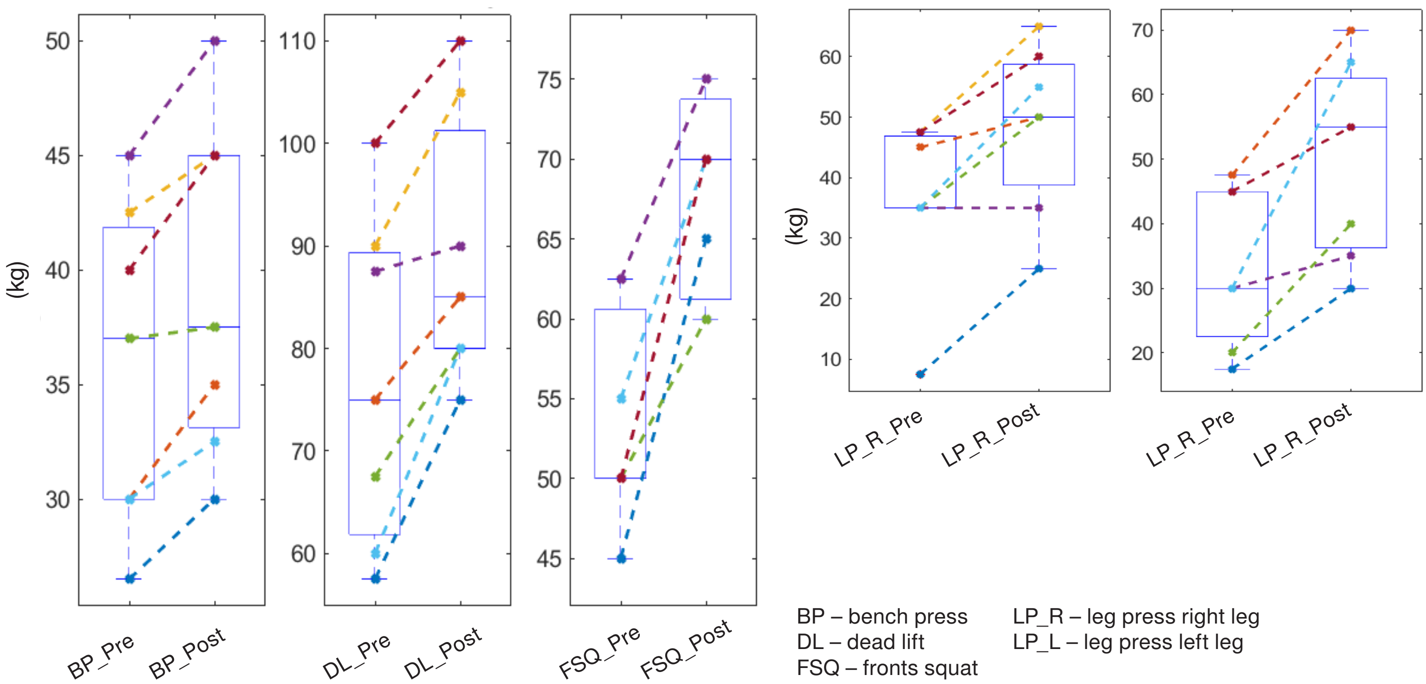


Figure 2. Individual 1RM comparison from pre- and post-measurements for bench press, deadlift, front squat, and single leg press performance for the control group

DSS results

Two-way ANOVA revealed statistically significant differences for pre- and post-measurements for all of the tests, with significant differences between subjects only for SP test ($p$ = 0.027) and the SUPINE test ($p$ = 0.055). Bonferroni pairwise comparison showed that there was a significant improvement in DSS in the EXP group between pre- and post-measurements. For the CON group, significant improvement between pre- and post-measurements occurred only for TE and SP.

In the EXP group, paired $t$-tests revealed significant differences between pre- and post-measurements for all DSS strength tests, while in the CON group, only 3 tests (TE, SP, and PRONE) were significantly larger when compared to pre- and post-measurements and

Table 4. Cohen's *d* and significance for paired sample test for core strength tests for the experimental group

| Test | Mean ± *SD* | Two-sided *p* | Cohen's *d* | 95% CI |
|---|---|---|---|---|
| Diaphragm test | 1 ± 0.58 | 0.004* | **1.732** | 0.5 to 2.92 |
| Trunk flexion | 1 ± 0.58 | 0.004* | **1.732** | 0.5 to 2.92 |
| Trunk extension | 0.71 ± 0.76 | 0.047* | **0.945** | 0.1 to 1.83 |
| Hip flexion | 1 ± 0.58 | 0.004* | **1.732** | 0.5 to 2.92 |
| Intra-abdominal pressure | 0.86 ± 0.9 | 0.045* | **0.953** | 0.02 to 1.84 |
| Side plank | 0.86 ± 0.69 | 0.017* | **1.242** | 0.21 to 2.23 |
| Supine test | 1.43 ± 0.98 | 0.008* | **1.464** | 0.34 to 2.53 |
| Prone test | 1.71 ± 1.11 | 0.007* | **1.541** | 0.39 to 2.64 |

* indicates statistically significant ($p < 0.05$); bold values indicate large effect size

Table 5. Cohen's d and significance for paired sample test for core strength tests for the control group

| Test | Mean ± *SD* | Two-sided *p* | Cohen's *d* | 95% CI |
|---|---|---|---|---|
| Diaphragm test | 0.43 ± 0.53 | 0.08 | 0.8 | –0.08 to 1.64 |
| Trunk flexion | 0.07 ± 0.03 | 0.6 | 0.2 | 0.95 to 0.55 |
| Trunk extension | 0.57 ± 0.53 | 0.03* | **1.07** | 0.1 to 1.99 |
| Hip flexion | 0.43 ± 0.53 | 0.08 | 0.8 | –0.08 to 1.64 |
| Intra-abdominal pressure | 0.14 ± 0.38 | 0.36 | 0.38 | –0.41 to 1.13 |
| Side plank | 0.71 ± 0.49 | 0.01* | **1.46** | 0.34 to 2.53 |
| Supine test | 0.43 ± 0.79 | 0.2 | 0.54 | –0.27 to 1.33 |
| Prone test | 0.71 ± 0.49 | 0.01* | **1.46** | 0.34 to 2.53 |

* indicates statistically significant ($p < 0.05$); bold values indicate a large effect size

had large effect sizes (Tables 4 and 5). The remaining results from the CON group were non-significant ($p > 0.05$) with small or medium effect sizes.

## Discussion

To the best of our knowledge, this study is the first to explore the impact of asymmetric load training on both DSS and maximal strength. This study focused on the influence of asymmetric load training on DSS and maximal strength in female softball players. Participants were engaged in an 8-week RT program that included exercises such as DL, BP, LP, and FSQ. Notable enhancements were observed in both DSS strength and 1RM strength, particularly in the group that performed asymmetric training. While traditional training regimes also significantly improved 1RM strength, only three tests assessing DSS showed statistically significant enhancement. This indicates that asymmetric training may offer superior DSS strengthening while still achieving comparable gains in maximal strength, confirming our initial hypothesis.

Many studies have highlighted the positive effects of DSS strengthening on sports performance. For instance, research by Šagát et al. [25] found a notable increase in throwing speed among female handball players following DSS training. Additionally, Luo's systematic review advocates for the integration of DSS training into basketball training programs. This recommendation is based on evidence showing that DSS training can enhance a player's overall athletic and skill performance. Improvements have been observed in various areas, including strength, sprinting, jumping, balance, agility, shooting, dribbling, passing, rebounding, and stepping [26]. These observations underline the benefits of integrating additional DSS strengthening methods into traditional training to enhance an athlete's overall performance. Furthermore, improvements in maximal strength through RT in an athlete's training programs can decrease the risk of soft-tissue injuries. Our study focused specifically on 1RM and DSS performance, highlighting significant improvements in DSS while maintaining strength gains from asymmetric training compared to traditional methods. This is consistent with Luo's broader findings, supporting the notion that DSS training contributes to significant improvements in athletic performance. In accordance with our results, asymmetric strength training focuses on both increasing maximal strength gained similarly to traditional training and significantly improving DSS performance to a much greater extent than traditional training.

Bordelon et al. [27], in their research, assessed the electromyographic (EMG) activity in several muscles – dominant upper and lower trapezius, latissimus dorsi, serratus anterior, bilateral glutei medii, and external obliques – during various unilateral dumbbell carry positions. Their research indicated that these exercises improve the contralateral lumbo-pelvic-hip complex (LPHC). Similarly, McGill et al. [7] studied EMG activity during a suitcase carry exercise, noting increased activity in the external obliques on the contralateral side and the internal obliques on the ipsilateral side. These findings suggest that such exercises are beneficial for LPHC strengthening. Our results support these findings, showing that increased unilateral loading from one side enhanced the activation of DSS muscles on the contralateral side to maintain proper technique while lifting the bar. This increased activation during the intervention led to improvements in DSS test results. However, asymmetric lifting with one hand can increase spinal loads, leading to a higher risk of injury, especially in individuals without a strong DSS [28]. Exercises with a smaller asymmetry in weight distribution could potentially reduce spinal load, making them more suitable for strengthening DSS, especially in the general population, therefore, this distribution of asymmetry was chosen. Based on previous research, it appears that our method holds a promising way to boost maximal strength in a manner similar to traditional strength training, while also simultaneously enhancing the strength of the DSS. Nonetheless, further studies are necessary to examine EMG activities and assess spinal load during offset training with varying degrees of asymmetry.

Recent studies have shifted focus towards enhancing DSS strength through core muscle activation. Jebavy et al. [29] indicated that traditional exercises like sit-ups and limb swings are less effective compared to stability-focused activities such as reverse sit-ups on gym balls and one-leg squats on Bosu balls. Additionally, there's an ongoing debate about the efficacy of stable versus unstable surfaces in these exercises [30]. On the other hand, Martuscello's [31] systematic review highlights that strength and conditioning specialists should prioritise multi-joint free weight exercises over core-specific ones for effective DSS muscle training in athletes and clients. This recommendation supports the importance of our findings, which further indicate that RT with an offset load could be particularly beneficial for enhancing DSS strength. Our results underscore the potential advantages of incorporating offset load RT into fitness routines for several reasons. Firstly, offset loading increases the demand on the DSS muscles, particularly the contralateral obliques and other stabilising muscles, which is crucial for maintaining balance and proper technique during asymmetric exercises [4], thereby improving DSS strength and performance. Secondly, unlike isolated core exercises, offset load training involves compound movements that mimic real-life and sports-specific activities, making the strength gains more transferable to athletic performances and daily tasks. Thirdly, by integrating offset loads into multi-joint exercises, athletes can simultaneously work on maximal strength and core stabilisation, reducing the need for additional core-specific workouts and making training sessions more time-efficient. Finally, exercises with a smaller degree of asymmetry in weight distribution can reduce spinal loads compared to one-handed asymmetric lifts, making offset loading safer and more suitable for a wider population, including those with weaker DSS. These factors collectively highlight the potential of offset load RT as a superior method for improving DSS strength, supporting the practical application of our study's findings in enhancing athletic performance and overall fitness. However, it is essential to conduct research that directly compares the effects of offset load RT with stability-focused exercises on actual performance outcomes. This approach will provide clearer insights into their impacts on enhancing DSS strength.

This research primarily focused on elite Czech female softball players, offering important findings on the impact of asymmetric load training for enhancing both DSS and maximal strength. However, it's crucial to acknowledge that male participants might exhibit different responses to the same training protocol, potentially due to differences in strength. This aspect underscores the need for further evaluation to determine how male athletes might react to such training regimens. Exploring these differences is essential for developing training strategies that are effectively tailored to each gender, considering their unique physiological characteristics and strength levels. Such research could significantly enhance training methodologies in sports where both strength and DSS capabilities are crucial.

## Conclusions

This study was initiated to explore the effects of asymmetrical strength training, on the enhancement of DSS strength and maximal power among female softball players. Our findings offer a novel insight into the potential benefits and considerations of incorporating asymmetrical training techniques in sports training regimes, particularly for female athletes. Results demonstrated a noticeable improvement in stabilisation strength and overall power among participants following a specialised training program. These results suggest that offset training could be a valuable addition to athletic training, particularly for sports that inherently involve asymmetric movements and require substantial DSS stability and power.

**Ethical approval**

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Charles University's Faculty of Physical Education and Sport (approval No. 146/2019).

**Informed consent**

Informed consent has been obtained from all individuals included in this study.

**Conflict of interest**

The authors state no conflict of interest.

**Disclosure statement**

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