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Original

The effect of a core training program on jump performance in female handball players

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ABSTRACT

Objectives: To analyze the effects of core strength training on jump performance in female handball players.
Methods: This is a randomized controlled trial. A total of 20 female handball players [age = 19.5 (1.4) years, height = 1.65 (0.05) m, body mass= 61.7 (9.3) kg] were recruited and split in: a core training group and a control group. The core training group participated in 8 weeks in-season of a core strength program (2 times/week). Pre- and post-intervention jump height, contact time and reactive strength index were collected during bilateral and unilateral drop vertical jumps. Frontal knee projection angle was measured only at unilateral drop jumps. Statistical significant difference was set at p <0.05.
Results: group x time interactions were statistically significant for bilateral and unilateral jump height and for FKPA (<0.05). Core training group increased the bilateral jump height by 18.8% and showed a statistically significant difference in reactive strength index from pre-intervention [0.07 (0.03)] to post-intervention [0.10 (0.04)]. The core training group also improved the unilateral jump height by 20%, but only at the non-dominant leg. This improvement was accompanied by a statistically significant decrease in the frontal knee projection angle from pre-intervention [13.8 (7.4) degrees]to post-intervention [9.3 (6.1) degrees]. Control group did not obtain significant improvements in any of the assessed variables. There were no significant differences between groups in the baseline (p>0.05).
Conclusion: A core strength training increased jump performance *(drop jump)* in female handball players.
Keywords: Strength; Valgus; Knee; Training; Exercise.

Efecto de un programa de entrenamiento del core en la capacidad de salto de jugadoras de balonmano

RESUMEN

Objetivos: Analizar los efectos del entrenamiento de la fuerza del core sobre el rendimiento del salto en jugadoras de balonmano.
Métodos: Ensayo controlado aleatorio. 20 jugadoras de balonmano [edad = 19.5 (1.4) años, altura = 1.65 (0.05) m, masa corporal = 61.7 (9.3) kg]. Dos grupos: entrenamiento del core y grupo de control. El grupo entrenamiento del core realizó 2 veces por semana (8 semanas) un programa de fortalecimiento específico del core. Fueron registradas pre-post intervención, la altura de salto, el tiempo de contacto, el índice de fuerza reactiva en saltos verticales de caída bilateral y unilateral y el ángulo de proyección frontal de rodilla en saltos con recepción unilateral (p 0.05) <0.05.
Resultados: las interacciones grupo x tiempo fueron estadísticamente significativas para la altura de salto bilateral y unilateral y la FKPA (p<0.05). El grupo de entrenamiento del core aumentó la altura de salto bilateral en un 18.8% y mostró diferencias significativas en el índice de fuerza reactiva desde la preintervención [0.07 (0.03)] hasta la post-intervención [0.10 (0.04)]. Asimismo, mejoró la altura de salto unilateral en un 20%, en la pierna no dominante. Esta mejora se acompañó de una disminución del ángulo de proyección frontal de la rodilla entre el pre [13.8 (7.4) grados] y el post [9.3 (6.1) grados]. El grupo de control no obtuvo mejoras significativas en las variables evaluadas. No hubo diferencias significativas entre los grupos antes de la intervención (p>0.05).
Conclusiones: el fortalecimiento del core ha influido positivamente en el rendimiento del salto (drop jump) en las jugadoras.
Palabras clave: Fuerza; Valgo; Rodilla; Entrenamiento; Ejercicio

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Efeito de um programa do treinamiento do Core na desempenho de saltos em jogadoras de handebol

RESUMO

Objetivos: Analisar os efeitos do treino de força central no desempenho de saltos em jogadores de andebol feminino.
Métodos: Ensaio controlado aleatorizado. 20 jogadoras de andebol [idade = 19,5 anos (1,4), altura = 1,65m (0,05), massa corporal = 61,7kg (9,3)]. Dois grupos: grupo núcleo de formação e grupo de controlo. O grupo de formação principal realizou 2 vezes por semana (8 semanas) um programa específico de reforço do núcleo. Foram registados a intervenção pré-pós, altura do salto, tempo de contacto, índice de força reativa em saltos verticais bilaterais e unilaterais, e ângulo de projeção do joelho frontal em saltos de captura unilaterais ($p < 0.05$).
Resultados: As interações grupo x tempo foram estatisticamente significativas para a altura de salto bilateral e unilateral, e FKPA ($p<0,05$). O grupo de treino principal aumentou a altura do salto bilateral em 18,8% e mostrou diferenças significativas no índice de força reativa desde a pré-intervenção [0,07 (0,03)] até à pós-intervenção [0,10 (0,04)]. Para além disso, a altura do salto unilateral melhorou em 20% na perna não dominante. Esta melhoria foi acompanhada por uma diminuição do ângulo de projecção do joelho frontal entre os pré [13,8 (7,4) graus] e os pós [9,3 (6,1) graus]. O grupo de controlo não teve uma melhoria significativa nas variáveis avaliadas. Não houve diferenças significativas entre os grupos na linha de base ($p>0,05$).
Conclusões: O reforço do núcleo teve um efeito positivo no desempenho dos jogadores no salto de queda.
Palavras-chave: Força, Valgus, Joelho, Treino, Exercício.

Introduction

The core is a functional concept referred to the muscular, osteoarticular and neural structures of the central part of the body. It is suggested that a strong core allows an athlete the full transfer of forces generated with the lower extremities, through the torso, and to the upper extremities and sometimes an implement.[1]

In recent decades, core exercises have been incorporated into strength training routines with the purpose of increasing sports performance and reducing injury incidence. Taskin[2] studied the effect of a core training program on speed, acceleration, vertical jump, and standing long jump in female soccer players and found that the core training group improved their results in all the variables measured. Prieske et al.[3] applied a core strength training in a group of soccer players and found statistical significant improvements only for sprint time and kicking performance, but they did not find it for countermovement jump height. Likewise, improving core stability through strength exercise is common in musculoskeletal injury prevention programs.[4,5]

Among sport performance tests, vertical drop jump is one of the most studied tests since numerous sports activities involve jumps and require appropriate jump landing techniques (i.e. volleyball, basketball, handball…).[6,7] However, studies focused on the effect of core training interventions on vertical jump performance show controversial results.[8] For example, studies performed on soccer,[2,9-11] basketball[12] and volleyball[13] players reported a positive impact of core training on vertical jump performance, while other studies have not recorded an improvement when applying this type of training routines, for example, in soccer,[3] lacrosse[14] and capoeira athletes.[15]

Handball is one of the most popular team sports.[16] It is a sport that requires an extensive number and variety of movements; jumps, settings, accelerations, changes of direction, and passing are the most frequent gestures.[17,18] In addition to technical and tactical skills, anthropometric characteristics as well as physical performance play an important role for success.[19,20]

The jump throw is the most applied throwing technique in team- handball, 73 - 75% of all throws during a competitive team-handball game are jump throws.[21] In order to counteract them, there are two common defense actions: blocking the ball and the players' collaboration with the goalkeeper in order to reduce the opponent's throwing success towards the goal. For both actions the defenders need the vertical jump. Thus, both in attack and defense, jumps with a vertical component acquire relevance in the technical-tactical actions of the game.

Various studies in handball have shown a positive effect of a specific core muscle training on handball players' throws performance.[22,23] For instance, Sasaki et al.[24] applied a core strength training in a group of female basketball players and found that peak knee-valgus moment decreased in the training group compared to the control group during the drop-jump test. Similar results were found by Jeong et al.[25] during a side-step cutting task.

Increased medial knee movement in dynamic actions has been pointed out as one of the risk factors for injury.[26] This increase in the angle in a landing action has to do with the pronation that occurs in the foot, the weakness of the hip abductor musculature, a greater internal rotation of the leg and furthermore, may be conditional to task demand.[27]

Therefore, given the inconsistencies in the literature regarding the effect of core training on vertical jump performance, together with the paucity of scientific studies in the field of team sports such as handball, the purpose of this study was to evaluate the effect of a core training program on bilateral and unilateral vertical drop jump (VDJ) performance in female handball players. We also evaluated the influence of the intervention on frontal knee projection knee angle (FKPA) during unilateral jumps. We hypothesized that players performing the core training will improve unilateral and bilateral VDJ performance variables (height, contact time and reactive strength index) and will decrease FKPA during unilateral landings compared to players who do not perform it.

Methods

Study Design

A randomized control trial was conducted to assess the impact of an 8-week core strength program on jump performance and dynamic knee valgus angle at landing in female handball players. Two teams from a female handball club were recruited and were randomly assigned to either a core training intervention (CTG) or control (CG) group. The allocation sequence was computed generated and one of the teams was assigned to CTG while the other served as control group with group allocation conducted by a research assistant who did not participate in the study. All players from both teams had similar practice and competition schedules throughout the study. The study was carried out in the middle of the soccer competition (February and March).

The CTG group performed the program twice a week as a warm-up before the team's regularly scheduled practices and was implemented by two experienced members of the research team.

Participants on the CG performed their usual warm-up exercises (running, dynamic stretching and ball exercises). Participants were assessed twice, one at baseline and again at the end of the training weeks.

Participants

Two teams, with a total of 20 young female handball players from the Spanish second division participated voluntarily in this study (CTG= 10 participants and CG=8 participants). There were 2 dropouts from the CG (due to injury). Players performed 3 handball sessions per week (1 hour and 30 minutes per session) plus the official weekend game. Inclusion criteria included female players between 18 and 20 years of age, with an organized handball previous experience of 5 up to 10 years, currently participating actively on a handball team and with no previous experience in a core training programme. Exclusion criteria included a prior anterior cruciate ligament (ACL) injury, lower extremity surgery within the past year, a serious lower extremity injury within the past 6 months (defined as an injury requiring more than 4 weeks of absence from participation in handball activity), and prior or current participation in an ACL injury prevention program. We recorded the dominant leg (DL) and non-dominant leg (NDL) in each participant and this information was used for subsequent analyses. The players self-reported their preferred upper limb for throwing a ball as their dominant upper limb and their preferred lower limb for kicking a ball as their dominant lower limb. All the 18 players reported the right upper and lower limb as their DL and their left upper and lower limb as their NDL. The anthropometric and training experience can be seen at Table 1.

Table 1. Anthropometric and sport profiles of the players.

	n	Age (years)	Body Mass (kg)	Height (m)	Practice (years)
CTG	10	19.7 ± 1.5	63.9 ± 10.1	1.68 ± 0.05	11.1 ± 2.0
CG	8	19.2 ± 1.4	59.4 ± 8.2	1.62 ± 0.06	11.4 ± 1.7
TOTAL	18	19.5 ± 1.4	61.7 ± 9.3	1.65 ± 0.05	11.2 ± 1.8

X: mean; SD: Standard deviation; CTG: Core training group; GC: Control group; n.: number of players; kg: kilograms; m:meters. Data are expressed as mean ± SD.

Before testing, institutional review board approval was obtained. Approval for the study was obtained from the Ethics Committee at the corresponding institution. The study was conducted in accordance with the Declaration of Helsinki, good clinical practices, and applicable laws and regulations.

Assessment procedure: Vertical Drop Jump Test

Pre- and post-intervention assessments at the same laboratory consisted on evaluation of the VDJ test performance and measurement of height and weight. Both assessments were performed at similar appointment times to avoid the influence of diurnal variation in test performance.

To conduct the test, the participants should wear short pants to be instrumented with markers to determine the landmarks according to the configuration of previous studies.[28] Markers were attached to: anterior superior iliac spine, patella, center of the ankle, greater trochanter, lateral surface of the thigh, lateral epicondyle of the femur, lateral surface of the leg, lateral malleolus and fifth metatarsus. The same evaluator was responsible for placing the markers to each participant and made sure they were not moved or detached from the skin during the test.

Previous to the test measurements, a standard 10-minute warm-up was performed for all players: 5 min running at a 5 km/h pace, 3 min of hip and leg dynamic stretches and 2 min of submaximal vertical jumps (5 bilateral jumps, and 5 jumps for right and left leg [10 sec rest between jumps]). The warm-up was controlled by an evaluator in order to ensure that the stipulated time and intensity was met. Two days previous to the intervention, a familiarization session was conducted. On test measurements, participants performed 3 drop jumps as specific warm-up to assure the correct performance of the VDJ (one with both legs, one with the right and one with the left). Then, the test was performed including 3 bilateral jumps and 3 unilateral right and left jumps whose order were randomized with 30 seconds rest between repetitions.

The players were instructed to put their arms in jar, hands supported on the hips (without covering the marks and feet barefoot) and drop from a 30 cm height, landing with the two feet on the ground and immediately jumping as high as they could to finally land again on the floor.

The jumps were considered invalid if participants jumped from the box instead of dropping down, if they moved their arms or if they clearly lost balance during the test. Further, in the unilateral test, this was considered invalid when the non-supporting leg touched the ground. When invalid repetition was performed, the participants were allowed to repeat it. The first 3 valid jumps of each type (two legs, right leg and left leg) were selected and included for further analysis.

For the recording of the test, one digital camera (Samsung ST66, Samsung, South Korea) was placed on the frontal plane, on a tripod at 110 cm in height and separated 4 meters from the jump box (30 cm high). The app Kinovea (GPLv2 license) was used to analyze the jump and to obtain the variable FKPA. FKPA was calculated measuring the angle formed by the markers placed at the anterior superior iliac spine, patella and center of the ankle (Figure 1).

Figure 1. Variable FKPA (measured with Kinovea).

Another digital camera (Samsung ST66, Samsung, South Korea) that recorded with a frame rate of 30 frames per second was placed on a sagittal plane at ground floor and separated 2 meters from the landing place. The application My Jump 2 was used to obtain the jump performance variables of jump height (JH), feet contact time (Ct) and the reactive strength index (RSI). JH was calculated from flight time that is the time between the takeoff and ground contact. Feet Ct was calculated as the time between feet first ground contact at landing to feet last ground contact at takeoff. RSI was calculated with the jump height (meters) divided by ground contact time (seconds). This is one metric commonly analyzed from DJ. It identifies an athlete's ability to quickly switch from an eccentric to a concentric contraction, and how much force the athlete is able to produce in the shortest possible time.

The reliability of the VDJ to analyze biomechanical variables in young athletes is excellent for the sagittal plane (intraclass correlation coefficient [ICC] between sessions > 0.8) and for the frontal plane (ICC between sessions > 0.75).[29]

The validity and reliability of the My Jump 2 app for measuring the reactive strength index (RSI) and drop jump performance has been studied.[30] Near perfect agreement has been found at 20 cm (ICC = 0.95) and at 40 cm (ICC = 0.98), while the validity at 20 cm and 40 cm has been found to be r = 0.94 and r = 0.97, respectively.

Pre- and post-intervention JH, Ct and RSI were collected during bilateral and unilateral drop vertical jumps. FKPA was measured only at unilateral drop jumps.

Core Strength Training

Over the 8-week training period, a total of 16 sessions of 30 minutes each were performed. During the sessions, two trained supervisors helped to control the correct execution of the exercises that were previously explained by one of the researchers.

The criteria to choose the exercises for core strength training were: involvement of multiple muscles and involvement of 3 types of exercises involving the trunk (extension, flexion and rotation) based on the proposal of Boyle.[31] Flexion exercises included: plank, plank moving forward and backward, abdominal wheel and crawling. Extension exercises included: Plank with arm extended, clock plank, isometric press pallof and press pallof. Rotation exercises included: lateral plank, lateral plank plus row with elastic, one leg kneeling woodchopper and both legs kneeling woodchopper. In addition, a specific work of gluteus medium was included, given the fundamental role that plays in core stability.

To establish working time and repetitions, we followed the model of other similar studies.[2] To individualize exercise intensity in the core strength exercises, participants using resistance bands were instructed to do as many repetitions needed in each set until moderate to intense exertion was perceived. The intensity was controlled by the 10-point modified Borg Scale, maintaining an intensity between 7 (moderate) and 8 (intense) for each set of exercises. Players who did not experience fatigue after the established work time for isometric contractions were required to add additional weight to ensure fatigue at the end of the exercise. The familiarization session was used to adjust exercise intensity for all players. Subjects' adherence rates were recorded throughout the study period. None of the participants missed more than 1 session as required to be included in the analysis. The baseline structure of the 8-week core stability and strength-training program is shown in Table 2.

Table 2. Structure of the 8-week core stability and strength training program.

Exercises	Week 1	Week 2
Plank	3x20s	3x25s
Plank with arm extended	3x20s	3x25s
Lateral Plank	3x20s	3x25s
Clamshell lying	3x20 reps	3x25 reps
	Week 3	Week 4
Plank forward and backward	3x20s	3x25s
Clock plank	3x20s	3x25s
Lateral plank + row with elastic	3x20s	3x25s
Clamshell lying	3x20 reps	3x25 reps
	Week 5	Week 6
Ab Wheel	3x20s	3x25s
Isometric press pallof	3x20s	3x25s
Kneeling whoodchopper	3x20s	3x25s
Hip abductions with elastics around knees	3x20 reps	3x25 reps
	Week 7	Week 8
Crawling	3x20s	3x25s
Press Pallof 1	3x20s	3x25s
Kneeling whoodchooper	3x20s	3x25s
Hip abductions with elastics around ankles	3x20 reps	3x25 reps

*Reps: repetitions; s: seconds

Recovery time was 20 s between sets and 60 s between exercises. Some of the exercises performed in the core strength training are shown in Figures 2a, 2b and 2c.

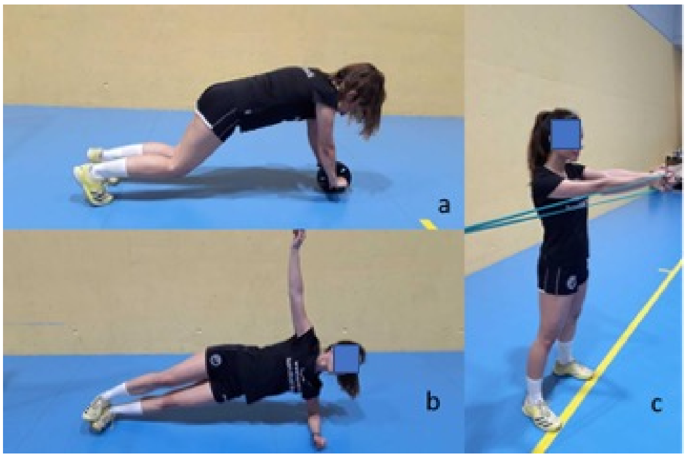

Figure 2. Some of the exercises performed in the core strength training

Statistical analysis

All data analysis was conducted using SPSS version 24 (SPSS Inc., Chicago, IL, USA). Descriptive data are presented as mean and standard deviation (SD). All the dependent variables were measured bilaterally when bilateral jumps were performed and unilaterally, when the jumps were performed on a single leg. The bilateral variables, (i.e. HJ, Ct, RSI and the FKPA) were analyzed using mixed MANOVA with the factors group (CG and CTG) and time (pre, post). Unilateral variables JH, Ct, RSI, and the FKPA were analyzed using another mixed MANOVA with the factors group (CG and CTG), time (pre, post) and laterality (right and left). Significant interactions were followed up with Bonferroni tests. Assumptions of statistical tests such as normal distribution and homoscedasticity of data were checked. The effect sizes for pairwise comparisons were calculated with 95% confidence interval for the difference. The differences between groups in age, height, weight and time of sport experience were checked with the Mann-Whitney U test (as the normality of the data was not assumed). 95% Confidence interval were obtained for the pairwise comparisons. Statistically significant difference was set at $p < 0.05$

Results

No significant baseline differences were found between groups in terms of age, body weight, body height, and years of practice.

There were no significant differences between groups at baseline in any of the variables recorded ($p > 0.05$). Further, there were no significant differences between hemi bodies ($p > 0.05$).

For the bilateral analysis, there was a significant interaction between Group x time for Jump height ($F[1,16]=9.98$, $p<0.05$, $\eta^2=0.38$. However, there were no significant interaction between the factors for RSI and Contact time ($p>0.05$).

For the unilateral, there was a significant interaction between Group x time for Jump height ($F[1,16]=5.07$, $p<0.05$, $\eta^2=0.24$) and FKPA ($F[1,16]=10.91$, $p<0.05$, $\eta^2=0.41$). However, there were no significant interaction between the factors for RSI, and Contact time ($p>0.05$).

Table 3 shows the descriptive results of the variables obtained for the bilateral jump in both CG and CTG. There was a statistically significant improvement in JH and RSI at post-training in the CTG.

Table 3. Descriptive results of the variables obtained for the bilateral jump in both CG and CTG.

		Pre Mean (SD)	Post Mean (SD)	95% CI of the mean difference
Jump Height (m)	CG	18.68 (3.22)	16.20 (5.73)	-0.89 to 5.85
	CTG	18.31 (3.87)	22.56 (3.66)*	-7.27 to -1.24
Contact time (s)	CG	255.75 (48.37)	232.00 (64.92)	-44.84 to 92.34
	CTG	277.80 (71.48)	253.10 (62.92)	-36.65 to 86.05
RSI (N)	CG	0.08 (0.02)	0.07 (0.03)	-0.02 to 0.03
	CTG	0.07 (0.03)	0.10 (0.04)*	-0.05 to -0.01

*: p<0.05 between groups; RSI: Reactive strength index; CG: Control group; CTG: Core training group; m: meters; N: newtons; s: seconds. Pre: Pre-intervention; Post: Post-intervention. CI: 95% confidence interval of the mean difference between pre and post-training.

Table 4 shows the descriptive results of the variables obtained for the unilateral dominant and non-dominant legs in both CG and CTG. The CTG showed a statistically significant improvement in JH and the FKPA for the NDL after the implementation of the core training program.

Discussion

The main contribution of this study shows the importance of applying a core muscle strength training to increase jump performance and knee stability during unilateral jumps in female handball players.

Our results showed an increased in JH and RSI at bilateral jump performance in the CTG, and an increased JH and a decrease in the FKPA at unilateral NDL jump performance. These results confirm our hypothesis, as we hypothesized that improving core strength would improve both bilateral and unilateral VDJ performance variables, and furthermore, would decrease FKPA angle during unilateral VDJ landing.

Our results are in line with other studies in which the authors showed a positive impact of core training on jumping performance in different sports as soccer[2,10,32] and basketball.[12] However, to the best of authors' knowledge, this is the first study analyzing the impact of a core training intervention on jump height. One of the reasons for the positive results found in this study could be related to the fact that increasing core strength increases the ability to control the position and motion of the trunk over the pelvis. As previously mentioned by other authors, an improvement of the neuromuscular function optimizes production, transfer and control of force and motion to the terminal segment in integrated athletic kinetic chain activities.[33] Another potential explanation is that almost all exercises imply hip extensor muscles, in isometric or dynamic contractions. This may be an effective stimulus to increase strength in these muscles, which may induce a positive transfer to jump performance.

Bilateral jumping is an important skill in handball, since actions such as throws over the defenders, pivots and wing player's throws or blocking long distance throws by defenders are very common during a handball game. Regarding bilateral jumping, our results are very similar to those reported by Dupeyron et al.,[34] who found a significant improvement of JH (16.9 %) and a decrease of contact time (– 6.5 %) during hopping after an 8-week hollowing transversus abdominis trunk exercise program in soccer players. According to them, the improvement was due by a 6.5% decrease in contact time and an increase of 8.8% in flight time. In our study, JH was not increased because a decrement of Ct since data did not show statistically significant differences. Maybe the lack of significance could be related to the small sample size (Type II error).

However, Ct is directly related to RSI, which is calculated based on contact time and jump height.[35] We obtained a statistically significant increase in RSI, and according to the literature, smaller angular displacements of the hip, knee and ankle joints are necessary to jump higher following a shorter landing duration.[36] Furthermore, RSI has been correlated to change of direction speed (r = -0.645, P = 0.001),[9] attacking agility (r = 0.625, P = 0.004) and defensive agility (r = 0.731, P < 0.001),[10] making the VDJ a useful performance test to help evaluate athletic tasks.[37,38] The previous mentioned motor actions showed an increase in RSI after applying a core training program in a group of adolescent male soccer players. It was concluded that the improvement of RSI might be attributable to increasing the joint stiffness of the trunk and hip during the VDJ by activating the co-contraction of trunk muscles. Therefore, although we did not measure leg stiffness, we can address that the core training program improved the athlete's ability to quickly switch from an eccentric to a concentric contraction, and to produce a higher force in a shorter time. This finding provides evidence that increasing hip muscle strength via core training should be considered when programming strength exercises to improve performance in handball players.

Apart from bilateral jumping, it was also important to analyze unilateral jumping, especially in the NDL since it is the responsible of the jump throws. The jump throw is the most frequently applied throwing technique in the game of team-handball. In fact, it has been found that 73 - 75% of all throws during the competitive handball games are jump throws.[21] It is important to highlight that handball players like basketball players[39] have as a NDL the leg that corresponds to the contralateral arm performing the throws to facilitate the technical execution of the jumping throw. In our study all participants were right hand and leg dominant. In this line, we obtained an improvement in JH only in the NDL. The NDL in handball players require to perform many jumps where the stretch-shortening cycle is specially addressed and more contact time is required, while the DL will be involved in shorter contact times looking for fast motor actions such as feints or changing direction displacements.[40] These differences in motor skills may explain the differences obtained after the core intervention in the CTG, which only improved the vertical jump on the NDL.

Bilateral jumping differences between DL and NDL have been previously addressed.[41] Most specific motor actions in handball require the NDL being the responsible of leading the throws, passes and the jumping and landing after a jump throw. Without specific instructions other than aiming for maximal vertical jumping height, drop jumps are performed in at least two different ways: (1) fast, that is, with a very short contact time and (2) slower, that is, with somewhat longer contact time on the ground.[42] Our players kept their regular handball training and, as

Table 4. Descriptive results of the variables obtained for the unilateral dominant and non-dominant legs in both CG and CTG.

		Dominant Pre	Dominant Post	95% CI of the mean difference	Non-dominant Pre	Non-dominant Post	95% CI of the mean difference
Jump Height (m)	CG	9.7 (3.1)	9.1 (3.8)	-2.4 to 3.6	9.2 (3.1)	9.4 (3.0)	-1.9 to 1-5
	CTG	9.8 (2.8)	12.1 (2.5)	-4.9 to 0.4	9.9 (2.4)	12.4 (3.2)*	-4.1 to 0.9
Ct (s)	CG	321.3 (68.0)	248 (74.7)	-9.1 to 155.6	310.4 (38.7)	288.4 (53.9)	-48.7 to 92.74
	CTG	333.8 (92.7)	333.5 (52.8)	-73.3 to 73.9	302.4 (65.8)	316.3 (88.6)	-77-2 to 94.4
RSI (N)	CG	0.03 (0.01)	0.04 (0.02)	-0.1 to 0.1	0.03 (0.01)	0.04 (0.03)	-0.1 to 0.1
	CTG	0.04 (0.01)	0.04 (0.01)	-0.1 to 0.1	0.03 (0.01)	0.04 (0.01)	-0.1 to 0.1
FKPA (º)	CG	10.4 (2.0)	11.5 (6.7)	-6.2 to 3.9	9.2 (6.4)	9.3 (5.4)	-4.5 to 4.2
	CTG	13.4 (7.4)	10.8 (8.6)	-1.9 to 7.1	13.8 (7.4)	9.3 (6.1)*	0.6 to 8.4

*: p<0.05 between groups; Ct: Contact Time; FKPA: Frontal knee projection angle; H: Height; m: meters; sec: seconds; º: degrees; N: Newton's; RSI: Reactive strength index; CG: Control group; CTG: Core training group. Pre: Pre-intervention; Post: Post-intervention. CI: 95% confidence interval of the mean difference between groups in the post-treatment in each lower extremity

suggested by other authors[2,10,32] the combination of core stability/strength training and regular sports training may produce improvement on the vertical jump.

The improvement of the NDL on the JH occurs simultaneously with the lower extremity position at landing reception measured as FKPA only at unilateral jumps. Further, although we did not measure leg FKPA at bilateral jumps, it would have been interesting to compare how the core training program affects this variable.

In the present study, as it occurred with the implementation of a core stability training in high school female athletes,[43] the strengthening of this part of the body reduced FKPA during a VDJ. We obtained a reduction of the FKPA in the DL (mean difference of 4.5º). These reductions were greater than those reported by Brown et al.[44] probably because of two reasons. The first one is that they did not implement a specific gluteus medius strength exercise. As previously mentioned, gluteus medius exercises have been shown to improve knee valgus during dynamic activities and, therefore, reducing knee valgus during landings.[45] The second one would be related to the proper control of the core intervention training since according to their study limitations they may have stemmed from a lack of expertise of the assistant training staff. Therefore, similar to other study on abdominal-bracing maneuver performed during landing,[46] our study provides evidence to recommend the application of a program aimed at improving strength and control in the core area, as it influences vertical jump performance and facilitate motor control of knee movement to positions that increase the risk of injury at landing in female handball players.

One limitation of the study was the absence of measures like muscle activation during tests. Such analyses may provide further insight into the current benefits of core strength training and should be explored in future studies. It would be interesting also to investigate, what specific core training: muscle stability or muscle strength, affect more positively jump performance. Another limitation is that participants in our study were used to perform stability and strength exercises for the core which might have a bigger stimulus compared to people familiarized with this type of exercises, so it could be useful to explore the results of a core intervention in untrained individuals. Finally, core exercises have not been performed on a bipodal standing position (except the press pallof and the lateral side-walk with elastic band), therefore it should be interesting to implement specific core exercises which challenge the core in this specific position.

Despite widespread acceptance that core training impacts on sports performance, further research needs to be performed to examine the impact on jumping performance.

As we hypothesized the implementation of an in-season, 8-week core training program for female handball players resulted in improvements on bilateral and unilateral jump performance. In addition, it has also been shown to improve FKPA during unilateral VDJ in the NDL, which is the most common type of jump in handball.

Future strength training efforts in young women handball players should include specific core exercises, because not only positively contributes to improve jump performance but reduce FKPA, a key issue in lower limb injury prevention.

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