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ORIGINAL PAPER

INVESTIGATION OF THE CORRELATION BETWEEN THE ABILITY TO CHANGE DIRECTION AND THE DEVELOPMENT OF THE HIP MUSCULATURE OF THE HUNGARIAN NATIONAL HANDBALL ACADEMY'S ADOLESCENT MEN'S HANDBALL PLAYERS

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Summary

Background. Hip adductor weakness is a common risk factor for groin injuries among adolescent male handball players. Targeted hip strengthening may improve functional performance and reduce injury risk.

Material and methods. 29 elite male handball players (aged 14-17) from the Hungarian National Handball Academy participated in a prospective, controlled study. 14 players completed an 8-week hip-focused training program, while 15 served as controls. Pre- and post-tests assessed hip adductor strength (ergoFET), dynamic balance (Y-Balance test), core stability (side and Copenhagen plank), and change of direction speed (5-10-5 CODS test). Statistical analysis included t-tests, ANOVA, ANCOVA (age as covariate), and correlation analysis.

Results. The intervention group showed significant improvements in hip adductor strength ($p<0.01$), balance ($p<0.01$), and agility at 10 m and 20 m distances ($p<0.05$), with strong correlations between adductor strength and both balance and CODS performance. No significant changes were observed in FMS scores.

Conclusions. The 8-week training program effectively improved hip adductor strength, dynamic balance, and directional change speed in adolescent handball players. These results

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support the integration of specific hip strengthening exercises into youth athletic training to enhance performance and reduce injury risk.

Keywords: hip adductor strength, youth handball, dynamic balance, injury prevention, agility

Introduction

Handball is a high-intensity team sport characterized by frequent and rapid changes of direction (COD), jumps, and physical contact. These demands place considerable strain on the musculoskeletal system, particularly the lower limbs. Recent studies have shown a high incidence of lower extremity injuries in handball, with muscle strains, sprains, and contusions being the most common. Among these, groin injuries—including those affecting the hip adductors—are particularly prevalent, especially in adolescent male players. Epidemiological data from international competitions highlight that up to 12% of handball players experience hip and groin pain or injury during the season, with the adductors being among the most frequently affected muscles [1,2].

The hip adductor muscles play a crucial biomechanical role in stabilizing the pelvis and enabling efficient force transmission during lateral movements. During COD tasks, the adductors help control pelvic rotation and medial-lateral displacement, contributing to balance and agility. Weakness in these muscles can compromise dynamic stability and increase the risk of injury, particularly during deceleration and pivoting maneuvers [1-3]. Furthermore, reduced adductor strength may result in altered movement patterns, leading to compensatory overuse and increased susceptibility to strains and tears [4-8].

Due to the high physical demands of handball and the frequent occurrence of groin injuries, there is a growing interest in preventive training strategies. Previous research has suggested that strengthening the hip adductor muscle group can significantly reduce injury risk

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and improve performance outcomes, such as balance and agility [9]. Therefore, the targeted development of this specific muscle group may offer dual benefits: injury prevention and performance enhancement.

The objective of this study was to evaluate the effect of an 8-week hip mobility and strengthening program—focusing specifically on the hip adductor and abductor muscles—on muscle strength, balance, and COD ability in adolescent male handball players.

In addition to the hip adductors, other components of the hip musculature—such as the abductors, rotators, and stabilizing muscles—play essential roles in lateral movement and postural control. The gluteus medius and minimus, for example, are critical for maintaining frontal plane stability during rapid deceleration and directional changes. These muscles contribute to pelvic alignment and prevent excessive medial knee displacement, which is a known risk factor for injury. Thus, a holistic approach to hip muscle development is essential when aiming to improve COD performance and reduce injury risk.

Although several previous studies have established a link between hip muscle strength and athletic performance in lateral movements, there remain important gaps in literature. Many investigations focus on isolated variables, lack longitudinal data, or omit key stabilization factors such as core strength and balance. The current study addresses these limitations by combining multiple objective assessments—including muscle strength tests, balance evaluation, and plank tests—to provide a more comprehensive evaluation of how hip-focused training can impact both performance and injury prevention in adolescent handball players.

Aim of the work

The aim of our research is to investigate an exercise program that aims to mobilize the hip joint and specifically increase the strength of the hip adductor and abductor muscles, thereby

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reducing the incidence of injuries. With our exercise program, our goal was to create a simple exercise system that would increase hip joint mobilization and increase muscle strength in the hip adductors and abductors and potentially impact player performance by continually increasing the exercises. This mobility program can be performed by athletes before training sessions with the permission of coaches. All subjects are adolescent males who are certified players of the Hungarian National Handball Academy. The players were divided into 2 groups, an intervention group and a control group. The members of the intervention group performed the exercise program before the training sessions, while the members of the control group did not perform any additional exercises and only did their usual training work.

Hypotheses

1. We hypothesized that after completing the 8-week developmental training program, there would be a significant positive change in the input and output indicators of the intervention group players in terms of hip adductor muscle strength, Y-balance test, lateral plank, Copenhagen test, and CODS test scores, as well as FMS test scores. In addition, the intervention group scores better than the control group in comparing outcome measures.
2. We hypothesized that there would be a significant correlation between hip adductor muscle strength measured with the ergoFet device and Copenhagen plank test; hip adductor muscle strength and Y-balance test scores, and hip adductor muscle strength and CODS test scores.

Material and methods

Participants

Our study was a longitudinal, prospective, and quantitative study. The research was conducted at the Hungarian National Handball Academy in Balatonboglár between August 01, 2023, and December 12, 2023.

Our target group consisted of adolescent (14-17 years old) male handball players (2 teams) who are players of the National Handball Academy and have a playing license from the Hungarian Handball Association, and both teams compete in the U18 championship. The intervention group consists of younger players who form one team in the championship, and the control group also forms one team in the championship.

Players were excluded if they had an injury requiring medical intervention within a year, missed 10% of practices, or had one of the general contraindications. The total number was 29 players – intervention group: N=14, control group: N=15.

The participants had an average of 5.2±1.1 years of formal handball training experience. All were elite youth athletes, training 5 days a week under the Hungarian National Handball Academy program.

Study design

In addition to regular daily training, the players (29) had to complete a mobilization and strengthening program at home after 2 training sessions per week, specifically focusing on the hip joint.

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For the input measurement, we used the Functional Movement Screening (FMS), which helped us observe basic movement skills, and we tested the 7 tests of bursting and obstacle crossing. The side plank test was used to test core muscle stability, and the Copenhagen plank test was used to measure adductor muscle strength.

The 5-10-5 change of direction speed (CODS) test was used to test the players' CODS. The Y-Balance test was used to assess the players' dynamic balancing ability. The muscle strength of the hip adductors of the players was measured with the ergoFet device.

Statistical analysis

The dependent variables were hip adductor muscle strength, core muscle strength, directional change ability, and balance ability, and the independent variables were the age, height, weight, and body mass index (BMI) of the study participants.

Descriptive statistics, correlation analysis, one-sample t-test, and ANOVA test were performed ($p<0.05$).

The Shapiro-Wilk test was used for normality analysis. The test showed a normal distribution. For comparison of the muscle strength and plank test and the speed test, Spearman's correlation analysis was used for the analysis, with R strength of association assessed at the significance level of relevance, where $p\leq0.05$. The ANOVA test was used to examine the difference in measurement values between groups, and to detect progress within groups, a one-sample t-test was used for a two-tailed normal distribution, also at the $p\leq0.05$ significance level.

Given the significant age difference between groups ($p<0.01$), ANCOVA was used to control for age as a covariate in outcome analyses to isolate the effect of the intervention. In addition to *p*-values, effect sizes were calculated using Cohen's *d* for t-tests for ANOVA to determine the magnitude of observed effects.

The statistical analysis was made with IBM SPSS 27.

Intervention

The handball players participated in 5 training sessions per week in the club. The players of the intervention and control groups each form one team in the championship, so the starting time of the training sessions was different, but the content program did not differ, and the location of the training sessions was also the same. The athletes of the intervention group also performed a special training program. The players of the control group only participated in the training sessions and matches prescribed by the sports club during the period of our study and did not receive any other therapy.

The goal of the development program applied in the intervention group was to improve the ability to change direction and balance by increasing the strength of the hip adductors and core muscles. The program lasted 8 weeks.

First 2 weeks: the player lies on his back with his knees bent. A rubber ball is placed between the two knees, and the player squeezes it and holds it for 10 seconds, 20 times. The player lies on his side and lifts the leg on top, holds it for 10 seconds, and releases it back to the ground, 20 times on each side. Inside position, the player lifts the bottom leg, holds it for 10 seconds, and releases it back to the ground, performing the exercise 20 times on each side. The player is positioned in a kneeling support. First the right leg is lifted to the side, then the left 10-10 lifts. The player is in a standing position. With the knees slightly bent, the player must walk sideways for 20 meters and then 5-5 times in the opposite direction. In the third and fourth weeks, the exercises were the same as in the first 2 weeks, but here we used resistance and made

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the exercises more difficult with a rubber band. In the fifth and sixth weeks, the athletes performed the exercises on an unstable surface. In the last 2 weeks of the program, we combined the difficulties of the previous weeks, i.e. rubber bands and unstable surfaces. The unstable surface for all athletes was uniformly BOSU (half fit ball) or fit ball. Adherence to the home-based program was monitored through weekly check-ins by strength coaches and completion logs submitted by the players. Players were provided with video demonstrations, and periodic in-person technique checks were conducted by physiotherapists to ensure correct execution.

Results

Demographic characteristics

The average age of the handball players in the intervention group was 14.64±0.50 years. The average age of handball players in the control group was 16.07±0.70. The average height of the athletes in the intervention group was 175.43±5.56 cm, and in the control group 182.6±3.81 cm. The mean weight of the handball players in the intervention group was 72.46±11.86 kg, while the mean weight of the control group was 80.55±8.5 kg. The mean BMI of the intervention group was 23.41±2.6, and the mean BMI of the control group was 24.12±1.97.

Hip adductor muscle strength test

Comparing the difference between the results of the first and the second measurement, the one-sample t-test showed a significant difference between the groups on both sides. The difference between the input and output measures of the two study groups in terms of the increase in hip adductor muscle strength was also tested using the two-sample t-test and showed a significant difference in favor of the intervention group (Tables 1 and 2).

Table 1. One-sample t-tests and Cohen's *d* values for mean muscle strength analysis in the intervention and control groups

One-sample t-test	sig (*p*)	Cohen's *d*
input-output INTERVENTION right	<0.01*	1.64
input-output INTERVENTION left	<0.01*	1.75
input-output CONTROL right	<0.01*	0.51
input-output CONTROL left	<0.01*	0.53

Notes: * – statistically significant.

Table 2. Values of ANOVA tests of mean muscle strength analysis between intervention and control groups

ANOVA test	sig (*p*)	Cohen's *d*
input INTERVENTION – CONTROL right	<0.01*	-2.07
input INTERVENTION – CONTROL left	<0.01*	-2.11
output INTERVENTION – CONTROL right	0.012*	-1.01
output INTERVENTION – CONTROL left	0.013*	-1.01

Notes: * – statistically significant.

The average muscle strength of the right hip adductors increased from 13.69 to 16.39 in the intervention group and from 17.97 to 18.24 in the control group. The muscle strength of the left hip adductors increased from 12.83 to 17.97 in the intervention group and from 17.97 to 18.37 in the control group.

Based on the Cohen's *d* values, the intervention program significantly improved hip adductor muscle strength, especially considering the lower baseline values in the intervention group. The very large effect sizes (*d*>1.2) indicate a strong impact of the intervention, which is also clinically relevant. The moderate improvement in the control group is likely due to natural development or measurement variability. Overall, the study clearly demonstrates the effectiveness of the intervention in increasing hip adductor strength.

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Changes in muscle strength within groups before and after the 8-week exercise program are shown in Figure 1.

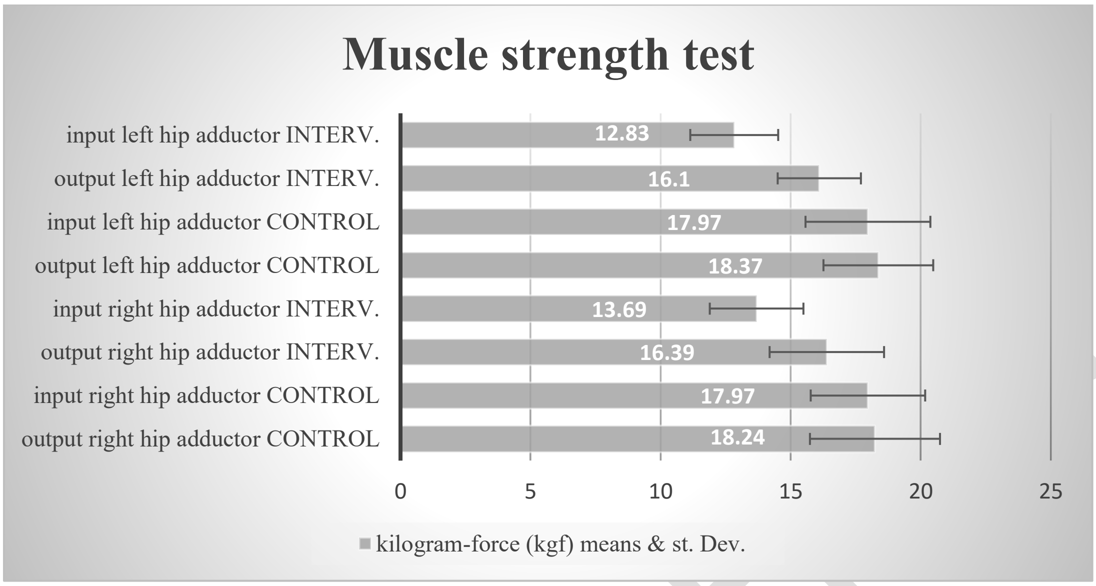

Figure 1. Mean results of muscle strength measurements in the groups before and after treatment (kilogram-force (kgf))

Y-Balance test

Comparing the difference between the input and output measurement results, the one-sample t-test showed a significant difference in all three directions in intervention group. The input and output measures of exercise performed with the right leg (anterior direction) varied from 76.21 to 79.71 in the intervention group and from 70.27 to 72.87 in the control group. The analysis of variance (ANOVA) of the measurement scores of the two groups was also significant. The first and second measurement scores of the left leg exercise (anterior direction) changed from 71.43 to 75.93 in the intervention group and from 72.8 to 74.53 in the control group. An analysis of variance (ANOVA) of the differences between the scores of the two groups showed a significant difference in favor of the intervention group. In the posterolateral

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direction, the change in the first and second measurements of the right leg exercise score increased from 85.14 to 87.43 in the intervention group and from 82.27 to 82.4 in the control group. Analysis of variance (ANOVA) of the two groups' scores showed a significant difference in favor of the intervention group. In the posterolateral direction, the scores on the input and output measures of the left leg exercise increased from 84.21 to 86.93 in the intervention group, and the mean of the second measure scores remained 85.67 in the control group. Analysis of variance (ANOVA) of the scores of the two groups showed a significant difference in favor of the intervention group.

In the posteromedial direction, the change in the first and second measurement of the right leg exercise score from 73.29 to 76.5 in the intervention group and from 75.8 to 76.33 in the control group. An analysis of variance (ANOVA) of the two groups showed a significant difference in favor of the intervention group. In the posteromedial direction, the change in the first and second measurements of the left leg exercise score increased from 73.21 to 77 in the intervention group and from 74 to 74.6 in the control group. After analysis (ANOVA) of the measurement results of the two groups, a significant difference was found in favor of the intervention group. The measurement results of the Y-Balance test are shown in Tables 3 and 4, and Figures 2 and 3.

Table 3. Values of the one-sample t-tests of the Y-Balance test in the intervention and control groups in all three directions

One-sample t-test	sig (*p*)	Cohen's *d*
input-output INTERVENTION right Anterior	<0.01*	-1.23
input-output INTERVENTION right Posterolateral	<0.01*	-1.25
input-output INTERVENTION right Posteromedial	<0.01*	-1.26
input-output INTERVENTION left Anterior	<0.01*	-1.55
input-output INTERVENTION left Posterolateral	<0.01*	-1.21
input-output INTERVENTION left Posteromedial	<0.01*	-1.48
input-output CONTROL right Anterior	0.63	-0.22
input-output CONTROL right Posterolateral	0.33	-0.25
input-output CONTROL right Posteromedial	0.17	-0.36
input-output CONTROL left Anterior	0.03*	-0.56
input-output CONTROL left Posterolateral	0.056	-0.59
input-output CONTROL left Posteromedial	0.09	-0.42

Notes: * – statistically significant.

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Table 4. Values of the ANOVA tests of the Y-Balance test between the intervention and control groups in all three directions

ANOVA test	sig (p)	Cohen's d
input INTERVENTION – CONTROL right Anterior	0.052	0.65
input INTERVENTION – CONTROL right Posterolateral	0.06	0.71
input INTERVENTION – CONTROL right Posteromedial	0.08	-0.68
input INTERVENTION – CONTROL left Anterior	0.47	-0.38
input INTERVENTION – CONTROL left Posterolateral	0.38	-0.33
input INTERVENTION – CONTROL left Posteromedial	0.5*	-0.25
output INTERVENTION – CONTROL right Anterior	0.45	0.28
output INTERVENTION – CONTROL right Posterolateral	<0.01*	1.31
output INTERVENTION – CONTROL right Posteromedial	0.6	0.19
output INTERVENTION – CONTROL left Anterior	<0.01*	0.33
output INTERVENTION – CONTROL left Posterolateral	<0.01*	-0.25
output INTERVENTION – CONTROL left Posteromedial	<0.01*	0.79

Notes: * – statistically significant.

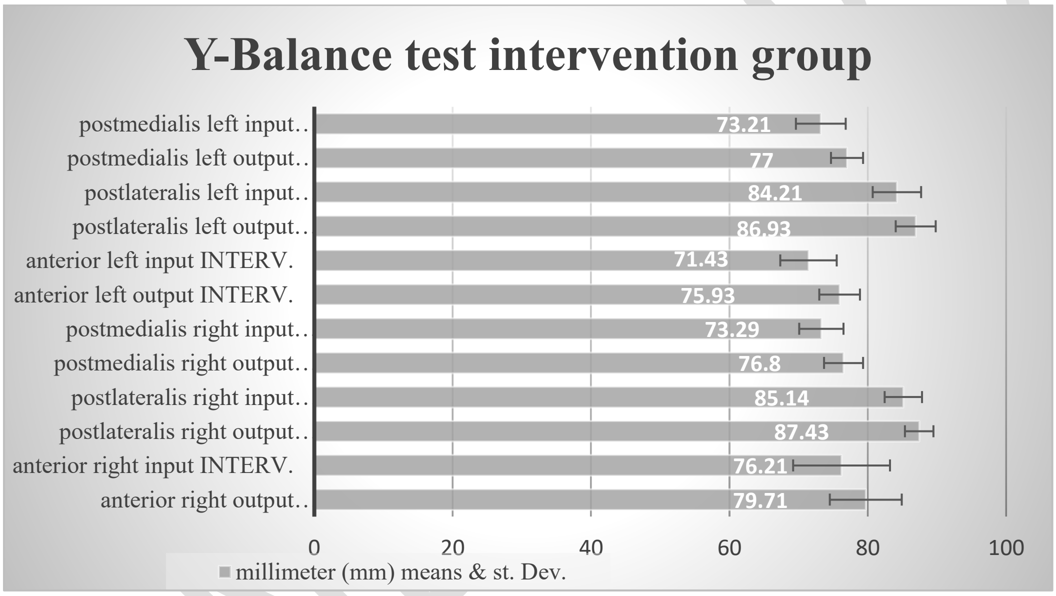

Figure 2. Y-Balance test input measurement mean results and output measurement mean results in the intervention group (millimeter, mm)

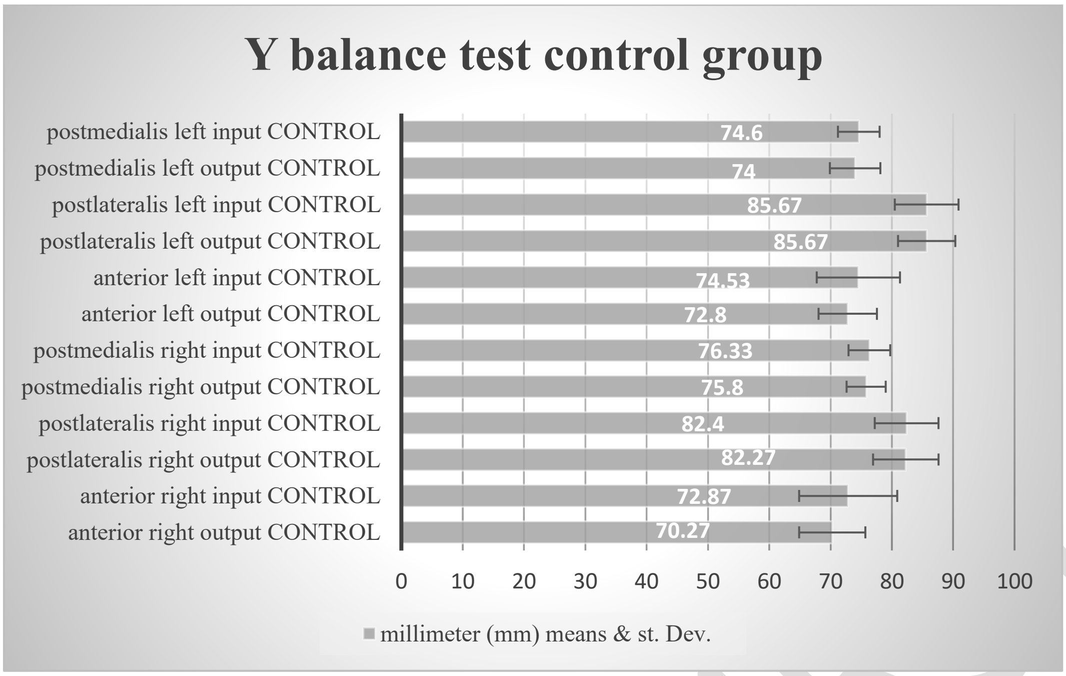

Figure 3. Y-Balance test input measurement mean results and output measurement mean results in the control group (millimeter mm)

Based on the Cohen's *d* values, the Y-Balance test results show that the intervention had a strong and significant effect on improving dynamic balance in the intervention group. The very large effect sizes ($d>1.2$) indicate that participants' performance improved considerably in all directions. In contrast, the control group showed minimal progress, with most effect sizes remaining in the small to moderate range. The ANOVA results confirm that the differences between the two groups became statistically and clinically significant after the intervention, especially in the posterolateral and posteromedial directions.

Side plank

We examined the difference between the input and output measures of the 8-week exercise program and compared the measured outcomes of the intervention and control groups.

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The study showed a significant increase on both sides in favor of the intervention group. The side plank measurement results are shown in Tables 5 and 6, and Figure 4.

Table 5. One-sample t-test values of the side plank test in the intervention and control groups

One-sample t-test	sig (*p*)	Cohen's *d*
input-output INTERVENTION right	<0.01*	2.46
input -output INTERVENTION left	<0.01*	2.69
input-output CONTROL right	<0.01*	3.2
input-output CONTROL left	<0.01*	3.69

Notes: * – statistically significant.

Table 6. ANOVA test values for the side plank test between the intervention and control groups

ANOVA test	sig (*p*)	Cohen's *d*
input INTERVENTION – CONTROL right	0.06	-0.22
input INTERVENTION – CONTROL left	0.23	-0.19
output INTERVENTION – CONTROL right	<0.01*	0.37
output INTERVENTION – CONTROL left	0.02*	0.47

Notes: * – statistically significant.

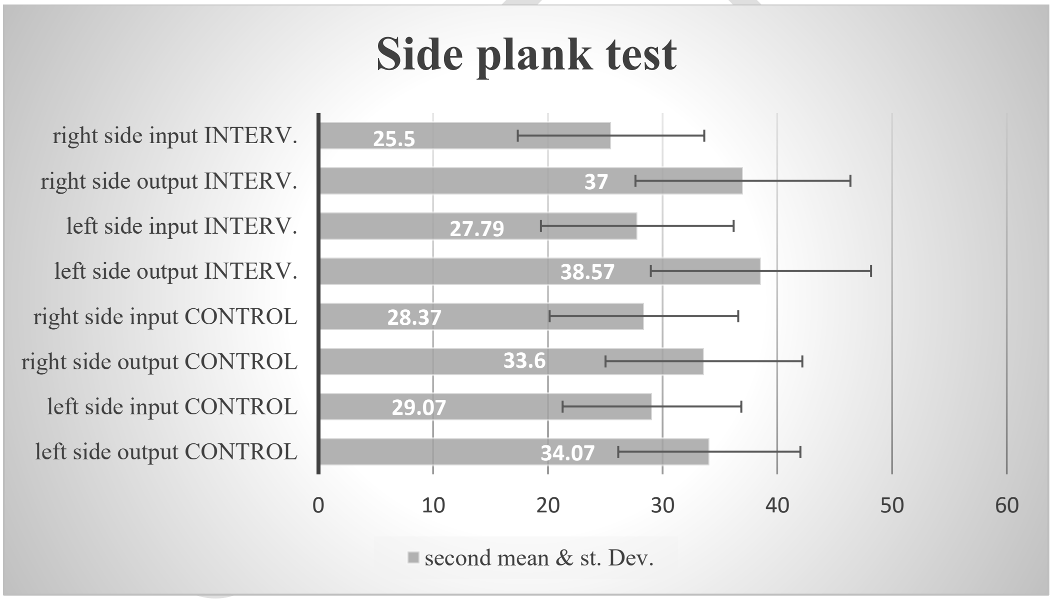

Figure 4. Mean input and output results of the side plank test by group (seconds, sec.)

The Cohen's *d* values indicate that the 8-week exercise program led to very large improvements in core stability (as measured by the side plank) in both the intervention and control groups. While the control group showed unexpectedly large gains, the intervention

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group demonstrated greater improvements when directly compared, as shown by the small-to-moderate effect sizes in the output ANOVA tests. This suggests that the intervention had a beneficial, though modestly superior, impact compared to no targeted intervention.

Copenhagen test

In the Copenhagen test intervention group, the one-sample t-test showed a significant difference on both sides. In the control group, we found no significant difference in the input and output measurements on either side. The ANOVA test showed a significant difference between the two groups on the right side and on the left side (Tabless 7 and 8, and Figure 5).

Table 7. The values of the one-sample t-tests of the Copenhagen test in the intervention and control groups

One-sample t-test	sig (*p*)	Cohen's *d*
input-output INTERVENTION right	0.7	0.26
input-output INTERVENTION left	0.66	0.22
input-output CONTROL right	0.12	0.24
input-output CONTROL left	0.21	0.27

Table 8. Values of the ANOVA tests of the Copenhagen test between the intervention and control groups

ANOVA test	sig (*p*)	Cohen's *d*
input INTERVENTION – CONTROL right	<0.01*	-1.01
input INTERVENTION – CONTROL left	<0.01*	-1.08
output INTERVENTION – CONTROL right	<0.01*	-1.1
output INTERVENTION – CONTROL left	<0.01*	-1.06

Notes: * – statistically significant.

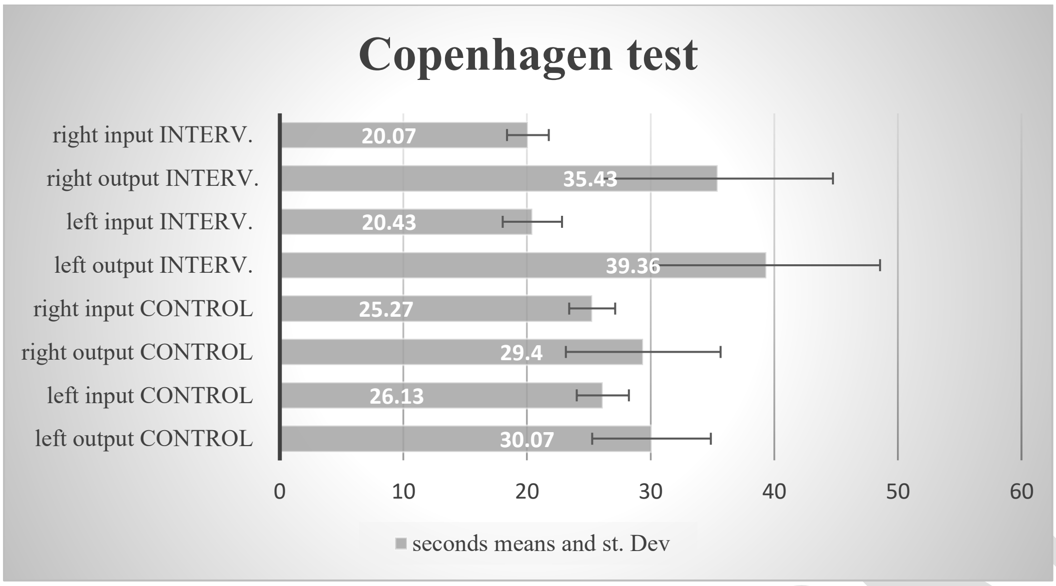

Figure 5. Mean input and output results of the Copenhagen test by groups (seconds, sec.)

Although the within-group changes in the Copenhagen test were not significant and showed only small effect sizes, the between-group comparisons revealed very large and statistically significant differences. This indicates that the intervention group consistently performed lower than the control group, both before and after the program. Therefore, the intervention did not produce measurable gains in eccentric hip adduction strength, as assessed by the Copenhagen test, within the 8-week timeframe. Further investigation is recommended to understand why this aspect of performance did not improve despite significant gains in other areas.

CODS test

In the intervention group, the 5 m CODS did not show a significant difference between the input and output measurements after one-sample t-test analysis, and the 10 m and 20 m indicated a difference. In the control group, the CODS only indicated a difference between the input and output measurements of 5 m by one-sample t-test, 10m, and 20 m. Between the

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groups, the output measurements of 10 m and 20 m by ANOVA analysis indicated a significant difference 10 m, 20 m. (Tables 9 and 10,and Figure 6)

Table 9. One-sample t-test values of the CODS test in the intervention and control groups at 5, 10, and 20 meters

One-sample t-test	sig (*p*)	Cohen's *d*
input-output INTERVENTION 5 m	0.26	-0.31
input-output INTERVENTION 10 m	0.04*	-0.27
input-output INTERVENTION 20 m	0.034*	0.27
input-output CONTROL 5 m	0.21	-1.14
input-output CONTROL 10 m	0.58	-0.5
input-output CONTROL 20 m	0.12	-0.44

Notes: * – statistically significant.

Table 10. Values of the ANOVA tests of the CODS test between the intervention and control groups at 5, 10, and 20 meters

ANOVA test	sig (*p*)	Cohen's *d*
input INTERVENTION – CONTROL 5 m	0.11	0.74
input INTERVENTION – CONTROL 10 m	0.23	0.60
input INTERVENTION – CONTROL 20 m	0.06	0.84
output INTERVENTION – CONTROL 5 m	0.1	0.76
output INTERVENTION – CONTROL 10 m	<0.01*	0.59
output INTERVENTION – CONTROL 20 m	0.036*	0.51

Notes: * – statistically significant.

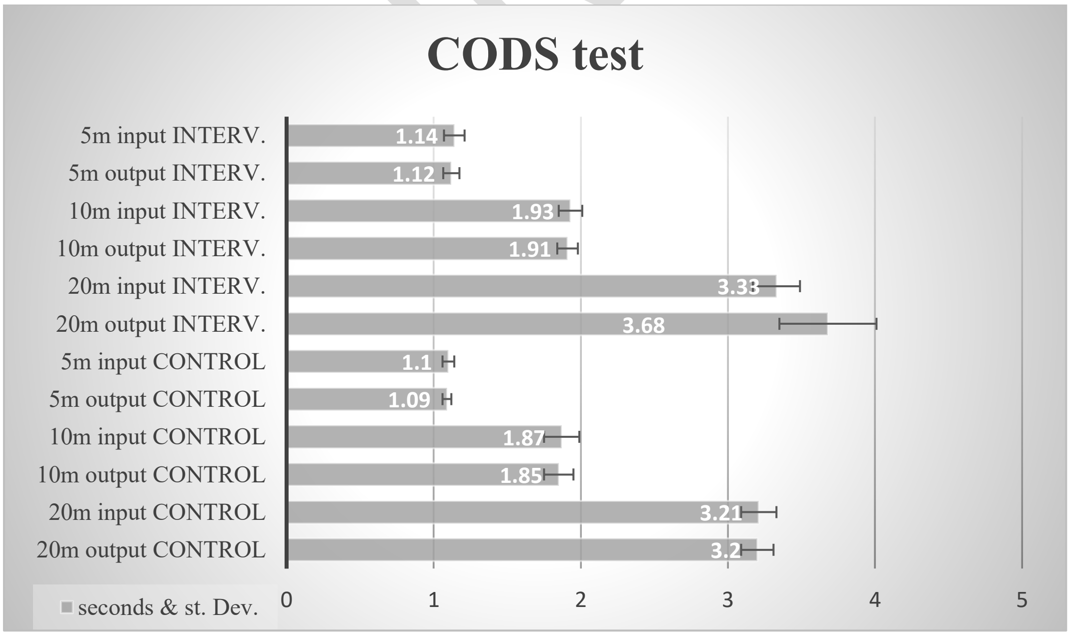

Figure 6. Mean input and output results of the CODS test by groups (seconds, sec.)

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The Cohen’s ’ values suggest that the intervention had a statistically significant impact on CODS performance over 10 and 20 meters, while no significant effect was observed at 5 meters. Although the control group showed an unexpected large improvement at 5 m, this was not consistent across other distances and may reflect testing variability. The between-group analysis confirms a moderate advantage for the intervention group at longer distances (10 m and 20 m), supporting the positive effectiveness of the 8-week program in improving agility and speed during directional changes.

FMS test

Comparing the difference between the first and second measurement results in both groups, the one-sample t-test showed no significant difference between groups (p_{interv}=0.16, $p_{control}$=0.34) in the intervention of the FMS test hurdle step and in-line lunge tests. The two-sample t-test results of the in-line lunge test showed no significant difference between groups (p=0.18). The differences from the results of the hurdle step tests of the two groups did not show a significant difference between the groups (p=0.31), but a mean difference can be seen in the groups.

Copenhagen plank test and hip adductors muscle strength test

In the study, we compared the muscle strength of the adductors on both sides in both the intervention and control groups with the results of the Copenhagen test. A significant correlation was found between the muscle strength of the right and left adductors of the intervention group players and the Copenhagen test. There was also a significant correlation between the scores of the players in the control group on both sides (Table 11).

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Table 11. Correlation analysis between Copenhagen test and hip adductor muscle strength test in both groups

Correlation	R	sig (p)	Cohen's d
Hip adductor – Copenhagen right INTERVENTION	0.48	<0.01*	-2.84
Hip adductor – Copenhagen left INTERVENTION	0.71	<0.01*	-3.45
Hip adductor – Copenhagen right CONTROL	0.29	<0.01*	-2.12
Hip adductor – Copenhagen left CONTROL	0.62	<0.01*	-2.11

Notes: * – statistically significant.

Based on the evaluation of the Cohen's d values, there is an extremely strong relationship between the Copenhagen plank test and hip adductor muscle strength, especially in the intervention group. This suggests that the Copenhagen test is a highly reliable indicator of adductor strength, particularly when assessing side-to-side differences or the impact of an intervention program.

The very large effect sizes in both groups confirm that performance in the Copenhagen test closely reflects the strength of the hip adductors. Therefore, it can be considered a valid and practical field-based tool for monitoring muscular strength and for injury prevention screening in athletic populations.

Hip adductor muscle test and Y-Balance test

Tests were performed in both groups with adductors on both sides in all three directions. After testing, correlation analysis was used to examine the relationship between muscle strength and Y-Balance test results. Significant correlations were found between the right adductor and anterior direction test, left adductors and anterior direction test, right adductors and posterolateral direction test, the right adductors and the posteromedial direction test, the left adductors and the posterolateral direction test, the right adductors and the posteromedial direction test, and the left adductors and the posteromedial direction test in the intervention group. The correlation analysis also showed a significant correlation between the muscle

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strength of the left adductors and the anterior test, muscle strength of the right adductor muscles and the posterolateral test, muscle strength of the left adductor muscles and the posterolateral test, muscle strength of the right adductor muscles, and muscle strength of the left adductor muscles and the posteromedial test in the control group (Table 12).

Table 12. Correlation analysis between Y-Balance test and hip adductor muscle strength test in both groups

Correlation	R	sig (*p*)	Cohen's *d*
Anterior right – hip adductor right INTERVENTION	0.48	<0.01*	1.95
Posterolateral right – hip adductor right INTERVENTION	0.44	<0.01*	1.96
Posteromedial right – hip adductor right INTERVENTION	0.61	<0.01*	1.95
Anterior left – hip adductor left INTERVENTION	0.72	<0.01*	1.98
Posterolateral left – hip adductor left INTERVENTION	0.47	<0.01*	1.95
Posteromedial left – hip adductor left INTERVENTION	0.16	=0.6	1.95
Anterior right – hip adductor right CONTROL	0.37	=0.07	1.94
Posterolateral right – hip adductor right CONTROL	0.5	<0.01*	1.95
Posteromedial right – hip adductor right CONTROL	0.32	=0.06	1.95
Anterior left – hip adductor left CONTROL	0.41	<0.01*	1.95
Posterolateral left – hip adductor left CONTROL	0.4	<0.01*	1.95
Posteromedial left – hip adductor left CONTROL	0.46	<0.01*	1.95

Notes: * – statistically significant.

All Cohen's *d* values range from 1.94 to 1.98, indicating very large effect sizes for all significant correlations. This underscores the practical and clinical relevance of the relationship between hip adductor strength and balance performance.

Even in cases where statistical significance was not reached (e.g. posteromedial left in the intervention group or anterior right in the control group), the associated Cohen's *d* values remain very large, suggesting that sample size or variability may have limited statistical power rather than a true lack of effect.

The correlation analysis and Cohen's *d* values strongly support the conclusion that hip adductor strength is closely linked to dynamic balance performance, particularly in the anterior and posterolateral directions. The intervention group showed stronger and more consistent

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correlations, likely reflecting the positive impact of the training program on neuromuscular control and muscle function.

The very large Cohen's *d* values (*d*≈1.95-1.98) further highlight the clinical significance of these relationships, confirming that hip adductor strength is a key component of balance ability and potentially injury prevention in athletic populations.

Hip adductors muscle strength measurement and CODS test

Our study was conducted in both groups with adductors on both sides and at all three distances. A two-sample t-test was used for the analysis. When analyze the muscle strength of the right hip adductors of the intervention group and the results of the CODStest, we found a significant correlation between the two variables at all three distances, 5 meters, 10 meters, and 20 meters. We also examined the correlation between hip adductor muscle strength and speed. We analyzed the results of the left hip adductor muscle strength and the CODS test for the intervention group and found a significant Spearman correlation between the two variables at all three distances, at 5 m, 10 m, and 20 m. The muscle strength of the right hip adductors of the control group and the results of the CODS test were analyzed, and a significant correlation was found between the two variables at one distance (20 meters).

Table 13. Correlation analysis between CODS test and hip adductor muscle strength test in both groups

Correlation	R	sig (*p*)	Cohen's *d*
5 m – hip adductor right INTERVENTION	0.66	<0.01*	0.76
10 m – hip adductor right INTERVENTION	0.74	<0.01*	0.69
20 m – hip adductor right INTERVENTION	0.39	<0.01*	0.51
5 m – hip adductor left INTERVENTION	0.42	<0.01*	0.76
10 m – hip adductor left INTERVENTION	-0.57	<0.01*	0.69
20 m – hip adductor left INTERVENTION	-0.31	<0.01*	0.51
5 m – hip adductor right CONTROL	-0.22	0.69	0.76
10 m – hip adductor right CONTROL	0.15	0.44	0.69
20 m – hip adductor right CONTROL	0.38	<0.01*	0.51
5 m – hip adductor left CONTROL	0.21	0.72	0.76

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10 m – hip adductor left CONTROL	0.27	0.67	0.68
20 m – hip adductor left CONTROL	0.41	<0.01*	0.5

Notes: * – statistically significant.

The correlation analysis and Cohen's *d* values indicate that hip adductor muscle strength is moderately associated with better COD performance, particularly in the intervention group. The intervention appears to have enhanced the functional connection between muscle strength and agility, especially at shorter distances (5-10 meters).

In contrast, the control group showed no consistent or meaningful correlation at shorter distances, confirming that training is a key factor in improving the strength-agility relationship. The moderate effect sizes further support the real-world relevance of these findings in athletic performance and injury prevention contexts.

Discussion

Before the exercise program, we measured better results on average in the control group than in the intervention group in the values of the input muscle strength measurement, but after 8 weeks of exercise, we observed a significant improvement in the intervention group. A similar study was carried out by Alonso-Fernández et al. [10], who investigated the effects of an 8-week program of adductor muscle exercise on muscle structure and flexibility (N=45). The study showed that after the training was completed, both variables returned to their initial values. These results suggest that an adductor strengthening exercise program would be an appropriate strategy to modify the strength of the adductors and thus prevent muscle injuries [10]. Our test results are similar to the test results mentioned above (p<0.01). We conclude that an important component for the prevention of hip injuries is the use of a hip adductor-abductor strengthening exercise program. In terms of our results, however, it should also be considered

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that, in addition to this exercise program, the players also participated in several training sessions per week, including specific handball, running, and gym training.

Our next analysis was to investigate the effect of our exercise program on the handball players' ability to balance, which we tested with Y-Balance. To develop balance, we used different unstable surfaces. To develop the ability of handball players to change direction, it is also necessary to develop their balancing skills, as the sudden movement causes them to shift their body weight from one foot to the other. The players in the intervention group showed an improvement in their balance after the movement program, as confirmed by the results of the outcome measures, while the players in the control group showed little improvement, demonstrating that if we want to improve their ability to change direction, we need to develop balance as well as muscle strengthening. This viewpoint has been confirmed by another research. Our study was compared with research by Wilson et al. [11] on the relationship between muscles around the hips and the Y-Balance test. The aim of Wilson's research was to identify the relationship between the isometric hip muscle and the Y-Balance test to provide sports scientists with better guidance on areas of muscle performance that need to be addressed due to poor performance on the Y-Balance test. They also concluded that professionals should test the strength of the hip abductors if patients show weakness in the Y-Balance test [11]. Although this research only concerns the hip abductors, our own research has also shown that with proper hip adductor muscle strength development, the Y-Balance test will also improve ($p<0.01$).

Our third analysis showed that the development of players' side plank test scores is influenced by the performance of our training program. One factor in the correct execution of the side plank is the muscle strength of the hip adductors. In our study, the input measurement showed that the average of the control group's scores was higher than the intervention groups, but the intervention group's scores were better than the average of the scores after the 8-week exercise program. After statistical analysis, it was shown that there was a significant improvement in favor of the intervention group on both sides. The data suggests that the 8-week exercise program had a positive effect on hip adductors. In addition, the fact that the players also participated in other training sessions should be considered in this conclusion. The Copenhagen test also confirmed that the intervention group showed improvement after completing the exercise program. Blasimann et al. [12] also studied the effect of strengthening the core muscles using the side plank. For two studies, a significant reduction in injury rates was found in the intervention group ($p<0.05$, $p<0.001$) [12].

Studies identifying different types of CODS performance (lateral, zigzag, back and forth, etc.) suggest that the concept of different types of reactive agility performance is also needed. In sports such as rugby and football, reactive agility mostly consists of non-stop running, while in other sports (e.g. tennis, handball, basketball) athletes often perform stop-and-go reactive agility patterns. Recently, testing protocols based on stop-and-go reactive agility have been designed and tested for reliability and validity [13], and the results showed that the newly developed CODS and stop-and-go reactive agility protocols provide a high level of reliability in indicating the athletes' perceptual and reactive abilities (P&RC). Handball involves multidirectional COD. Athletes often perform stop-and-go COD in response to unpredictable stimuli (ball, opponent, etc.) on a relatively small court. The handball-specific CODS test and its complementary reactive agility test were theoretically designed in consultation with high-level athletes and strong handball strength and conditioning experts, including coaches of the most competitive teams.

We analyzed the relationship between hip adductor muscle strength and the CODS test, which was also supported by Jones et al. in their research [14]. For both groups, we measured the players before and after the training program. The results were then compared with the muscle strength of the hip adductors of both legs. The results showed a significant relationship

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between muscle strength and the ability to change direction. From this, we can conclude that the introduction of a hip adductor strengthening training program for players would be an important factor in improving the ability to change direction.

This was also confirmed in our study, as the intervention group's output measures were significantly better than the input measures at 10 and 20 meters after completing the 8-week training program, and the control group's outcome measures were significantly better than the intervention group's. In 2020, Menai et al. published their research on the effects of hip adductors strengthening on sprint time and agility, which also supports our development [15].

In our next test, we looked for a correlation between the Copenhagen test times and hip adductor muscle strength. In the intervention group, a significant correlation was found between muscle strength and the plank test on both sides. From these statistics, we could conclude that the hip adductor muscles were positively affected by this 8-week training program, as not only the muscle strength of the adductors increased in the second measurement but also the Copenhagen plank test time. This assumption is supported by research published by Polgass et al. [16]. They also investigated the relationship between hip adductor muscle strength and the Copenhagen plank, which is consistent with our research findings.

We also tested the relationship between hip adductor muscle strength and the Y-Balance test. During the measurement, the players needed sufficient muscle strength to be able to do the Y-Balance test. In the intervention group, we observed a significant correlation in all three directions for hip adductors on both sides. The statistical data obtained and the results of our literature analysis suggest that strengthening the hip adductors is an essential step in the development of the ability to change direction, which also has an impact on balance. Our findings are supported by research published in 2022 by Domínguez-Navarro et al. [17], in which they investigated the relationship between hip adductor and abductor muscle strength with dynamic unbalance, as measured by the Y-Balance test, and ankle biomechanics in young

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female basketball players. The purpose of this study was to investigate the strength of the hip abductor and adductor and to examine the extent to which these factors influence balance ability and ankle dorsiflexion mobility in young elite basketball players [17].

We assumed that the Functional Movement Screen (FMS) test scores in the intervention group would show greater improvement than scores in the control group. Although scores increased after the exercise program, this did not show a statistically significant improvement between the intervention and control groups. Although the intervention group showed significant improvements in hip adductor strength, balance, and agility, no statistically significant change was observed in the FMS scores. This may be due to the relatively short duration of the program and the specificity of the exercises, which were primarily focused on hip strengthening rather than full-body movement patterns. Furthermore, the FMS may lack the sensitivity to detect subtle changes in isolated functional domains such as hip control, especially in well-trained youth athletes who already possess relatively high baseline scores. Future research could explore the impact of longer or more integrative neuromuscular training protocols on comprehensive movement quality outcomes.

Novelty and originality of the study

This study offers several novel contributions to the field of sports science and injury prevention:

1. Unique target population: The investigation focuses on elite adolescent male handball players (ages 14-17) from the Hungarian National Handball Academy. This highly specific and competitive youth cohort is rarely studied in current literature, particularly in the context of injury prevention and performance optimization.

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2. Comprehensive hip-focused intervention: The study presents a structured 8-week intervention program targeting hip adductors and abductors, integrating progressive overload principles and proprioceptive training (e.g. BOSU, resistance bands). This combined approach is innovative and not commonly evaluated in a longitudinal, performance-based setting.
3. Multidimensional performance assessment: Unlike previous studies that focus on single outcomes, this research simultaneously examines hip adductor strength, dynamic balance (Y-Balance test), core stability (side plank, Copenhagen plank), and agility (CODS test), allowing for a holistic view of functional improvements.
4. High-level statistical rigor: The application of ANCOVA to control for age differences, along with the calculation of effect sizes (Cohen's *d*), enhances the robustness of the findings. Strong correlations between hip adductor strength and multiple performance metrics (e.g. balance, agility) are reported with clinically relevant effect sizes.
5. Practical relevance for coaches and practitioners: The intervention protocol is easily implementable within regular training sessions or as a home-based routine. Its demonstrated effectiveness in improving both performance and injury-related indicators suggests that it can serve as a cost-effective, evidence-based conditioning strategy in youth handball.
6. New evidence supporting functional integration: The study provides novel evidence that improvements in hip adductor strength translate into measurable gains in dynamic balance and CODS, which are key performance elements in handball. This functional integration supports the implementation of targeted strength programs as part of sport-specific conditioning.

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Conclusions

In conclusion, the results of our longitudinal study showed that adequate hip adductor and abductor muscle strength is necessary for proper balancing ability. In our study, we formulated two hypotheses, of which those related to hip adductor muscle strength, balance ability, the importance of plank tests, and direction change ability were confirmed, with the FMS test showing no significant improvement. By comparing the associations found for hip muscle strength and Y-Balance tests, plank tests, and CODS tests with validated research, we conclude that the hip muscle training intervention improved hip muscle strength, Y-Balance, sprint time, the agility of handball players, and influenced their core muscles. As the intervention contributed to improving the performance of handball players, it should be incorporated into the players' routine conditioning program.

Disclosures and acknowledgements

The authors declare no conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Regarding medical research conducted on humans, the research complied with Decree 23/2002 (V.9.) of the Ministry of Health, and was compiled in accordance with the provisions of the applicable laws and the Declaration of Helsinki of the World Medical Association. Players and their parents filled in the consent form for testing and participation in the development program. The study was approved by the Research Ethics Committee of Hungarian University of Sports Science (no. TE-KEB/18/2022).

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