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Abstract

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Keywords

motor skills, coordination training, adolescent athletes, handball

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Article

The impact of coordination training on motor skills in adolescent handball players aged 14–15 years: A randomized controlled trial

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1. Introduction

According to the current scientific terminology, the term "fundamental motor skills" refers to specific categories of skills that form the basic elements of more advanced movements, such as object control or ball-handling skills, as well as locomotor skills or balance and stability skills [1]. Motor skills involve the development of complex movement patterns, which are refined and improved through intensive practice and training [2]. There is no doubt that motor skills are a key aspect in the specificity of every sport, especially in handball [3]. From an early age, children build appropriate levels of motor abilities through systematic physical activity [4,5]. Interestingly, the acquired motor abilities differ depending on age, which is influenced by differences in subcortical structures, such as the amygdala or hippocampus [6].

Focusing on the neuroanatomical basis, according to researchers, the main neuronal connections responsible for motor abilities partly result from organizational changes in the primary motor cortex and the proliferation of output pathways from other areas of the cerebral cortex, particularly from motor areas on the medial wall of the hemisphere [7]. Additionally, considering the cellular basis, it is important to mention corticospinal neurons (CSNs), which provide direct cortical outputs to the spinal cord and play a crucial role in motor control [8].

Analyzing the thematic scope of the work from a multifactorial perspective, one gets the impression that motor skills form the foundation for every athlete. Nevertheless, according to researchers, there are significant differences in motor abilities depending on the specific nature of the sport discipline [9]. In handball, a substantial influence of motor abilities on the accuracy and effectiveness of goal shots has been noted [10], and a significant relationship has been observed between higher levels of coordination skills and technical-tactical performance indicators in handball players [11]. This sequence of findings heightens researchers' need to develop new training methods aimed at maximizing handball players' motor abilities to the greatest possible extent.

As indicated by an in-depth analysis of the relevant literature, a significant need has been identified to illustrate the implementation of new training methods that could improve the development of motor abilities in young athletes, as well as to tailor the demands to appropriate age groups in line with the requirements of professional handball [12–16]. This study aims to provide new, up-to-date insights that may contribute to the modification of commonly used training methods among young handball players and influence their performance during competition. The purpose of the study was to evaluate the impact of specialized coordination training on changes in the motor ability profile of young handball players aged 14–15. The research compares the effects of an innovative training program with traditional methods, focusing on improving key motor parameters such as speed, endurance, strength, and coordination. The goal of the study is to demonstrate whether the application of modern training methods can significantly enhance the athletes' motor abilities and translate into their overall sports performance.

2. Materials and Methods

The study was conducted according to the Declaration of Helsinki and approved by the Bioethics Committee at the District Medical Chamber in Krakow (No. 205/KBL/OIL/2022). Participants were informed about the objectives and methods of the study, potential side effects, and the possibility of withdrawing from the study at any time without providing a reason. Written consent was obtained from the participants' parents or legal guardians for participation in the study.

2.1. Study Design

An experimental approach with repeated measurements and a randomized controlled trial was employed. The testing procedure was conducted before, during, and after the 8-month experimental training period. For the experimental group (EXP), the intervention was integrated into their regular training program, supplemented with specific coordination exercises. The control group (CON) followed their standard program of physical and technical–tactical training.

2.2. *Participants*

The study was conducted among a male population, specifically 27 elite handball players, active members of the "Vive" Kielce Sports Club. The participants' average age was 14.1±0.2 years, with an average training history of 4.3±0.72 years. Their training sessions lasted from 1.5 to 2 hours daily, 3–4 times a week. The averaged values of their morphological characteristics were as follows: height 175±5.9 cm, body mass 71.4±5.4 kg, lean body mass 56.2±3.4 kg, BMI 21±2.7 kg/m², and percentage of body fat 15.2±2.8%. Body mass and selected body composition variables were measured using the Tanita BC-601 body composition analyzer (Tanita, Tokyo, Japan) in the morning, on an empty stomach. Body height was measured using the SECA 2017 stadiometer (Seca, Hamburg, Germany). The measurements were made in accordance with anthropometric guidelines [17]. The sample size was calculated using the G*Power v 3.1.9.7 program, Düsseldorf, Germany (effect size f = 0.65, α = 0.05) with an actual power of 80%. Power analysis indicated that the minimum sample size required for this study ranged from 15 to 28 participants. A total of 45 athletes were initially recruited. Eighteen of them were excluded from the study due to inclusion/exclusion criteria which are presented in Table 1.

Table 1. Inclusion and exclusion criteria for handball players

Adolescent Handball Players (n = 45)	
Included: 27	**Excluded: 18**
Inclusion Criteria	**Exclusion Criteria**
Age 14–15 years	Players who did not successfully pass the medical examinations required for clearance to participate in team activities.
No history of trauma	Players or their families who did not provide written consent to participate in the study.
Training experience > 3 years training	Players taking medications that could affect the study results.
No experience with programs primarily based on coordination exercises	
No additional sports activities, such as gym workouts, swimming classes, or similar	

At this level, the recruited cohort was allocated into two groups (experimental group *n* = 15 and control group *n* = 12). The assignment was carried out randomly using a random number generator.

2.3. *Methodological Characteristics of the Experimental Intervention*

The research intervention involved manipulating the training process for players in the experimental group by modifying the training program. Three measurements were taken over the course of one macrocycle (which was also the experimental training period), lasting 8 months, from September 2023 to April 2024. The first assessment (pre-test) was conducted before implementing the experimental training into the training program. The second assessment (post-test 1) was carried out during the training program, 4 months after the experiment began (to control the effect). The final measurement (post-test 2) was conducted one week after the conclusion of the training program. During the experimental period, both groups performed handball training sessions lasting 90 min, 5 times a week. During this time, the control group followed the standard training included in their training program, which did not incorporate the experimental stimulus of additional coordination exercises.

2.4. Characteristics of the Experimental Training Program

The training content was part of a 90-minute training session. The key priorities of this program included: the level and variety of exercises used to develop and enhance motor coordination, a wide range of training equipment, modification of exercise complexity (which changed and increased throughout the experiment—based on the principle of progressively increasing difficulty), and the duration of stimulation during training (coordination exercises were not directly preceded by intense anaerobic or mixed exercises and were integrated into warm-up, technical-tactical exercises, and tactical activities). The content also included general and sport-specific exercises tailored to the discipline. The number of training units in the macrocycle that included exercises aimed at developing both general and specific motor skills, with a priority on motor coordination, ranged from 3 to 4 sessions per week. The exercises were designed and implemented with the intention of targeting all muscle groups of the participants, both analytically and holistically (following the principle of comprehensive muscle work).

Due to editorial limitations, a few examples of the applied exercise sets are listed below:

1. Differentiation and coordination of movements.
    - Technical-tactical exercises: Passing with two balls (one bounce, one mid-air), simultaneous passing with two balls, one-handed catching, ball toss, two-handed passing.
    - Coordination exercises: Juggling 2-3 balloons simultaneously, jumping in hula hoops, various jump combinations.
2. Reaction speed.
    - Reaction exercises: "Fitlights" light extinguishing, pair competition (hitting opponent's shoulder, knee, or foot), catching a reaction ball.
3. Rhythmizing and kinesthetic movements.
    - Dribbling exercises: Dribbling 2–3 balls of different sizes (handball, volleyball, basketball).
    - Coordination ladder exercises: A-skipping, various forward-backward-side movement variations.
4. Rhythmizing and reaction speed.
    - Exercises using court lines: Line jumps, scissors, stepping one foot over the line, cross-stepping.
5. Dynamic balance.
    - Balance exercises: Walking on different surfaces (rope, gymnastics bench) with eyes open and closed.
6. Technical-tactical exercises in a defensive context.
    - Defense: Blocking, clinching, movement, offensive fouls combined with passing balls of different sizes and weights.
7. Dynamic balance and coordination differentiation.
    - Exercises on gymnastics benches: Two-legged/one-legged jumps onto the bench, scissors on the bench, ball tosses while moving along the bench.

2.5. Testing Procedure

Physical fitness, in the context of motor abilities, was assessed using selected tests developed by the International Committee for the Standardization of Physical Fitness Tests (ICSPFT) [18] and the EUROFIT Physical Fitness Test [19]. The examiner demonstrated each test according to the procedure, followed by instructions and explanations. Effective recovery breaks (at least 15 minutes) were provided between attempts. Based on the obtained results, selected performance indicators were calculated. The testing procedure included the following trials:

1. 30-meter sprint: The participant performed a sprint from a standing start in a high position. The time was measured using OptoJump and OptoGate optical systems (Version 1.13.0, Microgate, USA).
2. 10-meter sprint: The participant performed the sprint from a flying start with a 6-meter approach, in a high position. The measurement was also conducted using the OptoJump and OptoGate optical systems (Version 1.13.0, Microgate, USA).
3. Standing vertical jump: The height of the vertical jump was calculated from the difference between the reach in the jump and the standing reach. From the vertical jump results, the maximum anaerobic work (MAP) was calculated using the formula [20]:

$$\boldsymbol{MPA = BM \times g \times h}$$

Where:
MPA – maximum anaerobic work [J],
BM – body mass [kg],
g – gravitational acceleration [9.81 m/s²],
h – vertical jump height [m].
*This calculated value can be considered an approximate measure of MMA (maximum anaerobic power).

4. 10 × 3-meter shuttle run: The participant had to run 3 meters ten times, touching the floor with both hand and foot behind the marked lines, alternating between the right and left sides. The participant started individually from a high position, and the stopwatch was activated after the first touch. The running was done facing forward. The test was performed twice with a 5-minute rest, and the better result was recorded. The results were used to calculate the maximum anaerobic power for the 10 × 3-meter run based on the formula [21]:

$$\boldsymbol{MMA = \frac{36000\,BM}{t^3}}$$

Where:
MMA – maximum anaerobic power,
BM – body mass [kg],
t – time to complete the trial [s].

In addition, the participants' relative MMA (R-MMA) was calculated, representing the ratio of generated MMA in the 10 x 3-meter run to total body mass using the formula [20]:

R-MMA = result MMA/Body mass [kg]

5. Medicine ball tapping: The participant sat on a mat against a wall, holding a 2 kg medicine ball. The task was to tap the ball against the mat between the legs and then against the wall above the head. The goal was to complete 10 tapping cycles (up–down) as quickly as possible. The stopwatch was started with the first tap on the mat and stopped after the 11th tap (10 full cycles). The trial was performed twice with a 5-minute rest, and the better result was recorded. The results were used to calculate the maximum anaerobic power for medicine ball tapping using the following formula [21].

$$\boldsymbol{MMA = \frac{20 \times (2 + 0.1 \times BM) \times g \times h_s}{t}}$$

Where:
BM – body mass [kg],
g – gravitational acceleration [9.81 m/s^2],
h_s – sitting height [m],
t – time to complete the trial [s].

Again, the participants' relative MMA (R-MMA) was additionally calculated.

6. Medicine ball throw from kneeling: The participant, kneeling on a mat, threw a 1-kilogram medicine ball forward with both hands from behind the head. The mat was positioned so that one-third of its surface was behind the throw line and two-thirds in front of it. The distance was measured with a tape to the nearest 10 cm. The participant performed the trial three times, and the best result was recorded.

7. Sit-ups (strength endurance of the abdominal muscles): The participant lay on a mat with feet 30 cm apart and knees bent at a 90-degree angle. Hands were clasped behind the neck, and a partner held the participant's feet. At the start signal, the participant sat up, touched the knees with elbows, and returned to the starting position. The duration was 30 seconds, and the result was the number of repetitions completed.

8. Static handgrip strength measurement: The participant, standing with feet slightly apart, held the dynamometer firmly in the fingers, with the arm positioned along the torso, ensuring the hand did not touch the body. The participant performed a brief maximal grip, while the other arm rested alongside the body. The better result of two maximal static strength tests of the dominant hand (HGSmax) was recorded using a dynamometer (MG 4800, Charder, Taichung, Taiwan) with an accuracy of 1 kg. The rest interval between tests was 5 minutes.

9. Beep test: This test was used to assess the players' aerobic capacity. It involved shuttle running over a 20-meter distance, where the running pace was determined by auditory signals from a recording. The participants began running at the start signal and had to reach the end line before the next signal. With each level, the time intervals between signals decreased, forcing the players to increase their running pace. The test ended when the participant failed to reach the line within the allotted time for two consecutive attempts. The result was the number of completed sections, which served as a measure of aerobic endurance.

2.6. Statistical Analysis

In the analysis of the research results, basic statistical methods were used, including the calculation of the arithmetic mean, median, standard deviation, minimum and maximum values, and the coefficient of variation. To assess the significance of differences between groups, the non-parametric Mann–Whitney U test was applied. To evaluate the significance of changes within a group, differences in progression were analyzed using the non-parametric Wilcoxon signed-rank test for paired observations. The choice of tests was preceded by checking the normality of variable distributions using the Shapiro–Wilk test, which indicated significant deviation from normal distribution. The degree of homogeneity within each group was assessed by interpreting the coefficient of variation values according to the following classification: CV < 25% indicates low variability; 25–45% indicates moderate variability; 45–100% indicates high variability; and >100% indicates very high variability. The collected data were analyzed using Statistica software, version 13.3 (Statsoft, Krakow, Poland).

3. Results

Table 2 presents the test results and the level of intergroup variation (groups: EXP vs. CON) of the participants.

Regarding the baseline assessment (Time I – pretest), a similar level of selected motor fitness components was observed between the groups, as measured by population tests, without significant differentiation ($p > 0.05$). The only significant exceptions were the results of the relative MMA index (the ratio of generated MMA to total body mass) during the medicine ball tapping test ($p < 0.05$) and the beep test ($p = 0.001$), where the EXP group showed significantly better test outcomes.

After 13 weeks of applying the experimental stimulus and standard training (Time II – posttest 1), the EXP group demonstrated better results in the 10 × 3 m run test variables (test trial, MMA, and relative MMA). The observed differences were statistically significant ($p < 0.05$). For the remaining test variables, no significant differences were noted ($p > 0.05$).

After 32 weeks of training (experimental vs. standard training), in the final measurement phase (Time III – posttest 2), significant differences were observed for the beep test results ($p = 0.001$) and abdominal muscle endurance against fatigue ($p < 0.05$), with better outcomes in the EXP group. In other trials, the observed differences did not show statistical significance (p > 0.05).

The variability coefficients indicate that internal variability in the analyzed test variables was very low in both groups (EXP vs. CON) (V = 3–24%). In the CON group, for the 10 x 3 m run indicators, i.e., MMA (V = 25%) and relative MMA (V = 25%), moderate internal variability was observed at the baseline measurement (Time I), bordering on very low. The averaged values from the three measurement sessions of V% show that homogeneity was greater in the EXP group and demonstrated progression in each subsequent post-test measurement during the experimental procedure (mean test-index of the EXP group V%: pretest = 12.29; posttest 1 = 11.86; posttest 2 = 10.71 vs. mean test-index of the CON group V%: pretest = 16.00; posttest 1 = 14.43; posttest 2 = 15.79).

Table 2. Statistical characteristics of motor fitness test results and their intergroup variation in the studied groups (EXP vs. CON) of handball players (n = 27)

Measurement	EXP Group (n = 15)						CON Group (n = 12)						d	p
	$\bar{x}$	SD	Me	min	max	V(%)	$\bar{x}$	SD	Me	min	max	V(%)		
Standing vertical jump [cm]														
I	44.5	6.1	42	37	56	14	49.1	7.0	48.0	38	61	14	-4.6	0.070
II	47.9	4.4	50	40	55	9	50.8	5.0	51.0	44	60	10	-2.9	0.085
III	49.1	3.0	50	44	54	6	49.1	6.1	48.5	40	62	12	0.0	0.825
MPA standing vertical jump [J]														
I	282	69	276	200	456	24	300	62	290	223	414	21	-18	0.367
II	296	54	284	202	405	18	312	63	300	229	426	20	-16	0.516
III	324	59	308	251	476	18	330	72	339	243	452	22	-6	0.905
Medicine ball throw from kneeling 1kg [m]														
I	10.5	1.5	10.3	8.5	14.1	14	10.3	1.9	10.0	8.0	14.0	18	0.2	0.696
II	11.2	1.5	11.1	9.3	14.1	13	10.2	1.8	10.0	7.9	14.0	18	1.0	0.102
III	12.5	1.3	11.2	10.1	14.2	11	11.0	2.3	10.6	8.0	15.5	21	0.5	0.392
Medicine ball tapping [s]														
I	5.8	0.26	5.8	5.2	6.2	5	5.9	0.56	6	5.0	7.0	9	-0.1	0.406
II	5.8	0.43	5.9	4.8	6.5	7	5.9	0.55	6	5.0	7.0	9	-0.1	0.591
III	6.0	0.29	6.0	5.6	6.4	5	6.2	0.69	6	5.3	7.6	11	-0.2	0.509
MMA medicine ball tapping														
I	258	35	263	195	311	14	237	52	226	177	334	22	21	0.103
II	255	39	240	199	347	15	250	55	244	172	351	22	5.0	0.905
III	260	39	252	200	346	15	260	55	233	196	348	21	0.0	0.614
Relative MMA medicine ball tapping														
I	4.0	0.26	4.0	3.6	4.5	6	3.8	0.28	3.8	3.3	4.3	7	0.26	**0.014**
II	4.0	0.31	3.9	3.6	4.8	8	3.9	0.40	3.9	3.2	4.6	10	0.07	0.661
III	3.8	0.20	3.8	3.4	4.2	5	3.8	0.37	3.8	3.1	4.4	10	0.02	0.845
10 × 3-meter shuttle run [s]														
I	11.3	0.6	11.3	10.3	12.5	5	11.9	1.0	11.9	10.4	13.5	8	-0.6	0.097
II	10.8	0.6	10.9	9.5	11.8	6	11.6	0.7	11.6	10.6	13.1	6	-0.8	**0.006**
III	10.8	0.7	10.7	10.0	12.3	6	11.1	1.1	10.9	9.9	13.8	10	-0.3	0.542
MMA 10 × 3 meter shuttle run [W]														
I	1623	277	1572	1207	2116	17	1374	350	1400	736	1905	25	249	0.083
II	1849	382	1829	1310	2708	21	1459	282	1484	1004	1944	19	390	**0.006**
III	1952	392	1836	1262	2481	20	1832	437	1863	1093	2772	24	121	0.486
Relative MMA 10 × 3-meter shuttle run [W/kg]														
I	25.4	4.2	24.9	18.3	32.9	17	22.1	5.6	21.5	14.5	31.9	25	3.3	0.088
II	29.2	5.4	27.9	21.8	42.0	18	23.4	4.3	22.9	15.9	30.5	18	5.8	**0.006**
III	28.8	5.0	29.3	19.5	36.3	17	27.3	6.5	28.4	13.7	37.7	24	1.5	0.575

Measurement	EXP Group (n = 15)						CON Group (n = 12)						d	p
	$\bar{x}$	SD	Me	min	max	V(%)	$\bar{x}$	SD	Me	min	max	V(%)		
Beep Test [m]														
I	1856	314	1900	1180	2380	17	1260	299	1200	900	1680	24	596	**0.001**
II	1916	278	1960	1240	2200	15	1768	394	1810	1240	2380	22	148	0.270
III	2343	306	2400	1900	2960	13	1950	303	1950	1400	2380	16	393	**0.001**
30-meter sprint [s]														
I	4.6	0.18	4.6	4.3	4.9	4	4.7	0.19	4.7	4.4	4.9	4	-0.04	0.625
II	4.8	0.19	4.8	4.4	5.0	4	4.7	0.22	4.7	4.3	5.1	5	0.08	0.366
III	4.6	0.20	4.6	4.3	4.9	4	4.6	0.30	4.7	4.0	5.0	6	-0.04	0.366
10-meter sprint [s]														
I	1.5	0.06	1.5	1.4	1.6	4	1.5	0.09	1.5	1.4	1.7	6	-0.02	0.844
II	1.5	0.05	1.5	1.4	1.6	3	1.5	0.07	1.5	1.4	1.6	5	-0.03	0.260
III	1.5	0.04	1.4	1.4	1.5	3	1.5	0.08	1.5	1.4	1.6	5	-0.02	0.824
Static handgrip strength measurement [kG]														
I	37.7	8.1	36	30	54	21	39.9	9.5	42.5	25	55	24	-2.2	0.588
II	40.6	7.5	40	30	58	18	42.0	8.8	43.0	30	57	21	-1.4	0.624
III	43.5	8.4	42	30	60	19	43.8	8.9	45.5	32	59	20	-0.3	0.769
Sit-ups [number of repetitions in 30 seconds]														
I	48.2	4.7	49	39	58	10	46.0	7.7	46	30	57	17	2.2	0.365
II	49.2	5.2	49	40	57	11	50.0	8.3	53	32	60	17	-0.8	0.492
III	55.1	4.5	55	48	65	8	48.5	9.1	50	28	61	19	6.6	**0.045**

$\bar{x}$ – arithmetic mean; **Me** – median; **SD** – standard deviation; **min** – minimum value; **max** – maximum value; **V%** – coefficient of variation; **I** – first measurement period (pre-test); **II** – second measurement period (post-test 1); **III** – third measurement period (post-test 2); **MPA** – maximum anaerobic work; **MMA** – maximum anaerobic power.
d – difference between means (delta); ***p*** – level of significance; statistically significant values are shown in **bold**.

Table 3 presents the range of progression in motor fitness components and the degree of intragroup variability in the studied groups (EXP vs. CON) of handball players.

In the EXP group, after a 32-week experimental training period (1st time point – pre-test vs. 3rd time point – posttest 2), a significant increase in test performance was observed for MPA vertical jump ($p < 0.001$), beep test, abdominal muscle endurance ($p = 0.001$), as well as in the tests for ball medicine tapping, relative MMA tapping, variables for the 10x3m run (test trial, MMA, and relative MMA), vertical jump, kneeling ball throw, 10m run, and handgrip strength ($p < 0.05$). Additionally, for the kneeling ball throw, variables of the 10 × 3m run (test, MMA, and relative MMA), beep test, 30m run, and grip strength, significant progression ($p < 0.05$) was already observed after 13 weeks of intervention (1st time point vs. 2nd time point). Furthermore, for the MPA vertical jump, ball medicine tapping (test trial and relative MMA), 30m and 10m run tests ($p < 0.05$), as well as the beep test and abdominal muscle endurance ($p = 0.001$), significant improvements were detected in the second half of the experiment (2nd time point vs. 3rd time point).

In the CON group, after 32 weeks of standard training, a trend of significant improvement was observed for MPA vertical jump, MMA tapping, grip strength, beep test, test trial and relative MMA of the 10 × 3m run ($p < 0.05$), and MMA of the 10 × 3m run ($p = 0.001$). After the first half of standard training (13 weeks, posttest 1), a significant improvement was found for ball medicine tapping variables (test trial, MMA, and relative MMA), beep test, grip strength, and abdominal muscle endurance ($p < 0.05$). Then, in the second 19 weeks of training (2nd time point vs. 3rd time point), further significant increases were observed for the MPA vertical jump, variables of the 10 × 3m run (test, MMA, and relative MMA), and handgrip strength ($p < 0.05$).

Table 3. Statistical characteristics of motor fitness gains and their intragroup variation in the studied groups (EXP vs. CON) of handball players ($n = 27$)

Variables	Measurement	EXP Group ($n = 15$)			CON Group ($n = 12$)		
		$\tilde{x}$	SD	p	$\tilde{x}$	SD	p
Standing vertical jump [cm]	I–II	3.40	7.27	0.088	1.67	4.21	0.208
	II–III	1.13	5.50	0.442	-1.67	4.50	0.551
	I–III	4.53	6.52	**0.020**	0.00	4.69	0.906
MPA standing vertical jump [J]	I–II	14.32	38.75	0.151	11.87	20.54	0.077
	II–III	27.43	33.12	**0.008**	18.07	24.09	**0.021**
	I–III	41.75	32.96	**0.000**	29.94	32.11	**0.007**
Medicine ball throw from kneeling 1kg [m]	I–II	0.77	1.02	**0.014**	-0.13	1.02	0.666
	II–III	0.30	0.98	0.258	0.80	1.15	0.060
	I–III	1.07	0.99	**0.003**	0.67	1.63	0.119
Medicine ball tapping [s]	I–II	0.04	0.50	0.851	0.02	0.02	**0.014**
	II–III	0.23	0.37	**0.038**	0.32	0.62	0.176
	I–III	0.27	0.35	**0.008**	0.33	0.62	0.116
MMA medicine ball tapping	I–II	-3.06	23.98	0.679	12.10	14.23	**0.009**
	II–III	5.34	20.23	0.208	10.91	32.78	0.470
	I–III	2.28	17.24	0.421	23.01	28.02	**0.012**
Relative MMA medicine ball tapping	I–II	-0.01	0.38	0.847	0.19	0.23	**0.005**
	II–III	-0.19	0.29	**0.025**	-0.14	0.42	0.301
	I–III	-0.20	0.27	**0.010**	0.05	0.32	0.674
10 x 3-meter shuttle run [s]	I–II	-0.49	0.56	**0.008**	-0.29	0.47	0.077
	II–III	0.05	0.52	0.820	-0.49	0.63	**0.012**
	I–III	-0.44	0.57	**0.013**	-0.78	0.59	**0.005**
MMA 10 x 3-meter shuttle run [W]	I–II	225.8	309.9	**0.015**	84.6	147.4	0.129
	II–III	103.7	288.2	0.252	372.8	319.7	**0.002**
	I–III	329.5	304.6	**0.002**	457.4	268.8	**0.001**
Relative MMA 10 x 3-meter shuttle run [W/kg]	I–II	3.75	4.75	**0.012**	1.33	2.51	0.129
	II–III	-0.42	4.40	0.847	3.90	4.33	**0.005**
	I–III	3.33	4.31	**0.016**	5.23	3.65	**0.002**
Beep Test [m]	I–II	60.0	115.9	**0.022**	508.33	436.6	**0.003**
	II–III	426.7	219.7	**0.001**	181.67	380.2	0.056
	I–III	486.7	241.9	**0.001**	690.0	279.8	**0.003**
30-meter sprint [s]	I–II	0.10	0.14	**0.014**	-0.02	0.14	0.553
	II–III	-0.16	0.17	**0.006**	-0.03	0.23	0.695
	I–III	-0.05	0.10	0.094	-0.05	0.29	0.766
10-meter sprint [s]	I–II	-0.01	0.05	0.470	0.00	0.06	0.788

Variables	Measurement	EXP Group (n = 15)			CON Group (n = 12)		
		$\tilde{x}$	SD	p	$\tilde{x}$	SD	p
	II–III	-0.02	0.04	**0.038**	-0.03	0.05	0.059
	I–III	-0.03	0.04	**0.016**	-0.03	0.07	0.182
Static handgrip strength measurement [kG]	I–II	2.87	3.81	**0.019**	2.08	2.97	**0.013**
	II–III	2.87	5.50	0.110	1.75	0.62	**0.002**
	I–III	5.73	6.06	**0.003**	3.83	3.10	**0.003**
Sit-ups [number of repetitions in 30 seconds]	I–II	1.00	3.00	0.193	4.0	3.28	**0.005**
	II–III	5.93	5.60	**0.001**	-1.5	3.61	0.143
	I–III	6.93	3.77	**0.001**	2.5	4.15	0.099

$\tilde{x}$—arithmetic mean; **SD**—standard deviation; **I**—first measurement period (pre-test); **II**—second measurement period (post-test 1); **III**—third measurement period (post-test 2); ***p***—level of significance.

4. Discussion

The study results present the impact of the experimental training program on the motor fitness profile of handball players, in a comparative analysis with the traditional training approach. The use of two different training protocols allowed for an evaluation of the effectiveness of innovative training methods and their comparison with the standard program. The analysis of test results reveals several significant differences between the experimental group (EXP) and the control group (CON), indicating clear benefits from the application of modern training stimuli.

Finally (pretest vs. posttest 2), in the context of the analyzed motor fitness parameters, the EXP group's results showed significantly greater progress compared to the CON group. Noticeable within-group improvements appeared in almost all test outcomes (except for the 30-meter sprint test) and in most operational indicators (MPA, MMA, R-MMA). These results indicate that the applied experimental training stimulus contributed to an increase in the athletes' overall physical fitness, particularly in anaerobic, aerobic, strength, strength-speed, and strength endurance abilities, as measured by the population tests. This also points to better training adaptation and related progression of the athletes under the innovative training stimuli conditions [22]. In particular, the beep test, which is an indirect measure of aerobic endurance, showed interesting results in the study. Both groups recorded significant progress, but by the final assessment (posttest 2), the CON group's result was significantly weaker compared to the EXP group's performance. A similar trend was observed for strength endurance (sit-up test), as confirmed by the analysis of intergroup variation in relation to the intervention groups (Table 2). These differences suggest that while traditional training is effective to some extent, it may not provide sufficient stimulation for optimal development of key motor skills when compared to more individualized and modern training methods [23]. The differences in the effectiveness of the two training programs were clear, particularly in the context of anaerobic power and muscular endurance. The EXP group significantly outperformed the CON group in strength and strength-speed tests, which may be the result of specific adaptations to the experimental training stimuli, which were more focused on improving strength and power [24, 25]. High maximum anaerobic power (MMA) values and their relative form (R-MMA) achieved in the running tests and the medicine ball tapping in the EXP group suggest that the applied program was more effective in developing the ability to quickly generate power, which is crucial for dynamic and short-duration activities typical in handball [26]. Statistical analysis revealed that these differences were not only significant but also had a substantial impact on overall athletic performance. The EXP group achieved better results in tests such as the 10 × 3 m run and the beep test, which are reliable indicators of anaerobic and endurance capacity [27]. These results suggest that athletes in the experimental group adapted better to intense and repeatedly performed activities, which are key in team sports.

After just 13 weeks of applying the experimental training program (pretest vs. posttest 1), the EXP group showed significant improvement in five tests and two indicators (Table 3), which assessed areas such as explosive power (kneeling throw), agility-speed hybrid [28], running speed (shuttle run, 30-meter sprint, and MMA, R-MMA indicators), aerobic endurance (beep test), and maximum static forearm strength (hand dynamometry). This demonstrates significant improvements already midway through the experimental procedure, providing both scientifically insightful and practical information for all involved in training environments (coaches, assistants, instructors, athletes). In the CON group, which followed standard training protocols, performance improvements were also observed; however, these changes were less pronounced and often did not reach statistical significance. This suggests that traditional training methods, while beneficial, may not be sufficiently effective at every stage of periodization for optimizing key motor abilities crucial for peak training and competition performance [29]. Similar observations were made in studies by Hermassi et al., where traditional strength training was compared with a more individualized approach involving tapering after intensive resistance training. The results showed that the control group, which followed standard training, also improved, but to a lesser extent compared to the experimental group, which followed a modified training plan [23]. Moreover, research by Saez de Villareal et al. [22] confirms that incorporating modern training methods, such as plyometric or eccentric training, leads to significantly greater gains in strength and power compared to traditional programs. The results of this study indicate that innovative approaches, which include dynamic stimuli, result in greater improvement in key fitness indicators, whereas traditional training often does not provide enough stimulation for maximum adaptation of athletes' motor potential [22].

Finally, in the second phase of the training intervention (posttest 1 vs. posttest 2), further significant progress was observed in selected aspects of motor fitness (five strength-speed and endurance tests) and indicators (operationalizing the dimension of anaerobic capacity) within the experimental group (Table 3). This underscores the appropriateness of the duration of the experimental intervention. Breaks in training due to calendar holidays and celebrations may also have contributed to this phenomenon, as the recovery phase and, consequently, the supercompensation phase [30] could have led to strong training adaptations [31].

The obtained results highlight the importance of modern training methods, which may serve as a valuable supplement or alternative to traditional training programs. The use of experimental training stimuli, which place greater emphasis on the development of anaerobic power, strength endurance, and the ability to generate power quickly, can bring significant benefits, particularly in sports such as handball, where short-term, high-intensity actions are critical [32, 33]. This study emphasizes that innovative training methods not only enhance physical performance but may also contribute to reducing the risk of overtraining by better adjusting training intensity and volume to the athletes' needs. Moreover, increased individualization of training allows for more efficient utilization of athletes' motor abilities, leading to better adaptation to the specific demands of their sport.

Study Limitations

However, certain limitations which may affect the interpretation of the study's findings should be noted. Firstly, the relatively small sample size and the specific profile of the participants (handball players) may limit the generalizability of the results to other athlete populations. Additionally, the lack of long-term follow-up after the intervention makes it impossible to assess the durability of the observed changes, which is an important aspect when evaluating the effectiveness of training programs. Moreover, the sample consisted exclusively of male teenage players. It is recommended that training programs be individualized based on player positions on the field, with personalized training content tailored to their specific roles. This poses a significant methodological challenge for future research and could contribute to further development of the sport. Future studies should also explore the validation of these findings in more diverse samples, including different age groups, genders, and other team sports.

5. Conclusions

The implemented experimental training program demonstrated an effective impact on the motor fitness profile of young handball players across a wide range of areas, including anaerobic, aerobic, strength, strength-speed, and strength-endurance abilities. Notably, improvements in strength-speed, strength, and endurance capacities were observed as early as 13 weeks into the program, with further progress recorded in the second half of the experiment. The scientific literature has shown a lack of exploration in this area, and these findings scientifically confirm that the time frame used (32-week training period) and the applied training stimulus in this study are both appropriate and highly effective in achieving significant progress in motor fitness competencies.

Practical Implications

Given the demonstrated effectiveness of the 32-week experimental training program in shaping and improving motor fitness profiles, it is recommended for application in training practices, including for other age groups and female athletes. It is also recommended that this program be modified for use in other team sports, where comprehensive motor fitness forms the foundation of training and competition activities and determines athletic performance outcomes.

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