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The Role of Kinesiotherapy in Enhancing Physical Performance and Self-Esteem: A Prospective Observational Study in Obese Adolescents

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Abstract: Obesity is a multifactorial chronic condition characterized by excessive fat accumulation, which adversely affects health and quality of life. This prospective observational study aimed to evaluate the impact of a 9-month tailored kinesiotherapy program on physical performance, body composition, and self-esteem in overweight and obese adolescents. Participants were divided into a study group (SG, n=40) and a control group (CG, n=40). The SG engaged in individualized kinesiotherapy sessions, while the CG maintained their usual activities. Both groups received education on the 5-2-1-0 rule for obesity prevention and management. Results indicated significant improvements in the SG, including enhancements in the 6-minute walk distance (6MWD), Timed Up-and-Go test (TUG), and Rosenberg Self-Esteem Scale (all $p < 0.001$). Notably, BMI and body fat percentage decreased significantly in the SG compared to the CG. Regression analysis revealed strong correlations between body composition, physical performance, and self-esteem improvements, particularly in girls and rural participants, highlighting the intervention's adaptability and effectiveness. Although limited by a relatively small sample size, short duration, and variability in adherence tracking, the study highlights the essential role of individualized physical activity programs in improving health outcomes. In conclusion, the findings from our study emphasize the significant role of individualized kinesiotherapy programs in improving physical and psychological health outcomes in overweight/obese adolescents. By integrating instrumental assessments, such as the BTS system, with subjective evaluations like PAQ-A and the Rosenberg scale, our study high-lights the multifaceted impact of physical activity on this vulnerable population.

Keywords: obese adolescents; kinesiotherapy program; body composition

1. Introduction

Obesity is a multifactorial chronic condition characterized by excessive fat accumulation, which adversely affects health and quality of life. Recognized as a serious public health issue by the World Health Organization (WHO), obesity significantly increases the risk of type 2 diabetes, cardiovascular diseases, and certain cancers [1-5]. For adolescents, obesity often comes with additional challenges, including compromised mental health, reduced self-esteem, and heightened social stigma, necessitating effective interventions. Among these, physical therapy (PT) has shown significant promise in improving both physical performance and psychological well-being. Physical activity is a vital non-pharmacological therapy that benefits multiple pathologies. It improves cardiovascular health, enhances metabolic regulation in diabetes and obesity, and alleviates pain in musculoskeletal disorders [6–10]. Exercise promotes neuroplasticity in neurological conditions [11], aid cancer survivors and patients with autoimmune or endocrine disorders by reducing fatigue, enhancing function, and modulating immune and hormonal responses [12,13]. Physical activity reduces BMI and body fat through a combination of cellular mechanisms, including enhanced lipolysis, fat oxidation, mitochondrial function, and adipose tissue browning. It also modulates inflammatory cytokines, improving the metabolic profile [14-16]. There are authors who identified variability in outcomes depending on exercise intensity and duration. While high doses showed greater benefits, studies using moderate exercise regimens had limited impact on body composition and central fat [17]. Aerobic and resistance exercises stimulate mitochondrial biogenesis via PGC-1α activation, enhancing muscular efficiency and endurance [18]. Additionally, reductions in systemic inflammation, evidenced by decreased levels of cytokines such as IL-6 and TNF-α, contribute to better physical functioning [19]. Physical therapy directly enhances physical capabilities in obese adolescents, with measurable improvements in endurance, mobility, and physical activity engagement. Reliable tools such as the 6-Minute Walk Distance (6MWD), the Timed Up and Go (TUG) Test, and the Physical Activity Questionnaire for Adolescents (PAQ-A) are commonly used to quantify these effects. The 6MWD is a widely utilized submaximal test to assess functional endurance. Structured PT programs have been shown to significantly enhance 6MWD scores in obese adolescents, reflecting improved cardiovascular and muscular endurance [18]. For instance, a 12-week aerobic exercise program resulted in a 15–20% improvement in walking distance compared to non-active controls [20]. The TUG test, which evaluates balance and mobility, demonstrates similar benefits. Adolescents involved in PT programs that integrate resistance and aerobic training consistently exhibit reduced TUG times, indicative of enhanced lower-body strength and agility [21]. Such improvements are vital for increased independence and reduced injury risk in daily activities. The PAQ-A offers insight into adolescents' weekly physical activity levels. PT interventions typically lead to higher PAQ-A scores, signifying increased participation in physical activities [22]. Elevated PAQ-A scores correlate strongly with better energy expenditure and weight management. Beyond physical health, PT interventions offer profound psychological benefits, addressing issues like low self-esteem, anxiety, and depression. These outcomes are often assessed using tools such as the Rosenberg Self-Esteem Scale and other mental health questionnaires. The psychological effects of PT are rooted in physiological changes:

- Brain-Derived Neurotrophic Factor (BDNF): Regular exercise boosts BDNF levels, promoting neurogenesis and synaptic plasticity in the hippocampus, which improves cognitive function and emotional resilience [23].
- Regulation of the Hypothalamic-Pituitary-Adrenal (HPA) Axis: PT modulates HPA activity, reducing cortisol secretion and enhancing stress management [24].
- Sleep Quality Improvements: Obese individuals often experience poor sleep, exacerbating mental health issues. Exercise helps regulate sleep patterns, contributing to improved mood and cognitive function [25].

Some researchers pointed out that risk of bias in studies and indirectness of outcomes undermine generalizability and some interventions failed to show consistent improvements in psychological measures like self-esteem [26]. Despite this findings, most authors considered physical therapy significantly boosts self-esteem among obese adolescents. Programs that combine aerobic, resistance, and recreational activities have demonstrated marked improvements in Rosenberg scores, reflecting enhanced body image and self-worth [27, 28]. A 10-week PT regimen featuring group-based exercises yielded a 25% increase in Rosenberg scores, showcasing its efficacy [29]. Physical activity triggers the release of endorphins and reduces cortisol levels, alleviating symptoms of anxiety and depression [30]. Adolescents engaging in consistent PT report better mood stability and reduced psychological distress, with longitudinal studies indicating a 30% reduction in anxiety scores post-intervention [31].

Group-based PT sessions promote social interaction, teamwork, and a sense of belonging. Improved physical performance enhances adolescents' ability to engage in peer activities, fostering social competence and mitigating feelings of isolation [32, 33]. Physical therapy's multifaceted approach addresses not only physical impairments but also mental health challenges, creating a comprehensive obesity management strategy. Aerobic exercises like walking, jogging, and swimming form the foundation of PT programs, targeting cardiovascular health and endurance [34]. Resistance training aids muscle strength and metabolic improvement [35]. Additionally, recreational activities such as volleyball or badminton encourage social interaction and alleviate the monotony of traditional exercises [36]. Family and community support amplify the benefits of PT. Family-based activities foster adherence to exercise routines, while community programs create opportunities for inclusive participation [37]. This collective support system is critical for sustaining long-term outcomes. The benefits of PT extend beyond adolescence. Improved physical performance and self-esteem lead to healthier lifestyle choices, better academic achievements, and higher socio-economic status in adulthood [19]. Integrating physical therapy with behavioral and nutritional interventions can maximize outcomes. Emerging technologies such as wearable devices and mobile applications offer real-time feedback and motivation, enhancing adherence and engagement [22]. Research into personalized PT protocols based on genetic and metabolic profiling may further refine intervention strategies. The objective of this prospective observational study is to combine instrumental measures and self-reported assessments to provide a comprehensive evaluation of both the physical and psychological impacts of a structured kinesiotherapy program. This dual approach aims to enable practitioners to track tangible improvements in physical performance and body composition while addressing the subjective experiences and self-esteem of overweight and obese adolescents.

2. Materials and Methods

2.1. Design Overview

A prospective observational study was conducted in the Pediatrics and Physical Medicine and Rehabilitation Departments of Filantropia Hospital, Craiova, between January 2022 and June 2024. A total of 80 overweight and obese adolescents aged 13 to 15 years, without other pathological conditions, were evaluated clinically, paraclinically, and functionally by a multidisciplinary team at baseline (T1). Participants were divided into two groups based on their expressed willingness to engage in daily additional physical activity:

- Study Group (SG): 40 adolescents;
- Control Group (CG): 40 adolescents.

The adolescents in the SG participated in a tailored physical exercise program adapted to their age group and compliance levels, integrated into their daily routines over a period of 9 months. In contrast, the CG maintained their regular daily activities without additional physical exercise.

To evaluate the effects of the kinesiotherapy program, a follow-up assessment was conducted 9 months after the initial evaluation (T2). Outcomes were measured and compared between the two groups using: Six-Minute Walk Distance (6MWD), Timed Up and Go (TUG) Test, Physical Activity Questionnaire for Adolescents (PAQ-A), Rosenberg Self-Esteem Scale (RSE).

Results were reported as means, standard deviations (SDs), and p-values between groups. Effect sizes were calculated, and a power analysis confirmed that the study was sufficiently powered to detect meaningful differences in the measured outcomes. Additionally, subgroup analyses by gender and background were conducted to ensure consistency and internal validity. For statistical accuracy, only participants who completed both evaluations, attended at least 80% of the kinesiotherapy sessions, and provided valid data were included in the final analysis (Figure 1). In the SG, 35 children (87.5%) completed the prescribed program and attended the follow-up evaluation, while in the CG, 37 children (92.5%) completed the follow-up evaluation.

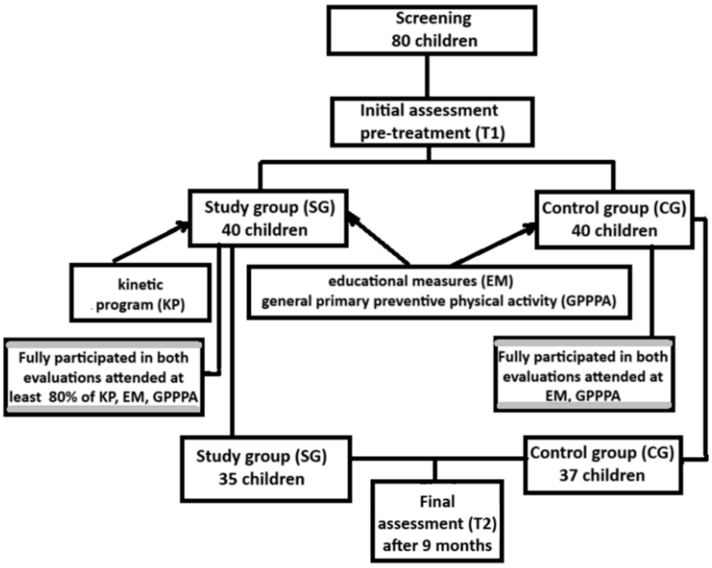

Figure1. Diagram of the study design.

2.2. Participants

Inclusion Criteria: (a) Written informed consent provided by a parent or guardian, along with verbal assent from the child, (b) children aged 12 to 18 years, (c) Body Mass Index (BMI) greater than 30.00 kg/m^2, (d) Clinically assessed as healthy by a pediatric specialist, (e) Ability to understand and communicate in national language, (f) No prior experience with kinesiotherapy, (g) No participation in sports activities (outside of regular school activities).

Exclusion Criteria: (a) Presence of any psychiatric disorders confirmed by a medical specialist, (b) Recent traumatic injuries or/and (c) Diagnosed orthopedic, respiratory, or neurological conditions that could impede participation in physical activities (for SG childs), (d) Lack of compliance or willingness to engage in a daily kinesiotherapy program (for subjects involved in SG), (e) The inability to understand or adhere to the dietary guidelines established by the medical team.

Following these criteria, eligible adolescents and their parents or guardians were fully informed about the study objectives and procedures and were provided with the necessary informed consent forms.

During the recruitment period, only children aged 13–15 were addressed to the hospital, and all those who met the inclusion and exclusion criteria were enrolled consecutively.

2.3. Study Treatment

For the SG, kinesiotherapy was initiated at the Physical Medicine and Rehabilitation Department under the supervision of a specialized physiotherapist. Participants were encouraged to engage in daily physical activities that were easy to perform without disrupting their regular daily routines.

The kinesiotherapy program was patient-centered, taking into account each child's activity behavior, which was assessed using the Compendium of Physical Activities developed by Ainsworth et al. [38]. Strength exercises were not recommended, as the participants were under 16 years of age [39].

Progress was monitored weekly by the same physiotherapist to ensure correct execution of exercises. The program primarily focused on flexibility, stretching, and adapted strength training tailored to the age and abilities of the participants.
Table 1 outlines the recommended program model, which was flexible and did not require a fixed order of activities. However, participants were instructed to perform aerobic exercises every two days, ensuring they were not done on consecutive days. On alternate days, they performed stretching and adapted strength training exercises.

Table 1. Model of a Kinesiotherapy Program (Adapted Physical Training)

Day	Activity Type	Description
Monday	Aerobic Exercise	Cycling / jogging at a comfortable pace; 30 – 60 minutes
Tuesday	Adapted Strength Training	Bodyweight exercises; 20- 30 minutes 2 – 3 sets for each exercise Squats - Stand with feet shoulder-width apart, lower the body as if sitting back into a chair, keeping the chest up and knees behind toes, 8-12 repetitions / set. Wall Sit - Stand with back against a wall, slide down until thighs are parallel to the ground, hold the position 15 – 30 seconds / set. Lunges - Step forward with one leg, lowering the hips until both knees are bent at about a 90-degree angle, then return to standing; 5-10 repetitons/ leg / set.
Wednesday	Flexibility & Balance	Stretching exercises, 20 – 30 minutes. Each exercise repetead for 5 times Neck Stretch- Sit or stand tall, gently tilt the head to one side, bringing the ear toward the shoulder. Hold for 15-30 seconds, then switch sides. Shoulder Stretch - Bring one arm across the body at shoulder height, using the opposite arm to gently pull it closer to the chest. Hold for 15-30 seconds, then switch sides. Chest Stretch - Stand with feet shoulder-width apart, clasp hands behind the back, and gently pull the arms back while lifting the chest. Hold for 15-30 seconds. Hamstring Stretch - Sit on the floor with one leg extended and the other bent. Reach toward the toes of the extended leg, keeping the back straight. Hold for 15-30 seconds, then switch legs. Calf Stretch - Stand facing a wall, place one foot behind the other, and lean forward, keeping the back leg straight and heel on the ground. Hold for 15-30 seconds, then switch legs.
Thursday	Aerobic exercise	Playing a sport 60 minutes (ball games)
Friday	Adapted Strength Training	Bodyweight exercises; 20 – 30 minutes (described above)
Saturday	Aerobic Exercise	Swimming / movements in water 30 – 60 minutes
Sunday	Fun Activity	Family walks - 60 minutes / dancing 30 minutes

The medical team from the Pediatrics Clinic supervised all adolescents included in the study, ensuring adherence to dietary guidelines throughout the study period. Participants were instructed to follow the 5-2-1-0 rule, which recommends: 5 servings of fruits and vegetables per day, 2 hours or less of screen time daily, 1 hour of physical activity per day, 0 sugar-sweetened beverages [40]. Additionally, the Physical Medicine and Rehabilitation team guided all participants to maintain compliance with school-based health education interventions, which are considered essential not only for managing BMI but also for promoting a healthy lifestyle [41].

2.4. Ethical Considerations

This study prioritized the safety and well-being of all participants. Eligible adolescents and their parents were thoroughly informed about the study, including its purpose, potential benefits, possible risks, and the confidentiality of personal information. They were also made aware of their right to withdraw from the study at any time without providing a reason or facing any negative consequences.

Parents or guardians provided written informed consent after receiving a clear explanation of these details. The study followed the principles outlined in the Declaration of Helsinki and Good Clinical Practices and was approved by the Ethics Committee (approval no. 38/01 March 2022).

2.5. Parameters and Measurements

The following parameters were assessed in the study: anthropometric data, subjective and objective physical performance tests, and self-assessment of self-esteem.

2.5.1. Anthropometric Data

The anthropometric measurements included height, weight, Body Mass Index (BMI), and body fat percentage (Body Fat %).

- Weight (kg) was measured using an electronic scale with a range of 0–150 kg and an accuracy of 100 g.

- Standing height (m) was measured with a portable stadiometer, accurate to 0.1 mm. During measurements, children were barefoot and wore minimal clothing (a light shirt and shorts). All anthropometric variables were assessed twice by the same evaluator to ensure accuracy.

-BMI was calculated using the standardized formula. Based on BMI, age, and sex, the thresholds for overweight and obesity were determined using internationally recognized cut-off points [42]. Although BMI percentiles were verified for each child using a standard online tool ([CDC BMI Calculator] (https://www.cdc.gov/healthyweight/bmi/calculator.html)), these percentiles were not included in the data analysis. Both groups consisted of children classified as overweight (85th < 95th percentile) or obese (>95th percentile), with no participant exceeding the 98th percentile [43].

- Body Fat Percentage (Body Fat %) was measured using bioimpedance analysis (BIA) with the Omron Healthcare BIA device. This method provides a quick estimation of body composition by passing a low-frequency electrical current through the body and measuring impedance. As fat and muscle tissue have different conductivities, this technique allows for the monitoring of changes in body composition over time.

To minimize variability and ensure accurate results, the bioimpedance analysis was conducted under standardized conditions: at the same time of day, following similar food intake patterns, at least a few hours after any physical activity. The measurements were performed by the same evaluator, and results were interpreted using standardized values adjusted for age and sex [44].

2.5.2. Physical Performance Tests

Physical performance was assessed through gait analysis using the BTS G-WALK/BTS G-SENSOR 2 wireless system (BTS Bioengineering Corp., Italy). This system features an inertial sensor comprising a triaxial accelerometer, a magnetic sensor, and a triaxial gyroscope. Worn by the patient, it enables a comprehensive functional gait analysis. Two tests were used to evaluate functional status: 6MWD and TUG. These parameters were chosen for the following reasons:

- 6MWD: this test is valuable because it is easy to administer, requires no specialized equipment, is well-tolerated by children, and provides essential information about their exercise capacity [45].
- TUG: this test is crucial for assessing mobility and balance in overweight or obese adolescents, offering insights into their risk of falls. Additionally, it provides accurate data on gait stability, transitions from sitting to standing, and changes in walking direction [46].

Each child was given detailed instructions on how to perform the tests correctly and was familiarized with the equipment. Standardized verbal encouragement was provided throughout the tests to ensure maximum effort:

- TUG: in this test, the child begins seated on a chair. They are instructed to: 1. Stand up from the chair. 2. Walk 3 meters at a safe, comfortable pace to a marked line. 3. Cross the line, turn around, and return to the chair. 4. Sit back down without assistance. The total time taken to complete the task was recorded.
- 6MWD: the 6MWD test was conducted indoors along a 20-meter corridor, marked every 2 meters with brightly colored tape. The start and end points were indicated by two cones. Each child was tested individually and instructed to walk as far as possible within 6 minutes. Standardized encouragement, such as "keep going" or "you're doing well," was provided, along with time updates to help maintain motivation. The total distance walked during the six minutes was recorded.

2.5.3. Subjective Assessment of Physical Performance

This method offers a simple and effective way to quantify general activity levels in adolescents. Subjective evaluation of physical performance was conducted using the PAQ-A. This is a self-administered, 7-day recall questionnaire designed to measure moderate to vigorous physical activity levels during the school year. The PAQ-A provides a summary physical activity score based on eight items, each rated on a 5-point scale. Participants assigned a score from 1 to 5 for each of the eight items. The final PAQ-A activity score was calculated as the average of these eight item scores.

A score of: 1 indicates low physical activity, while 5 indicates high physical activity [47,48].

2.5.4. Self-Esteem Assessment

Each child's self-esteem was assessed using the RSE, a 10-item scale designed to measure overall self-esteem. Participants responded to each statement based on how strongly they agreed or disagreed, choosing from: Strongly agree, Agree, Disagree, or Strongly disagree.

Score Interpretation: the total score ranges from 0 to 30: 15 to 25-Normal self-esteem range; Below 15- Low self-esteem [49,50].

2.6. Statistical Analysis

Collected data were inserted into a Microsoft Excell spreadsheet. Statistical analysis was performed using Microsoft 365 Excel and SPSS version 26.0. All data were presented using mean and Standard Deviation (SD) for continuous data and, and percentages for categorical data (such as gender and environmental). In this study, we utilized the Wilcoxon test, a non-parametric statistical method, to compare two related samples. This test is particularly effective when the data does not meet the assumptions of normality required for parametric tests, allowing us to assess whether the median difference between paired observations is significantly different from zero. A low p-value (again, typically less than 0.05) indicates that the median difference between the paired observations is significantly different from zero, suggesting a meaningful change or effect.

The formula for calculating the required sample size for the Wilcoxon signed-rank test is based on the expected effect size and the desired power of the test. A commonly used formula for estimating the sample size for non-parametric tests like the Wilcoxon signed-rank test is:

$$N = \frac{Z\,\alpha\,/\,2+Z\,\beta}{d}$$

In this formula, N is the required sample size per group; $Z\alpha/2 = 1.96$ (alpha = 0.05) is the z-score corresponding to the desired significance level (alpha); $Z\beta = 0.84$ (for 80% power) is the z-score corresponding to the desired power (1 - beta); d = 0.843 is the expected effect size (the calculated average effect size of approximately 0.843 indicates a strong relationship between the specified parameters - BMI, body fat, PAQ, Rosenberg, 6MWD, and TUG - in the "Study subjects")

The required sample size for the Wilcoxon signed-rank test, calculated using the provided values, is approximately 12 participants per group. This confirms that the earlier estimate aligns with the calculations based on the effect size and desired power.

Additionally, we employed Spearman correlation to analyze the relationships between variables due to its suitability for non-parametric data and ordinal variables. This method does not assume a normal distribution and effectively captures the strength and direction of monotonic relationships by ranking the data. It ranges from -1 (a perfect negative correlation) to 1 (a perfect positive correlation).

Also, the regression analyses were conducted to explore the relationships between various physical and psychological measures.

Together, these methods provide robust insights into the relationships and differences within our dataset.

Research manuscripts reporting large datasets that are deposited in a publicly available database should specify where the data have been deposited and provide the relevant accession numbers. If the accession numbers have not yet been obtained at the time of submission, please state that they will be provided during review. They must be provided prior to publication.

Interventionary studies involving animals or humans, and other studies that require ethical approval, must list the authority that provided approval and the corresponding ethical approval code.

3. Results

3.1. The Demographic and Anthropometric Data

The demographic characteristics of the participants included in the study are summarized in **Table 2**. The mean age of the two groups was similar: 13.2 years for the SG and 12.83 years for the CG, with no significant differences (p=0.2148). All patients fell within the 13–15 age range in both groups.

Table 2. Anthropometric data at the T1 moment

	Study Group (SG) n = 35 children	**Control Group (CG)** n = 37 children	**p value**
Age (years)	13.2 ± 0.91	12.83 ± 3.35	0,2148
Boys	22 (49 %)	17 (46 %)	0.3721
Girls	23 (51 %)	20 (54 %)	0.1572
Urban	22 (%)	21 (56 %)	0.3724
Rural	23 (%)	16 (44%)	0.4123
Weight (kg)	64.66 ±5.62	58.36 ±19.33	0.3980
Height (cm)	153.13 ±10.80	146.46 ± 20.20	0.4460
BMI	30.79 ± 8.63	29.84 ± 7.65	0.2736

Variables are reported as mean (SD) (standard deviation), n=number of subjects, BMI=Body Mass Index; t-test for independent samples.

The urban/rural ratio was 22/23 (0.95) for SG and 17/13 (1.30) for CG, with no statistically significant differences (p=0.3724 for urban, p=0.4123 for rural participants). Regarding gender distribution, SG included 23 girls (51%) and 22 boys (49%), while CG had 16 girls (54%) and 14 boys (46%). The girl-to-boy ratio was similar across groups, with no significant differences (p=0.3721 for girls, p=0.1572 for boys).

Participants were classified into overweight and grade 1 obesity categories based on BMI:

- SG: 11 girls and 12 boys were overweight, while 12 girls and 10 boys had grade 1 obesity.
- CG: 7 girls and 9 boys were overweight, while 9 girls and 5 boys had grade 1 obesity.

The p-value (p=0.2736) indicates no statistically significant differences in BMI classification between groups, supporting the homogeneity of the study groups.

Additionally, an analysis of BMI by gender and residence showed no statistically significant differences (p > 0.1), indicating that residential area had no influence on BMI.

3.2. Study Group, time- evolution:

The results indicate significant differences between the initial and final measurements for all parameters tested. We observed distinct differences in the magnitude of changes between boys and girls across parameters (**Figure 2**).

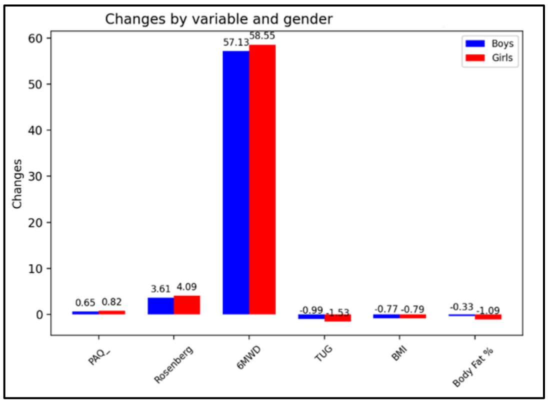

Figure 2. Changes in the Mean Values of Parameters for the SG by Gender (Girls/Boys) PAQ=Physical Activity Questionnaire for Adolescents; Rosenberg=Rosenberg Self-Esteem Scale; 6MWD=6 Minutes Walking test; TUG=Up and Go Test; BMI=Body Mass Index; Body Fat %=Body Fat Percentage; Histogram.

Notably, girls exhibited a greater increase in Rosenberg self-esteem scores and 6MWD, with changes of approximately 4.09 (p = 0.0032) and 58.55 (p = 0.0026) respectively, compared to boys who showed changes of 3.61 (p = 0.0041) and 57.13 (p = 0.0144) in the same parameters. Conversely, boys demonstrated a slightly greater reduction in TUG and Body Fat %, decreasing by about 0.99 seconds (p = 0.0145) and 0.33% (p=0.0136) respectively, whereas girls showed reductions of 1.53 seconds (p=0.0012) and 1.09% (p=0.0027).

We observed notable differences across several parameters between urban and rural settings (Figure 3). The rural group exhibited a more pronounced improvement in the Rosenberg self-esteem scores and the 6MWD, with increases of approximately 4.13 (p=0.0013) and 59.83 (p=0.0026) respectively, compared to the urban group, which showed increases of 3.55 (p=0.0051) and 55.73 (p=0.0071) in these parameters. Conversely, the urban group demonstrated slightly smaller reductions in the TUG and Body Fat%, decreasing by about 1.18 seconds (p=0.0051) and 0.72% (p=0.0063) respectively, whereas the rural group showed reductions of 1.32 seconds (p=0.0017) and 0.68% (p=0.0014).

3.3. Control group, time- evolution:

For the control group (CG), statistically significant differences were observed only for Body Fat % ($p < 0.001$), BMI ($p < 0.001$), and the Rosenberg Self-Esteem Scale ($p < 0.001$), although the mean values at the two evaluation points were relatively similar (**Table 3**).

Table 3. Mean Values of Evaluated Parameters (T1, T2, T1/T2)

	Study Group (SG)			**Control Group (CG)**			**T1 p-values between SG / CG**	**T2 p- values between SG /CG**
	T1 Mean (SD)	**T2** Mean (SD)	**p-value SG T1/ T2**	**T1** Mean (SD)	**T2** Mean (SD)	**p-value CG T1/T2**		
BMI	28.61 ± 3.66	27.83 ± 3.48	p < 0.001	30.73 ± 3.32	30.43 ± 5.50	p < 0.001	p = 0.011	p = 0.0010
Body Fat %	36.18 ± 3.56	35.48 ± 3.31	p < 0.001	38.29 ± 2.53	38.12 ± 2.57	p < 0.001	p = 0.003	p = 0.0013
6MWD	490.11 ± 47.79	547.93 ± 46.44	p < 0.001	501.46 ± 48.38	502.86 ± 48.21	0.078	p = 0.321	p < 0.001
TUG	14.82 ± 1.64	13.57 ± 1.45	p < 0.001	16.16 ± 18.83	17.62 ± 18.44	0.137	p = 0.218	p < 0.001
PAQ	2.57 ± 0.49	3.31 ± 0.55	p < 0.001	2.46 ± 0.50	2.73 ± 0.47	0.271	p = 0.354	p < 0.001
RSE	13.64 ± 1.46	17.48 ± 1.99	p < 0.001	13.7 ± 1.14	15.6 ± 1.59	p < 0.001	p = 0.002	p < 0.001

SD = Standard Deviation; BMI=Body Mass Index; Body Fat %=Body Fat Percentage; 6MWD=6 Minutes Walking test; TUG=Up and Go Test; PAQ=Physical Activity Questionnaire for Adolescents; RSE=Rosenberg Self-Esteem Scale; The Wilcoxon test used for p value.

3.4. SG versus CG:

At baseline, significant differences were observed between the two groups for BMI ($p = 0.011$), Body Fat % ($p = 0.003$), and RSE scores ($p = 0.002$). However, no significant differences were found for PAQ ($p = 0.354$), 6MWD ($p = 0.321$), or TUG ($p = 0.218$).

After 9 months, a comparison of the mean values between the two groups revealed that the SG showed significantly greater improvements across all studied parameters ($p < 0.01$) compared to the CG (**Table 3, Figure 3**).

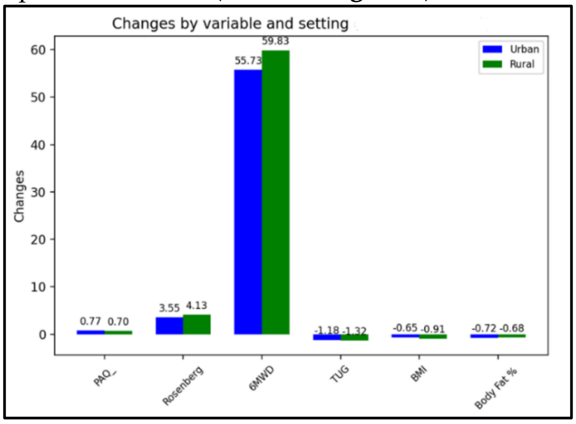

Figure 3. Changes in the Mean Values of Parameters for the SG by Area of Residence (Rural/Urban)

PAQ=Physical Activity Questionnaire for Adolescents; Rosenberg=Rosenberg Self-Esteem Scale; 6MWD=6 Minutes Walking test; TUG=Up and Go Test; BMI=Body Mass Index; Body Fat %=Body Fat Percentage; Histogram.

The changes in the mean values of the studied parameters from T1 to T2 were different for the two groups, as summarized below (**Figure 4**):

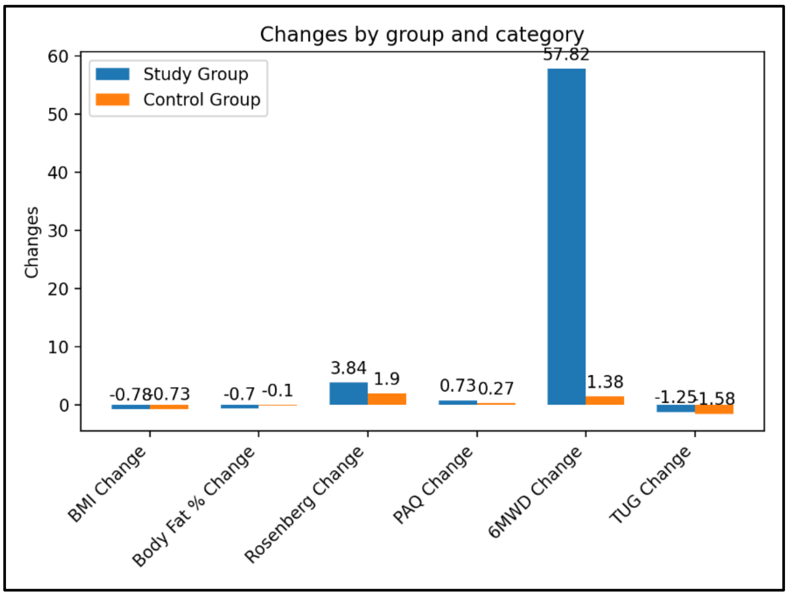

Figure 4. Changes in the Mean Values of Parameters for the Two Groups
PAQ=Physical Activity Questionnaire for Adolescents; Rosenberg=Rosenberg Self-Esteem Scale; 6MWD=6 Minutes Walking test; TUG=Up and Go Test; BMI=Body Mass Index; Body Fat %=Body Fat Percentage; Histogram.

- BMI: The SG showed a decrease in BMI from initial to final measurements (mean change: -0.78), while the CG remained relatively stable. This suggests that the intervention had a positive impact on weight management in the SG.
- Body Fat %: Both groups exhibited a reduction in body fat percentage. However, the SG achieved a slightly greater improvement (mean change: -0.70) compared to the CG. This highlights the effectiveness of the intervention in managing body composition in the SG.
- RSE: The SG experienced a significant increase in Rosenberg scores (mean change: +3.84), reflecting improved self-esteem. The CG showed only a slight improvement (mean change: +1.9), suggesting that the intervention in the SG positively influenced psychological well-being.
- PAQ: The SG showed an increase in PAQ scores (mean change: +0.73), indicating higher levels of physical activity. The CG also experienced a minor increase (mean change: +0.27), but the changes were more substantial in the SG, suggesting that the intervention encouraged more active lifestyles.
- 6MWD: The SG demonstrated a significant improvement in 6MWD (mean change: +57.82 m), indicating enhanced physical fitness and endurance. In contrast, the CG remained relatively stable (mean change: +1.38 m), suggesting no significant changes in physical activity levels.
- TUG: The SG exhibited a decrease in TUG time (mean change: -1.25 s), reflecting improved functional mobility. Meanwhile, the CG showed an increase in TUG time (mean change: +1.58 s), indicating a decline in mobility. This highlights the intervention's effectiveness in enhancing functional mobility in the SG.

These results are supported by the statistical analysis performed, specifically the Wilcoxon signed-rank test, which confirmed significant differences between the initial

(T1) and final (T2) measurements for each group. The findings underscore the positive impact of the intervention on the SG across multiple physical and psychological parameters.

3.5. Regression Analyses

Regression analyses were performed to investigate the relationships between various physical and psychological measures.

3.5.1. Study Group Analysis

- 6MWD (6-Minute Walk Distance): a regression analysis between 6MWD at baseline (T1) and 6MWD after the intervention (T2) revealed a strong positive correlation, with an R^2 value of 0.7545. This indicates that 75.45% of the variance in 6MWD(T2) can be explained by 6MWD(T1). The regression coefficient of 0.84397 suggests that for every unit increase in 6MWD(T1), 6MWD(T2) is expected to increase by approximately 0.844 units (**Figure 5**).
- TUG (Timed Up-and-Go Test): similarly, the regression analysis between TUG at baseline (T1) and TUG after the intervention (T2) showed a strong relationship, with an R^2 value of 0.7022. This means that 70.22% of the variance in TUG(T2) can be explained by TUG(T1). The regression coefficient of 0.7447 indicates that for every unit increase in TUG(T1), TUG(T2) is expected to increase by approximately 0.745 units (**Figure 6**).

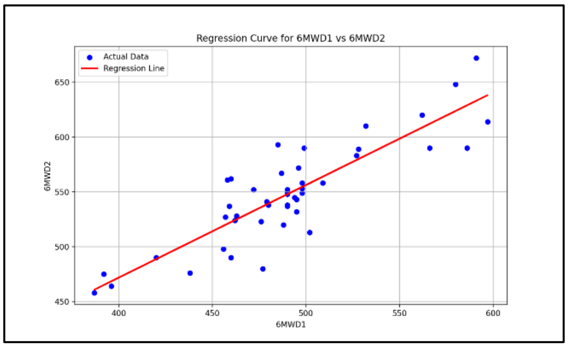

Figure 5. 6MWD(T1) – 6MWD(T2) (SG) regression analysis

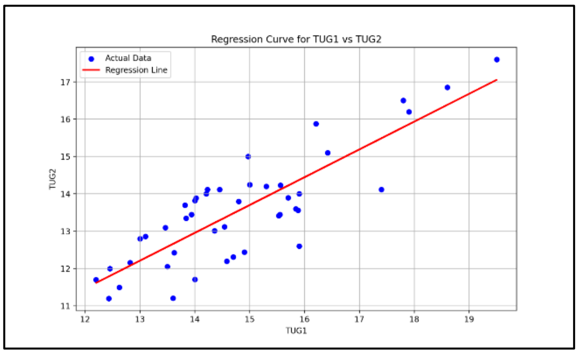

Figure 6. TUG(T1) – TUG(T2) (SG) regression analysis

In contrast, the regression analysis for PAQ(T1) and PAQ(T2) showed a moderate relationship, with an R^2 score of 0.3189, indicating that 31.89% of the variance in PAQ(T2) can be explained by PAQ(T1). The regression coefficient of 0.6296 suggests a moderate positive relationship between these two variables.

For the Rosenberg Self-Esteem Scale (RSE), the regression analysis between RSE(T1) and RSE(T2) revealed a very weak relationship, with an R^2 score of 0.0085, meaning that only 0.85% of the variance in RSE(T2) can be explained by RSE(T1). The regression coefficient of 0.1254 indicates a minimal positive relationship.

Overall, these findings demonstrate varying degrees of association among the studied measures, highlighting the need to account for multiple influencing factors when interpreting the results.

To further support these findings, heatmaps were generated for each group to illustrate the relationships between the parameters analyzed.

The heatmap analysis for the Study Group (SG) dataset (**Figure 7**) revealed several strong positive and negative correlations among the studied parameters:

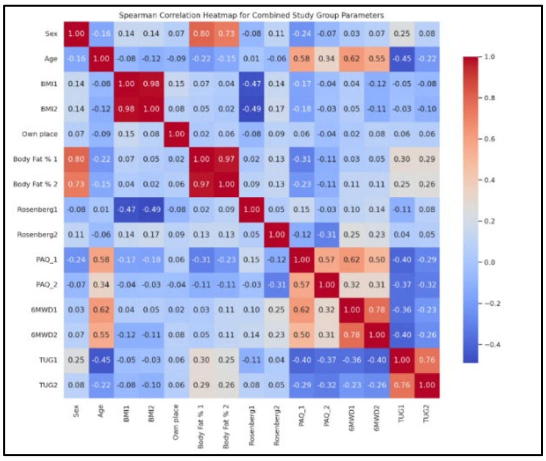

Figure 7. The correlation matrix for SG. Spearman correlation. The heatmap for SG dataset.

Strong Positive Correlations:

- BMI(T1) and BMI(T2): r = 0.98. Indicates that BMI values at baseline and after the intervention are nearly identical.
- Body Fat %(T1) and Body Fat %(T2): r = 0.97. Suggests a high degree of consistency between body fat percentage measurements at the two time points.
- 6MWD(T1) and 6MWD(T2): r = 0.78. Demonstrates a close relationship between the two measures of the 6-Minute Walk Distance.
- TUG(T1) and TUG(T2): r = 0.76. Indicates a strong correlation between Timed Up-and-Go test results at baseline and follow-up.

Strong Negative Correlations:

- Rosenberg(T1) and BMI(T1): r = -0.47. Suggests that higher BMI at baseline is associated with lower self-esteem.
- Rosenberg(T1) and BMI(T2): r = -0.49. Further supports the inverse relationship between BMI and self-esteem.
- TUG(T1) and PAQ(T1): r = -0.40. Indicates that higher physical activity levels at baseline are associated with better performance on the TUG test.
- TUG(T1) and PAQ(T2): r = -0.37. Reinforces the negative relationship between physical activity and TUG test performance.
- TUG(T2) and 6MWD(T2): r = -0.76. Indicates that as the time taken for the TUG test increases, the distance walked in 6 minutes tends to decrease.

We also observed a moderate positive correlation between age and 6MWD (r = 0.62 at baseline and r = 0.55 at the final assessment), indicating that older children tend to achieve higher distances in the 6-minute walk test.

Additionally, a moderate positive correlation (r = 0.15) was found between the RSE scores at baseline and follow-up, suggesting some level of consistency in self-esteem scores over time.

3.5.2. Control group analyses:

The heatmap analysis for the CG dataset (**Figure 8**) revealed several strong positive correlations (r) among the studied parameters.

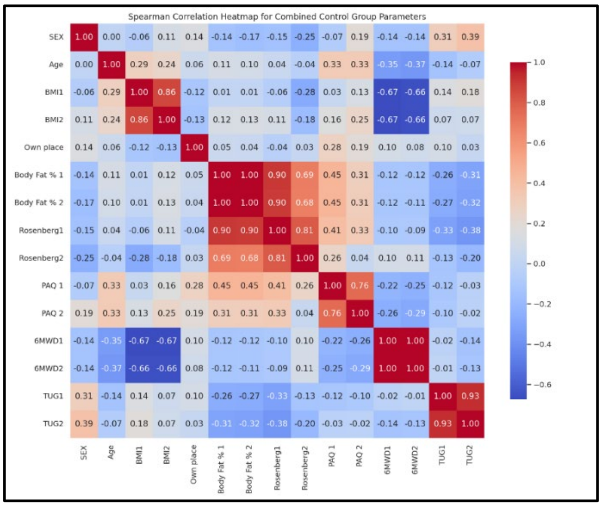

Figure 8. The correlation matrix for CG. Spearman correlation. The heatmap for CG dataset.

The interpretations of these correlations are as follows:

- BMI(T1) and BMI(T2): r = 0.86. Indicates that children with a higher BMI at baseline are likely to maintain a higher BMI after 9 months.
- Body Fat % (T1) and Body Fat % (T2): r = 0.99. Suggests that body fat percentage remains highly consistent between the two time points.
- 6MWD(T1) and 6MWD(T2): r = 0.99. Demonstrates that the distance walked in the 6-minute walk test is consistent over time, with little variation in the CG.
- Rosenberg Self-Esteem Scale (RSE) Scores (T1 and T2): r = 0.81. Shows that children who report higher or lower self-esteem at baseline tend to report similarly high or low self-esteem after 9 months.
- TUG(T1) and TUG(T2): r = 0.93. Indicates that the time required to complete the Timed Up-and-Go test is highly consistent across both time points, suggesting stable functional mobility in the CG over the observed period.

4. Discussion

This study, conducted on overweight/obese adolescents, focused on the objective (using the BTS system) and subjective (PAQ-A questionnaire) assessment of physical performance after a kinesiotherapy program. It also included the evaluation of self-esteem using the Rosenberg questionnaire. The kinesiotherapy program was personalized to each adolescent, aligning with recommendations from Al Qahtani and Al Eisa, who emphasized the importance of gender-specific and individualized interventions for effective obesity management [51]. In addition, the integration of the 5-2-1-0 rule into the program was critical for maintaining metabolic balance and overall homeostasis, as supported by recent evidence [52].

The present study results align with studies showing the effectiveness of physical activity in managing obesity and improving physical performance. However, unlike some studies reporting inconsistent effects of exercise on body composition [53], our study demonstrated significant reductions in BMI and body fat percentage in the SG, indicating that kinesiotherapy can effectively improve body composition in overweight adolescents.

The kinesiotherapy program was specifically designed to address the unique challenges faced by overweight/obese adolescents, such as reduced aerobic capacity, muscular strength, and fitness levels. These issues have been well-documented in the literature, with studies indicating that obese children perform 14% worse on the 6MWD test compared to their normal-weight peers [54] and exhibit weaker performance on tests requiring body propulsion or lifting [55, 56]. The present findings revealed significant improvements in physical performance parameters, including 6MWD, TUG, and PAQ scores, in the SG. These results align with other studies showing that structured physical activity improves both aerobic capacity and muscular strength in overweight adolescents [57]. Moreover, our findings challenge conclusions from studies suggesting minimal improvements in motor coordination in overweight adolescents following exercise programs [58]. Instead, we observed substantial gains in physical performance parameters such as 6MWD and TUG, highlighting the benefits of structured kinesiotherapy.

The significant reductions in body fat percentage and BMI observed in the SG highlight the program's effectiveness in improving body composition, as supported by the inclusion of bioimpedance analysis, a more accurate measure of health than BMI alone [59].

The Rosenberg Self-Esteem Scale was used to assess the psychological impact of the kinesiotherapy program. Our results demonstrate significant improvements in self-esteem in the SG, particularly among rural participants and girls, who showed greater compliance and motivation due to concerns about physical appearance during adolescence. This aligns with findings that physical activity positively correlates with self-esteem and body image [60, 61]. Interestingly, a small but significant increase in self-esteem was also noted in the CG, possibly due to the initial awareness raised by participating in the study. However, the improvement in the SG underscores the unique benefits of physical activity in addressing the psychological challenges faced by overweight adolescents, consistent with previous cohort studies [62, 63].

The strong relationships observed between BMI, body fat percentage, and physical performance tests (6MWD, TUG) in the SG support our hypothesis that physical activity has a multifaceted impact on clinical, functional, and emotional outcomes. The negative correlation between BMI and self-esteem reinforces the need for interventions targeting both physical and psychological health in overweight adolescents [64, 65]. Our study also identified gender-specific responses, with girls in the SG showing more significant improvements in 6MWD, TUG, and self-esteem, while boys demonstrated greater reductions in body fat percentage. These findings align with literature suggesting that girls often exhibit higher motivation for body image improvements during adolescence [66]. Contrary to earlier findings that urban adolescents tend to engage in more physical activity than their rural counterparts [67], the present study found significant improvements in physical activity, self-esteem, and endurance among rural adolescents. This may reflect changes in urban and rural infrastructure, where physical activity opportunities are now more equally distributed, consistent with recent observations by Kawalec et al. [68].

The use of the BTS G-WALK/BTS G-SENSOR 2 system for objective gait analysis in overweight/obese adolescents is pioneering, as no similar studies assessing pre- and post-kinesiotherapy program changes in physical performance were found in the literature. While previous studies have utilized this system to evaluate gait patterns in overweight/obese children, they did not explore how these parameters change following a structured kinesiotherapy program [69]. This highlights the originality of our approach and the importance of instrumental assessments in understanding therapy outcomes.

Limitations of the study: While the sample size may be limited, the statistical significance of the results (in BMI, body fat percentage, self-esteem, 6MWD, TUG) and the use of objective tools such as BTS G-WALK, PAQ-A, and bioimpedance analysis provide robust evidence of the intervention's effectiveness.

Although the study duration is limited, it was sufficient to demonstrate meaningful short-term changes, which are critical for designing effective intervention strategies. These short-term findings highlight the feasibility and value of such interventions, providing actionable insights for clinicians and policymakers while advocating for longer-term follow-up studies.

The inclusion of urban and rural participants ensures diversity and enhances the external validity of the results. However, the absence of deeper contextual analysis reflects the real-world challenges of designing and implementing a focused, practical study within a controlled framework. This study creates an opportunity for future research to explore these contextual factors further.

Another limitation of this study is that while adherence to the kinesiotherapy program was monitored, detailed records of session compliance and effort levels were not systematically documented, which may have introduced variability in the outcomes. This limitation does not diminish the importance of the findings but emphasizes the need for enhanced adherence monitoring in future studies. The observed results remain significant and provide a realistic representation of program implementation in a clinical or community setting.

The Internal Validity of this study was enhanced by incorporating a robust evaluation framework that included anthropometric measurements, body composition analysis and functional parameters. These were assessed using objective tools like the BTS G-WALK system and bioimpedance analysis, ensuring precise and reproducible measurements. Additionally, subjective measures complemented the objective tests, providing a multidimensional evaluation of the intervention's impact. To minimize internal bias, comparable group sizes were ensured between the study and control groups. The study included only children within a narrow age range (13–15 years), reducing variability due to developmental differences. A single team of specialists conducted all evaluations at both baseline and follow-up, ensuring consistency in data collection and interpretation. These measures collectively strengthen the study’s internal validity by reducing potential confounders and ensuring reliability in the observed results.

Regarding the External Validity, the findings of this study can be generalized to a broader population, as the key characteristics contributing to overweight and obesity among the participants (poor diet and lack of physical activity) are prevalent globally among children and adolescents. The inclusion of participants from both urban and rural environments further enhances the applicability of the results, reflecting diverse lifestyles and socioeconomic contexts. By addressing common modifiable factors of obesity, such as physical inactivity and suboptimal dietary habits, the intervention model used in this study offers practical insights that can be adapted to different healthcare settings, school programs, and community initiatives worldwide. This broad applicability underscores the external validity of the findings.

Future directions: While the 9-month duration of our study was sufficient to observe meaningful changes in physical and psychological parameters, longer-term studies are needed to assess the sustainability of these outcomes. Additionally, while we included a robust analysis of body composition and physical performance, future research should consider a broader range of anthropometric and metabolic markers for a more comprehensive evaluation.

5. Conclusions

The findings from our study emphasize the significant role of individualized kinesiotherapy programs in improving physical and psychological health outcomes in overweight/obese adolescents. By integrating instrumental assessments, such as the BTS system, with subjective evaluations like PAQ-A and the Rosenberg scale, our study highlights the multifaceted impact of physical activity on this vulnerable population. The study identifies gender-specific responses, with girls showing greater compliance and psychological improvements, and environmental influences, with

rural adolescents showing notable physical performance gains. These findings underline the need to account for social and demographic factors in designing intervention programs. Finally, the study results support incorporating structured physical activity programs into school curricula and public health policies targeting adolescent obesity.
Future interventions should continue to prioritize individualized approaches and address both clinical and psychological aspects of obesity management.

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