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CONTENTS

ORIGINAL ARTICLE

Foot health and physical fitness: investigating the interplay among flat feet, body balance, and performance in junior high school students

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

Abstract

Background and Study Aim Foot health and physical fitness in children are closely interconnected, playing a vital role in ensuring their overall well-being and performance. This study aims to determine the relationship between flat feet, body balance, and physical performance of junior high school students.

Material and Methods A total of 109 junior high school students from five schools in Surabaya, Indonesia, with ages ranging from 12 to 14 years, participated in this research. Data collection was through the wet footprint test, stork standing balance test, Bass test, Y-agility Test, and Illinois Change of Direction Test. The correlation of flat feet with static and dynamic balance and physical performance in the school environment was analyzed using the non-parametric Spearman Rank statistical test.

Results The results showed significant relationships between foot grade and static balance, dynamic balance, agility, and change of direction. These relationships were indicated by correlation coefficients that showed statistical significance at $p < 0.05$. Additionally, static and dynamic balance exhibited a negative correlation, while agility and change of direction showed a positive correlation. This suggests that higher foot grades corresponded to longer durations in static and dynamic balance tests and shorter completion times in agility and change of direction tasks.

Conclusions The findings of this study highlight the importance of investigating the relationship between flat feet, body balance, and physical performance among junior high school students. Understanding these correlations is crucial for optimizing the overall well-being and performance of adolescents.

Keywords: flat feet, static balance, dynamic balance, physical performance.

Introduction

Flat feet, also called pes planus, are characterized by a decreased arch on the medial side of the foot so that most of the sole touches the ground when standing. The transverse and longitudinal arches maintain the appropriate shape of the legs; the transverse and longitudinal arches are flexible and have different shapes; the transverse and longitudinal arches protect other body systems by offering shock absorption and supporting the entire body while maintaining balance [1]. The performance efficiency of the foot depends on its anatomy and exceptionally well-formed transverse and longitudinal arches [2]. The main factor that causes flat feet is structural abnormalities in the bones, which can cause muscles, tendons, and ligaments to work beyond their capacity, causing an increased risk of injury and decreased tolerance for physical activity and performance [3, 4].

Flat feet can occur in children and adults [5]. However, flat feet are higher in children [3, 6, 7, 8, 9], with an estimated 20-30% of children worldwide experiencing it [10]. A previous study investigated the incidence rate of flat feet and associated personal factors among public elementary school students [9]. Study findings revealed a significant correlation between a higher prevalence of flat feet and increasing age, with the 6-year-old group showing the highest prevalence. Boys are twice as likely to be diagnosed with flat feet as girls. In addition, children who are obese have a three-and-a-half times greater risk of experiencing flat feet than children of average weight. A previous study reported the prevalence of pes planus in children aged 7 to 14 years [11]. Their research showed that around 29.5% of the children sampled showed flatfoot deformity. This prevalence is still much higher compared to the prevalence in developed countries. In addition, a significant

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association was found between children's age and the likelihood of developing pes planus. Previous studies investigated the correlation between the Foot Posture Index (FPI) version 6, comprising six items, clinical measurements, foot anthropometry, and other radiological data regarding foot position in children aged 5 to 8 [6]. The results showed a positive correlation between FPI-6 and the Navicular Drop (ND) test and Center of Pressure (COP) Sway Index (CSI) in children aged 5 to 8 years. Three prominent foot posture indicators (FPI-6, ND, and CSI) can be used effectively as primary tools or preferences in clinical practice. Research on the treatment of flat feet has been carried out by researchers from various countries, such as China [12], Spain [13], the United States [14], Japan [15], Italy [16], Greece [13] and Germany [17]. These studies emphasize the importance of early screening to detect flat feet and treatment for sufferers to maintain their physical condition and overall health.

The impact of flat feet can be felt on body balance. Body balance is divided into two types: statistical and dynamic balance. Statistical balance relates to maintaining a still posture with limited movement. In contrast, dynamic stability is the ability to perform movements while maintaining or restoring stability [18]. The condition of the feet is an essential element that can influence maintaining body balance [19].

The condition of the feet plays a vital role in maintaining an individual's performance and physical activity, especially concerning agility and change of direction, which significantly influence balance and coordination. Factors such as posture, balance, and support are reliant on the health of the feet. Abnormal foot conditions, such as flat feet, also impact physical performance and balance [20].

However, this aspect still needs more attention, especially in sports education. This is evidenced by the need for more research discussing flat feet in the context of students' physical education performance. Research that discusses the relationship between flat feet and balance and students' physical performance is limited, so the results of this research have an essential role in overcoming and preventing bad possibilities in the future.

This study aims to determine the relationship between flat feet, body balance, and physical performance of junior high school students.

Materials and Methods

Participants

Participants for this research were selected using random sampling and consisted of 109 junior high school students from five schools in Surabaya, Indonesia. Their age range is between 12-14 years. To ensure a natural situation, researchers collaborated with physical education teachers. In addition, researchers obtained permission from the respective school principals by obtaining research permission and research ethics guidelines.

Research Design

This research uses a quantitative correlation approach to determine the relationship between flat feet, body balance, agility, and student's ability to change direction in physical education. A correlational design is used to test the relationship between variables. Using this design, the study aims to determine whether there is a correlation between flat feet, body balance, and physical performance.

Instrument Test. In order to collect data, the researcher employed three instruments: the wet footprint test, the stork standing balance test, the bass test, the Y-agility Test, and the Illinois Change of Direction Test. Wet footprint test. Foot arch assessment is carried out using the footprint method. As seen in Figure 1, participants soaked their feet in colored ink and then pressed them against a sheet of paper. A normal foot arch occurs when at least half of the medial longitudinal arch is visible in the footprint. Pes planus, conversely, is defined as a decrease in the medial longitudinal arch that causes the medial edge of the foot to touch the ground completely. A wet imprint test that gives a positive result shows the disappearance of the depression on the medial edge of the plantar surface. To classify the severity of flat feet, a grade system is used, where grade I indicates that the medial edge of the plantar surface is still concave and is to the medial side of the foot axis; grade II occurs when the medial edge of the plantar surface becomes straight and does not cross the median axis of the foot; and grade III occurs when the medial edge of the plantar surface becomes convex and crosses the axis of the foot [21].

The stork standing balance test measured the students' static balance while standing on one foot with closed eyes [20, 22, 23]. The test was conducted three times, and the best score was recorded. The objective of this test was to maintain this position for the maximum possible duration. The modified bass test was used to measure the students' dynamic balance during and after movement with a validity of 0.83 and a reliability of 0.93 [20]. This research conducted the test three times, and the best result from the three trials was recorded. The test evaluated the students' balance performance while moving and after movement. The test was considered valid and reliable in measuring student's dynamic balance. The Y-agility Test is utilized to assess agility and is conducted reactively, as described by [24]. The best time out of eight attempts is selected for further analysis. The Illinois Change of Direction Test involves setting up a rectangular area measuring 9.3 by 7.2 meters, as described by [25]. The best time out of three attempts is recorded as the ILL score, representing the time to complete the Illinois test.

Statistical Analysis

Data are presented using mean and standard deviation. Data analysis was done using non-parametric statistical tests to analyze the relationship between flat feet and students' balance and physical performance. The Spearman Rank test is used to see the significance level of the relationship between variables, the strength of the relationship, and the direction of the relationship. Variables are declared correlated if the sig value is <0.05. At the same time, the strength of the relationship uses the criteria of 0.00-0.25, very weak correlation, 0.26-0.50 moderate correlation, 0.51-0.75 strong correlation, 0.76-0.99 very strong correlation, and 1 is perfect correlation. The direction of the relationship is expressed with a positive or negative value; if the value is negative, the relationship between the two variables is in the same direction, whereas if the value is negative, the relationship is not in the same direction. The data will be analyzed and processed quantitatively using SPSS software version 24.0. Data analysis uses Spearman Rank. The results of the analysis will be presented in the form of tables and graphs for easier understanding.

Results

The average and standard deviation of several anthropometric parameters measured in three categories of flat feet: Normal, Grade 1, and Grade 2. Age, weight, height, and Body Mass Index (BMI) are parameters shown in Table 1.

The difference between static and dynamic balance, agility, and change of direction is shown in Figure 2. The result shows an average static balance of 13.35±2.66, dynamic balance of 72.97±24.96, agility of 3.24±.72, and change of direction of 23.64±.90.

The average, standard deviation, minimum value, maximum value, and number of samples (N) for the four parameters measured in three levels of flat feet severity: Normal, Grade 1, and Grade 2, as well as the overall total shown in Table 2. These parameters are static balance, dynamic balance, change of direction, and speed. The data shows that the higher the severity of flat feet, the lower the average results for each parameter measured, except speed, which shows an increasing trend.

It is interpreted that Grade Feet has a significant relationship to static balance, Dynamic Balance, Agility, and Change of direction, which has a value of .000<0.05, as shown in Table 3. The strength of the relationship between grade feet and static balance is in the strong correlation category, Dynamic balance is in the strong correlation category, agility is in the strong category, and change of direction is in the strong category. The relationship's direction for static and dynamic balance is negative. In contrast, agility and change of direction are positive, which means that the better the foot grade, the longer the static balance and dynamic balance test results will be. In contrast, the resulting time will be shorter for agility and change of direction.

Figure 1. Flat Foot Classification. (A = Normal; B= Grade 1; C=Grade 2; D=Grade 3)

Table 1. Characteristic of Group.

Grade Feet	Age (years)	Weight (kg)	Height (cm)	BMI (kg/m^2)
Normal	13.06±0.69	50.72±7.09	154.70±4.99	21.23±3.15
Grade 1	13.05±0.66	55.00±5.63	155.29±3.86	22.86±2.65
Grade 2	13.06±0.87	49.56±7.11	155.78±3.12	20.48±3.24

Data are presented as mean±SD

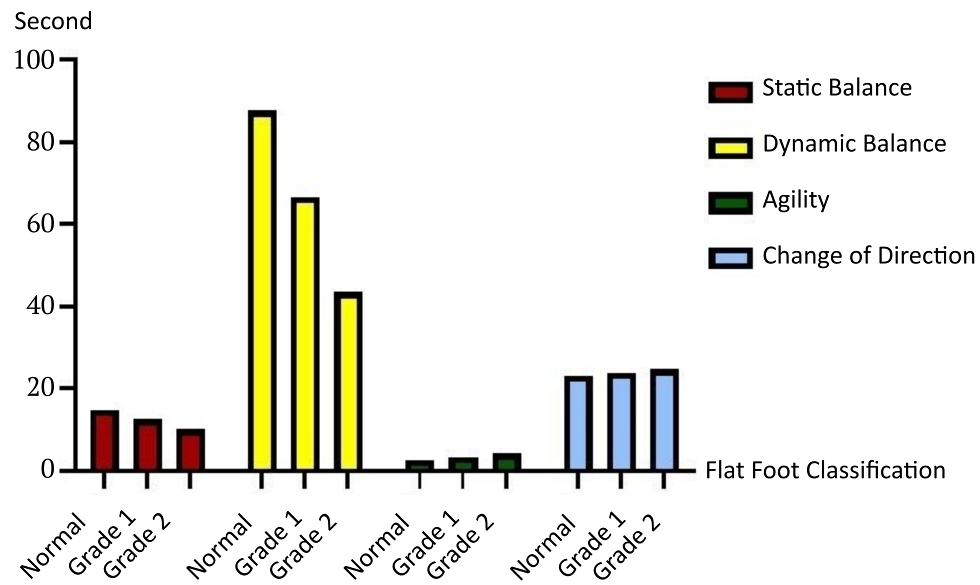

Figure 2. Result of Balance and Physical Performance Test.

Table 2. Description of body balance and physical performance data based on foot category

Grade Feet		Static Balance (s)	Dynamic Balance (s)	Agility (s)	Change of Direction (s)
Normal	Mean±SD	14.96±1.46	87.58±14.47	2.78±.40	23.09±.41
	Minimum	12.37	62.30	2.35	22.69
	Maximum	15.95	95.95	3.73	24.03
	N	53	53	53	53
Grade 1	Mean±SD	12.64±2.60	66.59±24.85	3.44±.67	23.87±.88
	Minimum	8.34	28.44	2.35	22.65
	Maximum	15.99	95.99	4.67	25.57
	N	38	38	38	38
Grade 2	Mean±SD	10.09±1.82	43.44±17.14	4.18±.41	24.80±.72
	Minimum	8.20	28.40	3.67	23.87
	Maximum	12.19	62.19	4.83	25.63
	N	18	18	18	18
Total	Mean±SD	13.35±2.66	72.97±24.96	3.24±.72	23.64±.90
	Minimum	8.20	28.40	2.35	22.65
	Maximum	15.99	95.99	4.83	25.63
	N	109	109	109	109

Data are presented as mean±SD.

Table 3. Spearman Rank Test Results

			Grade Feet	Static Balance	Dynamic Balance	Agility	Change of Direction
Spearman's rho	Grade Feet	Correlation Coefficient	1.000	-.755	-.738	.722	.716
		Sig. (2-tailed)		.000	.000	.000	.000
		N	109	109	109	109	109

Data are presented as mean±SD; Significant, p<0.05.

Discussion

This study investigated the correlation between flat feet on static and dynamic balance and students' physical performance in the school environment. One hundred nine students from 5 elementary schools in East Java, aged 12 to 14, participated in this research. Data was collected using measuring instruments: the wet footprint test, the stork standing balance test, the Bass test, the Y agility test, and the Illinois Change of Direction test. Spearman Rank analysis is used to analyze the correlation of flat feet with static and dynamic balance and students' physical performance in the school environment.

The results showed that flat feet were significantly correlated with students' body balance. These findings support previous research conducted by [26, 27], who revealed that flat feet significantly affect body balance. This is in balance with [19], who found that the condition of the feet significantly influences overall body balance. Imbalances in the feet can cause muscles, tendons, and ligaments to overwork, increasing the chance of injury and fatigue. How a person stands and moves can also be affected, causing stability and coordination problems. This finding aligns with research by [3, 4], who reported that foot disorders can increase the likelihood of injury and decrease physical activity and performance endurance. The results of this study also explain that the presence of flat feet has a negative effect on students' physical performance in school activities. This may be due to the body's imbalanced influence on the musculoskeletal structure, leading to the overuse of muscles, tendons, and ligaments, thereby increasing the likelihood of injury and fatigue in individuals with flat feet. However, this finding differs from [22, 28] research findings that explained no relationship between flat feet and body balance.

Another finding in this research is the positive influence of flat feet on students' agility and ability to change direction. This is because to change direction quickly, a person must have balance, coordination, and speed. Body balance is essential for human movement and activities [19, 23, 29]. Maintaining body balance relies on rapid and continuous feedback from various sensory systems. The visual system provides information about the surrounding environment, the vestibular system provides information about body position and movement in space, and the somatosensory system provides information about pressure, touch, and body movement [18]. However, body balance is not simply a statistical process; it is dynamic, allowing movement, changing positions, and adapting to different situations. Therefore, body balance is a complex process that requires integrating various physiological systems and continuous adaptation to the surrounding environment [29, 30, 31].

Additionally, [11] emphasized that disorders that affect the condition of the feet can interfere with a person's athletic performance and increase the risk of injury. Having abnormalities in the legs can cause a decrease in physical abilities, resulting in decreased endurance and stability when exercising, and can make a person more susceptible to injury. It is essential to monitor the condition of students' feet and take steps to address underlying problems to maintain physical health and avoid injury [12, 13, 14, 15].

Compared to our findings, it is noteworthy that some previous research [22, 28] reported no significant relationship between flat feet and body balance. These discrepancies may arise from differences in sample characteristics, measurement methods, or analytical approaches. Further investigation is warranted to reconcile these inconsistencies and gain a deeper understanding of the complex interplay between foot health, body balance, and physical performance in school-aged children.

Conclusions

this study elucidates the significant correlation between flat feet and students' body balance, as well as its impact on physical performance in school activities. These findings underscore the importance of monitoring foot health among students and implementing interventions to address underlying issues. Future research could explore additional factors influencing the relationship between flat feet, body balance, and physical performance, as well as evaluate the effectiveness of interventions aimed at improving foot health in school-aged children.

Conflict of interest

Authors do not receive endorsement from any organization for submitted work.

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ORIGINAL ARTICLE

Development of physical test norms for early age Pencak Silat

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Abstract

Background and Study Aim The evaluation serves as a cornerstone in the continuous improvement of sports, significantly relying on the analysis of measurement data. The primary objective of this research is to develop tailored norms for physical tests specifically designed for early-age Pencak Silat practitioners.

Material and Methods The development of the test consisted of several key stages: design of the instrument, testing of the instrument, and finally, assembly of the instrument. The study included a total of 210 participants, with a breakdown of 111 male and 109 female martial artists. The techniques for data collection involved a variety of tests and measurements. The instruments used in this research included: sit-and-reach test for assessing flexibility, 30-meter sprint for speed evaluation, side step test for agility, sit-ups for abdominal strength, push-ups for arm and chest strength, wall sit test for leg muscle strength, and beep test for cardiovascular endurance. Data analysis was performed using a technique that grouped values into five standard categories, aided by the use of Microsoft Excel.

Results The findings of the study led to the establishment of norms for each component of the physical tests tailored to early-age Pencak Silat practitioners. These components have been classified into five distinct levels: very poor, poor, average, good, and excellent.

Conclusions The outcomes of this research facilitate the development of specific norms for each test item, incorporating weighting for every physical test component. These weightings have been meticulously adjusted in accordance with the primary energy systems utilized in the sport of Pencak Silat.

Keywords: norm arranging, pencak silat, martial arts, early age

Introduction

Pencak Silat, an indigenous Indonesian martial art, has started gaining international recognition, evidenced by its inclusion in national and international competitive sports arenas [1, 2]. The sport features diverse competition categories such as sparring, individual, doubles, team, and creative performances, organized across various age groups including early age, pre-teen, teen, adult, and master [3, 4]. Successful competition participation demands athletes to be in prime physical condition, showcasing advanced techniques, strategic tactics, and robust mental strength. The role of parental support and effective sports organization management is pivotal in reaching peak performance levels [5]. Consequently, sports management bodies have launched talent identification and development programs specifically for Pencak Silat, aiming to cultivate skilled athletes and ensure a seamless transition for athlete regeneration upon retirement [6, 7]. This involves designing customized training programs tailored to meet the exacting demands of competition, with coaches often innovating these programs to maximize outcomes and maintain engagement [8].

The ongoing enhancement of sports performance is being advanced through the continual development of training programs [9]. This includes the creation and application of evaluative instruments and norms to assess training outcomes effectively [10, 11]. Such instrument development covers the gamut of tools necessary for measuring an athlete's physical, technical, tactical, and mental states [12, 13, 14, 15], with rigorous testing for validity and reliability to ensure data accuracy [16, 17, 18]. Following this, norms for each measurement item are established, providing meaningful insights into the collected data. Tailored to meet the unique demands of various sports disciplines, the development of physical test instruments is crucial. Their effectiveness is significantly heightened when closely aligned with the specific requirements of a sport, resulting in more precise and actionable data from the measurement process [19, 20, 21].

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In general, physical fitness assessments organized by sports organizations typically utilize a set of common instruments [22]. This approach means that the same measurement tools are applied across all sports disciplines [23], which can introduce biases into the measurement results. Such bias stems from the varying physical demands and conditions inherent to each sports discipline [11, 24, 25], including differences in dominant energy systems and muscle groups used [26]. For instance, when sports organizations conduct physical fitness tests encompassing flexibility, speed, muscle strength and endurance, agility, and cardiovascular endurance – with the cardiovascular component accounting for 25% of the total score – sports emphasizing aerobic energy systems may inherently benefit. In contrast, sports like archery and chess could be at a disadvantage, primarily because the score weighting does not reflect the unique characteristics of each sport. Despite the standardization in assessment, training programs are often specifically tailored to the needs of each sport [27]. Hence, there's a critical need to develop physical test instruments and establish norms that are aligned with the specific requirements of each sport to ensure the collection of accurate and relevant data.

The primary objective of this research is to develop tailored norms for physical tests specifically designed for early-age Pencak Silat practitioners.

Materials and Methods

Participants

The subjects of this research are martial artists aged 10 to 12 years. The age grouping aligns with the competition categories in Pencak Silat. To represent the characteristics of each ability, the subjects participating in this study consist of martial artists training in sports clubs, martial artists under the district training center, martial artists under the provincial training center, and martial artists who have participated in national championships. The total subjects in this study are 210, comprising 111 male martial artists and 109 female martial artists. All participants were briefed on the study's objectives, and informed consent was obtained from their parents. The study was approved by the regional ethics committee, ensuring that all procedures adhered to the ethical standards outlined in the Declaration of Helsinki.

Research Design

This research contributes to the development of a physical test evaluation model tailored for early-age martial artists. The methodology employs a modified version of the Wilson Model and the Oriondo and Antonio Model [28], encompassing the following steps: (1) instrument design, (2) instrument testing, and (3) instrument assembly. During the instrument design phase, objectives are defined, and the structure of the instrument is conceptualized. The testing phase assesses the instrument's validity and reliability. The assembly phase involves developing norms for the newly developed instruments. Throughout these stages, specific physical test instruments for early-age martial artists were devised with input from experts in physical fitness, Pencak Silat, child development, and coaching. Following their formulation, these instruments underwent validity and reliability tests before norms were established.

Validity testing in this study employs concurrent validity, while reliability is assessed through a test-retest approach. The process for conducting these tests involves having the participants – referred to as fighters – perform each physical test item twice at different times. The validity of each test result is then evaluated using the product moment method, and reliability is assessed with the Cronbach alpha formula. The validation outcomes for the physical test instruments tailored to early childhood Pencak Silat revealed scores of 0.94 for males and 0.89 for females, indicating strong validity. Reliability scores were equally impressive, with 0.96 for males and 0.94 for females, showcasing the instruments' consistency over time. Following the confirmation of validity and reliability, the next step involved the development of norms. These norms are crucial for interpreting the raw scores obtained from the measurements, serving as the foundation for this research's primary goal: to establish norms for physical tests specific to early-age Pencak Silat. The methodology for data collection in this study includes various tests and measurements, with each martial artist undergoing a set of tests provided once.

Measures. The instruments employed in this study, developed and validated by experts, encompass a comprehensive suite of tests designed to assess various aspects of physical fitness. These include the sit-and-reach test for evaluating body flexibility, the 30-meter sprint test for speed assessment, the side step test for agility measurement, sit-ups for determining abdominal muscle strength, push-ups for evaluating arm and chest strength, the wall sit test for leg muscle strength, and the beep test for assessing cardiovascular endurance of the lungs. These instruments have been rigorously tested for validity and reliability in earlier development stages, ensuring their efficacy in accurately measuring the intended physical capacities.

Procedure. The research procedure entails a sequential execution of tests and measurements for each item, utilizing a comprehensive test battery format. To accommodate this, twenty measurers are deployed, each responsible for a designated measurement station. Martial artists begin by registering, receiving a physical test form, and being assigned a chest number. They then perform stretching and warming-up exercises in preparation for the measurements. Starting at the first station, participants systematically proceed through to the seventh station, undergoing assessments for flexibility, speed, arm muscle strength, abdominal muscle strength, agility, leg muscle strength, and lung cardiovascular endurance, in that order. A brief rest period of 1-2 minutes is allowed between stations to ensure accuracy and prevent fatigue. Each martial artist completes the series of tests once. Upon finishing all seven stations, the physical test forms are submitted to the officials. Should any test item not be completed satisfactorily, the entire set of measurements for that martial artist is deemed invalid.

Statistical Analysis

The data analysis technique employs a methodology that categorizes values into a five-tier standard scale, facilitated by Microsoft Excel. Initially, for each test item, Microsoft Excel is used to calculate the average value and standard deviation. These statistical measures are then applied to derive scores based on a formula that segments results into five standard values. The scores obtained from this segmentation are referred to as raw scores, which are subsequently converted into standard scores. These standard scores for each physical test item fall within a five-tiered scale: A (very good), B (good), C (average), D (poor), and E (very poor). The formulas for the five standard values and the conversion process to standard scores are detailed in Table 1.

Table 1. Five Standard Value Formulas and Standard Scores

Values on a Scale of 5	Score	Category
> M + 1.5SD	5	Excellent (A)
M + 0.5SD to M + 1.5SD	4	Good (B)
M - 0.5SD to M + 0.5SD	3	Average (C)
M - 1.5SD to M - 0.5SD	2	Poor (D)
< M - 1.5SD	1	Very Poor (E)

Note: "M" – Mean; "SD" - Standard Deviation. The ranges are determined based on the mean plus or minus the product of the standard deviation (SD) and a factor (1.5 or 0.5), specifying the boundaries for each category.

Based on these criteria, norms for physical tests tailored to early-age Pencak Silat practitioners can be established. Given that each test item employs a distinct unit of measurement, it is necessary to interpret each item's results individually before aggregating them into a comprehensive score. This interpretation can utilize numerical values, exemplified by a range such as 10-50, to accommodate the varying significance of each test item. Importantly, the norms for physical tests in early-age Pencak Silat vary across test items, reflecting the different weight each carries. This weighting is carefully adjusted to align with the specific movement characteristics and energy systems pertinent to Pencak Silat. Details on the weighting of values for test items, along with the formula used to categorize classification norms for physical tests in early-age Pencak Silat, are delineated in Table 2. Additionally, an example formula for normative classification specifically for the sit-and-reach test is outlined in Table 3.

Table 2. Percentage (%) weighting of values for each test item

No	Test Components	Score	Weight
1	Sit and reach	10-50	10%
2	Sprint 30 meters	10-50	20%
3	Push up 30 seconds	10-50	8%
4	Sit up 30 seconds	10-50	7%
5	Side step	10-50	10%
6	Wall sit	10-50	20%
7	Beep test	10-50	25%

Table 3. Example Formula for the Normative Classification of the Sit and Reach Item

Sit And Reach (Cm)	Weight 10%	Score	Category
> M + 1.5SD	50	5	Excellent
M + 0.5SD to M + 1.5SD	40	4	Good
M - 0.5SD to M + 0.5SD	30	3	Average
M - 1.5SD to M - 0.5SD	20	2	Poor
< M - 1.5SD	10	1	Very Poor

Note: "M" – Mean; - "SD" - Standard Deviation. The notation "to" is used to indicate ranges between two statistical measures.

The table 3 specifies how scores for the sit and reach test are categorized into different levels based on deviations from the mean (M) using standard deviation (SD) as a measure.

Results

After analyzing the data, we have established normative settings for each test item. Flexibility test norms are presented in Table 4, while Table 5 contains norms for speed tests. Hand Grip Strength test norms can be found in Table 6, and Table 7 outlines norms for Abdominal Strength tests. Norms for Agility tests are detailed in Table 8, Leg Strength tests in Table 9, and Aerobic Endurance tests in Table 10. These norms are divided into five distinct categories for both male and female participants. The results of these measurements are then converted into standard scores, which fall into predetermined categories. Specifically, each score from the physical test items is categorized into one of five standard scores: A (very good), B (good), C (average), D (poor), and E (very poor).

In Table 5, the ranges indicate the minimum and maximum values for each category, tailored to gender. The 'Weight 10%' column reflects the significance of this test in the overall physical fitness assessment.

The table 5 provides a gender-specific range of times for each category, reflecting the required performance levels for male and female athletes in the sprint 30-meter test. The "Weight 20%" indicates the importance of this test in the overall physical fitness evaluation, emphasizing speed.

The table 6 outlines gender-specific performance norms, with scores allocated according to the number of repetitions achieved. The "Weight 8%" column reflects the test's relative importance in the overall assessment of upper body strength.

In Table 7, the ranges indicate the number of sit-ups completed in 30 seconds, with separate thresholds for male and female athletes. The scores reflect the athlete's performance level, with the "Weight 7%" indicating the significance of this test in the overall physical fitness evaluation, focusing on abdominal strength.

The table 8 outlines performance levels for

Table 4. Flexibility Norms (Sit and Reach)

Sit and Reach (cm)			Weight 10%	Category
Male	Female	Score	Score	
> 33.38	> 34.41	50	5	Excellent
29.12 to 33.38	29.52 to 34.41	40	4	Good
24.86 to 29.12	24.62 to 29.52	30	3	Average
20.60 to 24.86	19.73 to 24.62	20	2	Poor
< 20.60	< 19.73	10	1	Very Poor

Note: The notation "to" is used to indicate ranges between two statistical measures.

Table 5. Speed Norms (Sprint 30 Meter)

Sprint 30 Meter (seconds)			Weight 20%	Category
Male	Female	Score	Score	
< 5.11	< 5.69	50	5	Excellent
5.11 to 5.87	5.69 to 6.3	40	4	Good
5.87 to 6.57	6.3 to 6.92	30	3	Average
6.57 to 7.27	6.92 to 7.53	20	2	Poor
> 7.27	> 7.53	10	1	Very Poor

Note: The notation "to" is used to indicate ranges between two statistical measures.

Table 6. Push Up Norms (30 Seconds)

Push Up 30 Seconds (times)			Weight 8%	Category
Male	Female	Score	Score	
> 25	> 23	50	5	Excellent
19 to 25	18 to 23	40	4	Good
13 to 19	13 to 18	30	3	Average
7 to 13	8 to 13	20	2	Poor
< 7	< 8	10	1	Very Poor

Note: The notation "to" is used to indicate ranges between two statistical measures.

Table 7. Abdominal Strength Norms (Sit Up)

Sit Up 30 Seconds (times)			Weight 7%	Category
Male	Female	Score	Score	
> 23	> 21	50	3.5	Excellent
18 to 23	17 to 21	40	2.8	Good
13 to 18	13 to 17	30	2.1	Average
8 to 13	9 to 13	20	1.4	Poor
< 8	< 9	10	0.7	Very Poor

Note: The notation "to" is used to indicate ranges between two statistical measures.

the side step agility test, indicating the number of steps completed, with distinct benchmarks for male and female athletes. The "Weight 10%" column highlights the test's importance in evaluating overall agility, with scores ranging from 1 (Very Poor) to 5 (Excellent).

The table 9 specifies gender-specific benchmarks for the wall sit test, indicating endurance levels in leg strength. Scores are allocated based on the duration an athlete can maintain the wall sit position, with the "Weight 20%" reflecting this test's importance in the overall assessment of physical fitness, particularly focusing on leg strength.

The table 10 outlines the beep test levels required for different categories, with separate standards for male and female athletes. The scores reflect the athlete's aerobic endurance level, with the "Weight 25%" signifying the importance of this test in evaluating cardiovascular fitness.

After obtaining the norms for each physical test item for early-age Pencak Silat. Then a norm for the conclusion of the overall physical test results is prepared. The overall norms of physical tests are also categorized into 5 categories. The norms for the overall physical condition are presented in Table 11.

The table 11 the score ranges are consolidated

Table 8. Agility Norms (Side Step)

Side Step			**Weight 10%**	**Category**
Male	**Female**	**Score**	**Score**	
> 12.5	> 12	50	5	Excellent
11 to 12.5	10.5 to 12	40	4	Good
9.5 to 11	9 to 10.5	30	3	Average
8 to 9.5	7.5 to 9	20	2	Poor
< 8	< 7.5	10	1	Very Poor

Note: The notation "to" is used to indicate ranges between two statistical measures.

Table 9. Leg Strength Norms (Wall Sit)

Wall Sit (seconds)			**Weight 20%**	**Category**
Male	**Female**	**Score**	**Score**	
> 145.13	> 120.65	50	10	Excellent
104.95 to 145.13	87.03 to 120.65	40	8	Good
64.77 to 104.95	53.41 to 87.03	30	6	Average
24.59 to 64.77	19.79 to 53.41	20	4	Poor
< 24.59	< 19.79	10	2	Very Poor

Note: Times are measured in seconds. The notation "to" is used to indicate ranges between two statistical measures.

Table 10. Aerobic Endurance Norms (Beep Test)

Beep Test (Level)			**Weight 25%**	**Category**
Male	**Female**	**Score**	**Score**	
> 41	> 31	50	12.5	Excellent
32 to 41	25 to 31	40	10	Good
23 to 32	19 to 25	30	7.5	Average
14 to 23	13 to 19	20	5	Poor
< 14	< 13	10	2.5	Very Poor

Note: The notation "to" is used to indicate ranges between two statistical measures.

Table 11. Overall Physical Fitness

Score Range (Male and Female)	**Category**
43 to 50	Excellent
35 to 42	Good
27 to 34	Average
18 to 26	Poor
10 to 17	Very Poor

Note: The notation "to" is used to indicate ranges between two statistical measures.

for both male and female athletes, indicating the overall physical fitness category based on total scores. Based on the results of the preparation of physical test norms for early childhood pencak silat, every martial artist can determine their physical condition. To determine the physical condition, the standard results from measuring each test item are then added up. The summed results are then adjusted to the standard category overall score for each item of the early childhood pencak silat physical test in Table 11.

Discussion

Based on the research findings, norms have been established for each component of the physical tests tailored to early-age Pencak Silat practitioners. These components are classified into five distinct levels: very poor, poor, average, good, and excellent. The established numerical benchmarks within these norms were derived from measurements taken from male and female early-age martial artists. These artists varied in their experience and training backgrounds, encompassing novice participants, those under district and provincial development programs, and martial artists receiving private or independent training. This comprehensive approach was adopted to ensure the resultant physical condition data would cover all essential aspects. In addition to capturing a wide range of physical conditions, the sample size for norm development was also carefully considered, with a minimum of 100 subjects deemed necessary [12]. These subjects were distinct from those involved in the validity and reliability testing of the instruments. Furthermore, all test subjects were required to be in good health and optimal condition to minimize any potential measurement bias [29].

The research findings also delineate varied weightings for interpreting the scores of each test item, tailored to the specific characteristics of the Pencak Silat sport as identified by experts. The allocated weight values for each physical test item in Pencak Silat, as determined by these experts, are as follows: sit and reach at 10%, sprint 30 meters at 20%, push-ups for 30 seconds at 8%, sit-ups for 30 seconds at 7%, side step at 10%, wall sit at 20%, and the beep test at 25%. These weightings are critical for achieving objective scores, especially when a participant's performance in one test item may be lower than in others [30]. This approach to weighting differentiates the test battery as a measurement instrument from existing methodologies. With the establishment of these norms, the newly developed instrument offers coaches and relevant organizations a valuable tool for collecting data to evaluate the efficacy of training programs [31].

Besides paying attention to the health conditions and characteristics of subjects, and weighting in the development of norms for the instrument being constructed, other aspects need consideration in the norm-setting process to obtain good data. For instance, the equipment used in the norm-setting process [32, 33] should be ensured to be in good condition and well-prepared to facilitate the data collection process [34]. Additionally, the quantity of equipment used must be adjusted according to the number of subjects [35], ensuring that subjects do not wait too long. Excessive waiting time can introduce bias to the data, especially considering predetermined time intervals between measurement stations.

Moreover, ensuring the safety of the data collection location is essential. Safety considerations for the data collection site include flat, non-slippery ground without holes, meeting the specified requirements for data collection [36, 37]. Ensuring safety helps prevent the risk of injuries during the measurement process [38, 39] and ensures that subjects are not disrupted during measurements, thereby preventing biased data collection [40]. Additionally, another important aspect of the data collection process is preparing for alternative measurements in case of unfavorable weather conditions, particularly when measurements are conducted outdoors [41].

Administrative and procedural management in physical fitness measurement is essential and should be conducted [42]. This involves assigning tasks to each administrative section, field officers, and data analysis officers. Personnel involved in data collection need to be well-prepared for the norm-setting process [43], as they are directly involved in data collection [4]. Data collectors should undergo training before commencing their duties, covering implementation procedures, completion of assessment forms, calculation processes, recording procedures, proper use of measurement tools, and consideration of errors during the measurement process [44].

Furthermore, data analysis officers play a crucial role in the norm-setting process [11]. They are responsible for inputting data into the computer and compiling norms using predetermined formulas. Therefore, it is crucial to organize all personnel involved in the data collection and data analysis processes. Researchers developing measurement instruments in sports should carefully consider these aspects.

Further research is essential to assess instruments in subsequent age stages in Pencak Silat. The development of instruments for technical, tactical, and mental abilities in Pencak Silat is also crucial. It would be advantageous if the measurement instruments developed were in digital form to simplify the measurement process.

Conclusions

Norms have been established for each item in the physical tests for early-age Pencak Silat, as well as overall norms. These norms are categorized into five levels: excellent, good, average, poor, and very poor. Additionally, the weighting for each test item is determined according to the characteristics of Pencak Silat, as advised by experts. This weighting is carried out to adjust for the dominant energy requirements in the martial arts sports branch.

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ORIGINAL ARTICLE

Longitudinal analysis of physical abilities and fundamental skills among the Real Madrid Foundation UNY football players

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

Abstract

Background and Study Aim Football requires physical ability and fundamental skills. Observations regarding this aspect are still mostly carried out in the short term so the results found cannot be said to be comprehensive. The research aims to determine the development of physical abilities and fundamental skills simultaneously within a period of one year.

Material and Methods The research is quantitative and descriptive with a longitudinal approach. Participants consisted of 31 male soccer players aged 13-15 years, with weights ranging from 47 to 60 kg and heights ranging from 146 to 164 cm. Sit and reach instruments, 30-meter sprint, vertical jump, MFT, arrowhead, ball throwing, dribbling, passing, receiving, and shooting instruments. Wilcoxon, Kruskal Wallis, and Posh Hoc test data analysis techniques assisted by SPSS 23.

Results The Post Hoc analysis yielded comprehensive results, with overall Adj.Sig values ranging from 0.000-0.023 < 0.05 for variables of physical abilities and fundamental skills. Wilcoxon test results for physical abilities, flexibility, coordination, speed, power, agility, endurance sig 0.000 - 0.024 <0.05. Fundamental skills shooting, dribbling, receiving, passing sig 0.000<0.05. The results of the Kruskal Wallis test for physical ability and fundamental skills have a sig value of 0.000 <0.05.

Conclusions Based on the results obtained, it can be concluded that observations for one year illustrate that the physical abilities and fundamental skills of soccer players in the second semester are better than in the first semester. Apart from that, there is simultaneous development of the physical abilities and fundamental skills of soccer players within a period of one year.

Keywords: longitudinal study, physical abilities, fundamental skills, football players, young age

Introduction

Physical abilities and fundamental skills are crucial aspects often considered in the professional development of football players [1]. These respectively include flexibility, endurance, coordination, speed, and power [2], as well as dribbling, shooting, receiving, and passing, which play significant roles in determining the results of a match [3]. Seamless coordination, agility, and speed are required when running, dribbling, passing opponents, and shooting football. Additionally, adequate endurance is needed to maintain performance during a twice 45-minute match [4]. A study reported that elite players commonly execute 150-250 intense and brief actions in a single match [5], signifying the importance of cultivating physical abilities and fundamental skills among the young age group.

In response to the challenges, the Real Madrid Foundation at Yogyakarta State University (UNY) implements football coaching focused on long-term athlete development (LTAD). This approach includes planned, systematic, and sustainable coaching aimed at achieving early victories alongside the development of life skills, such as cooperation, tolerance, leadership, respect, and a sense of ownership [6]. Additionally, age groups of football players are adjusted based on chronological or actual age, years of training, as well as physiological, psychological, and pedagogical principles [7]. Despite these efforts, optimal implementation of the LTAD concept in football coaching has not been attained.

Previously, Fischeeti & Greco applied a multilateral training approach to enhance physical, technical, and motor skills [8]. Several other studies implemented resistance training based on LTAD [9], explored the opinions of coaches on LTAD effectiveness [10], and assessed the sociological perspective of LTAD adaptation and application [11]. Some sources conducted a narrative model study on the development and coaching of young athletes [12], physiological monitoring [13], and application of game experience learning in football adapting the LTAD concept [14]. Further examinations extended

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to the development of LTAD-based training models in various stages of sports such as judo [15] and pencak silat (17), testing of LTAD concept impact on physical development and academic performance [16], as well as performance augmentation based on physical education [17]. Recently, LTAD-based programming was implemented to enhance physical abilities and fundamental skills in basketball [18].

Most of the studies are confined to short-term coaching, LTAD-based model development, and cross-sectional experimental designs, lacking correspondence with LTAD terminology, particularly in terms of long-term monitoring through longitudinal studies. Additionally, the LTAD concept has been criticized for solely being a theoretical process without practical verification [19]. More scientific evidence and evidence-based analyses are suggested for the validation of LTAD effectiveness. This observation is reinforced by the report of various limitations arising from model-based assumptions and less comprehensive study techniques [13], hence scientists need to revise, question, and thoroughly test the LTAD concept [13].

Physical abilities and fundamental skills testing in football should not be viewed solely as a short-term improvement measure because it is unfit to serve as a final benchmark in LTAD implementation. However, training consistency and natural selection provide real evidence of football player performance. In the holistic development of young athletes, internal factors as well as environmental aspects, including parental support, discipline, and adequate coaching resources, need to be examined [16].

Considering the existing gaps in previous investigations, this study aimed to conduct a longitudinal analysis of physical abilities and fundamental skills in young football players at the Real Madrid Foundation Academy of UNY.

Material and Methods

Participants

This study comprised 31 male football players aged 13-15 years, with weights of ±47-60 kg and heights ranging from 146-164 cm. Furthermore, the participants were affiliated with the Real Madrid Foundation Academy in UNY, Indonesia.

Informed consent was acquired from parents, and the study received approval from the Yogyakarta State University ethics committee because the procedures were in accordance with the standards set forth in the Declaration of Helsinki.

Study Design

This quantitative descriptive study applied a longitudinal approach that obtained facts through continuous and time-focused observational analysis [20]. The study used a longitudinal panel study design, concentrating on time, with variables examined from the same sample at different times [21]. Data were collected through observational and field tests, aiming to explore the state of physical abilities, including flexibility, speed, vertical jump, aerobic endurance, agility, and coordination, as well as fundamental skills comprising dribbling, passing, receiving, and shooting. Instruments used to measure physical abilities included sit and reach, 30-meter sprint, vertical jump, multistage fitness test, arrowhead, as well as ball catching and throwing [22]. Meanwhile, fundamental skills were assessed with dribbling, passing, receiving, and shooting [23] according to the following testing order.

Preparation Phase

Current individual status, including physical abilities and fundamental skills, was assessed through observation of the Real Madrid Foundation UNY football players aged 13-15 years old. Due to insufficient data resulting from previous studies based on cross-sectional designs, the need for longitudinal observations was identified. Subsequently, instruments for conducting field tests on characteristics such as physical abilities and fundamental skills, were prepared.

Study Phase

From January to June 2023, observations and field tests were conducted to obtain supporting data and rationalization materials. In June 2023, the first-semester assessment of physical abilities and fundamental skills was performed. Generated data were collected, evaluated, and interpreted, then the total results of first-semester tests were analyzed. In December 2023, the second-semester assessment was performed. The second-semester data were collected, evaluated, and interpreted, then the general results were analyzed.

Final Phase

From first and second-semester tests, numerical and language data were interpreted to observe the development of physical abilities and fundamental skills. The percentage results of each observed variable were analyzed, comparing first-semester and second-semester tests, and examining the simultaneous influence of second-semester tests on physical abilities and fundamental skills.

Statistical Analysis

Quantitative data analysis was conducted to derive minimum, maximum, mean, and standard deviation values [24]. Subsequently, the nonparametric Wilcoxon test was used to compare first and second-semester results for each component [14]. To observe a simultaneous difference in second-semester results, the Kruskal-Wallis test, an alternative to the Manova test, was used [25], and the entire analysis processes were performed with SPSS version 23.

Results

Descriptive analysis results, including values from first and second-semester tests, are presented in Table 1.

Second-semester tests yielded mean values greater than those of first-semester tests in every component of physical abilities and fundamental skills. Specifically, in both semesters, the mean values of flexibility, power, agility, endurance, coordination, and speed had differences of 3.8, 3.94, 0.88, 0.7, 3.97, and 0.42, while passing, dribbling, shooting, and receiving had differences of 5, 2.76, 36, and 6, respectively. These showed that second-semester tests identified better development among the football players compared to first-semester tests conducted. Moreover, the results of the Wilcoxon test comparing the first and second-semester tests, are presented in Table 2.

The Wilcoxon test results showed that both physical abilities and fundamental skills had overall Asymp.sig. (2-tailed) values <0.05, presenting significant differences between the first and second-semester tests. Specifically, flexibility, power, agility, endurance, coordination, and speed had values of 0.002<0.05, 0.000<0.05, 0.000<0.05, 0.000<0.05, 0.024<0.05, and 0.000<0.05, while passing dribbling, shooting, and receiving had 0.000<0.05, 0.000<0.05, 0.000<0.05, and 0.000<0.05, respectively. Moreover, Table 3 presents the results of the Kruskal-Wallis test for the simultaneous development of physical abilities and fundamental skills assessed in second semester.

The Kruskal-Wallis test results showed that variables of physical abilities and fundamental skills yielded Asymp.sig. (2-tailed) values of 0.000 < 0.05, signifying the existence of a simultaneous difference between both. To further observe simultaneous differences between several variables, Post Hoc analysis was conducted, generating the following results presented in Table 4.

The Post Hoc analysis yielded comprehensive results, with overall Adj.Sig values ranging from 0.000-0.023 < 0.05 for variables of physical abilities and fundamental skills. This suggested significant and simultaneous development of several variables subjected to second-semester tests among the football players. Figure 1 provides a clearer representation of the results through yellow lines connecting the related variables.

Discussion

The purpose of this study is to determine the development of the physical and fundamental skills of young soccer players. Based on the results obtained from observations during the first year, the results of the second semester test are better

Table 1. Descriptive analysis results of first and second-semester tests

Physical Abilities	Min	Max	Mean	Std. Dev
Flexibility 1	19	39	31.81	5.833
Flexibility 2	2	46	35.61	5.619
Power 1	29	57	44.58	6.536
Power 2	39	62	48.52	5.638
Agility 1	17	22	18.91	1.082
Agility 2	16	21	18.03	1.137
Endurance 1	47	54	50.79	1.820
Endurance _2	47	55	51.49	1.831
Coordination 1	40	73	52.16	7.819
Coordination 2	28	73	56.13	10.069
Speed 1	4.11	5.22	4.72	0.30232
Speed 2	4.00	5.00	4.30	0.29137
Fundamental Skills	**Min**	**Max**	**Mean**	**Std. Dev**
Passing 1	2	12	8	2.484
Passing 2	10	20	13	2.767
Dribbling 1	22	32	24.74	3.215
Dribbling 2	20	28	21.98	1.855
Shooting 1	17	55	34	9.983
Shooting 2	32	90	70	15.883
Receiving 1	7	14	11	1.911
Receiving 2	9	22	17	3.749

Table 2. Wilcoxon test results for the first and second-semester tests

Aspect	Variable	Mean	Difference	Asymp.sig. (2-tailed)
Physical Abilities	Flexibility 1	31.81	3.8	0.002
	Flexibility 2	35.61		
	Power 1	44.58	3.94	0.000
	Power 2	48.52		
	Agility 1	18.91	0.88	0.000
	Agility 2	18.03		
	Endurance 1	50.79	0.7	0.000
	Endurance 2	51.49		
	Coordination 1	52.16	3.97	0.024
	Coordination 2	56.13		
	Speed 1	4.72	0.42	0.000
	Speed 2	4.30		
Fundamental Skills	Passing 1	8	5	0.000
	Passing 2	13		
	Dribbling 1	24.74	2.76	0.000
	Dribbling 2	21.98		
	Shooting 1	34	36	0.000
	Shooting 2	70		
	Receiving 1	11	6	0.000
	Receiving 2	17		

Table 3. The Kruskal-Wallis test results for physical abilities and fundamental skills

Variable	Asymp.sig. (2-tailed)
Physical abilities (flexibility, power, agility, endurance, coordination, and speed) * fundamental skills (passing, dribbling, shooting, and receiving)	0.000

than the results of the first semester test in aspects of physical and fundamental skills, and there is a simultaneous increase. Based on these findings, the author can state that monitoring the increase in physical and fundamental skills in football needs to be carried out comprehensively. In this case, exercise programming is carried out in a planned, systematic, and sustainable manner. Optimizing the development of physical and fundamental skills in soccer players is one of the basic ways to achieve achievements driven by the day.

Physical abilities and fundamental skills share a positive relationship in football performance, hence this study explains the components of physical abilities sequentially. The explanation starts with flexibility, defined as the ability to move joints and muscles to the maximum extent [26]. Additionally, dynamic flexibility is the ability to move the body repeatedly, while extent flexibility is the capability to stretch the trunk and back muscles to the maximum limit.

An innovative study in basketball for 11-12-year-olds applied the Raise, Activation Mobility, and Potentiation (RAMP) principles to develop flexibility [18]. Raise includes characteristic movements such as lifting the front, back, and side thighs, which increases blood flow, core and muscle temperature, elasticity, and nerve conduction activation [18][26]. The Activation and Mobility phases feature active and passive stretching activities [18], while the Potentiation phase incorporates a series of specific movements as preparation for core exercises [26].

Despite the importance of the RAMP principles, many coaches occasionally neglect stretching, considering it an additional exercise not specifically programmed. At the age of 14 years, football players enter the peak high-velocity (PHV) phase, leading to motor disturbances because soft tissues adapt more slowly to rapid bone growth [27]. This slower adaptation results in joint range of motion challenges, abnormal movement pattern development, as well as decreased muscle and tendon flexibility, increasing the risk of extremity injuries [27]. Although this study shows increased flexibility, continuous development is essential as players age chronologically and gain experience, considering the integral role of flexibility in enhancing speed, power, agility, and coordination.

Table 4. Post Hoc analysis results for physical abilities and fundamental skills

Variable	Total statistics	Std.error	Std.test statistics	Sig	Adj.Sig
Speed-Receiving	-70.065	20.492	-3.419	0.001	0.023
Speed-Agility	-75.935	20.492	-3.707	0.000	0.008
Speed-Dribbling	-122.452	20.492	-5.976	0.000	0.000
Speed-Flexibility	157.516	20.492	7.687	0.000	0.000
Speed-Power	197.581	20.492	9.642	0.000	0.000
Speed-Endurance	-214.906	20.492	9.642	0.000	0.000
Speed-Shooting	-235.968	20.492	-11.515	0.000	0.000
Passing-Dribbling	-80.774	20.492	-3.942	0.000	0.003
Passing-Flexibility	115.839	20.492	5.653	0.000	0.000
Passing-Power	155.903	20.492	7.608	0.000	0.000
Passing Endurance	173.129	20.492	8.449	0.000	0.000
Passing-Shooting	-194.290	20.492	-9.481	0.000	0.000
Receiving-Flexibility	87.452	20.492	4.268	0.000	0.001
Receiving-Power	127.516	20.492	6.223	0.000	0.000
Receiving-Endurance	144.742	20.492	7.063	0.000	0.000
Receiving-Shooting	165.903	20.492	8.096	0.000	0.000
Agility-Flexibility	81.581	20.492	3.981	0.000	0.002
Agility-Power	121.645	20.492	5.936	0.000	0.000
Agility-Endurance	-138.871	20.492	-6.777	0.000	0.000
Agility-Shooting	-160.032	20.492	-7.810	0.000	0.000
Dribbling-Power	75.129	20.492	3.666	0.000	0.009
Dribbling-Shooting	-113.516	20.492	-5.540	0.000	0.000
Flexibility-Shooting	-78.452	20.492	-3.828	0.000	0.005

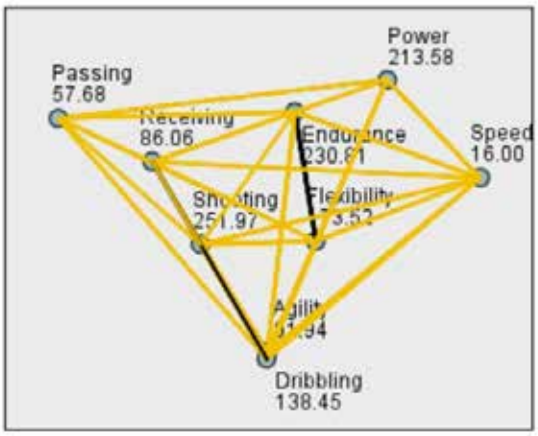

Figure 1. Pairwise comparisons of physical abilities and fundamental skills.

Coordination is a combined movement of two or more related joints to produce effective fundamental skills [28], often enhanced through the agility, balance, and coordination (ABC) running exercise model [29]. Improved coordination contributes to better accuracy in shooting [30,31], while flexibility and coordination positively impact motion speed in football sport.

Speed training stages are influenced by flexibility and endurance strength, as football athletes with good flexibility and techniques often move effectively and efficiently. A strong player can move quickly, and an enduring type will perform quick movements repeatedly for a long duration. Characteristics such as maximum cyclic speed, agility, and quickness are highly needed in football.

Agility is an integrated speed, which refers to the ability to change direction quickly in a relatively short time with a stimulus [32]. Integration between balance, coordination, flexibility, and reflex speed needs to be achieved before maximizing agility training. Scientific approaches to improve movement quality and increase running step frequency contribute to effective speed training.

The combination of speed and strength yields power, but 14 to 15-year-old players engaging in power training should focus on foundational development [33]. Integration of power training with agility ladder drills and techniques requires careful consideration [34]. A combination of weight training and plyometrics enhances jump height, strength, and running performance at various ages. However, characteristics such as intensity, volume, and type of exercise must correspond to the maturity and initial strength level of players [35]. Training concentrated on speed, strength, and endurance forms the foundation for developing physical abilities.

The movement patterns in football include low, moderate, and maximum intensity. Players run approximately 13 km in a single match, with predominant distances covered being low-intensity long-duration and high-intensity short-duration [36]. An in-depth analysis of elite football players showed 28% high-intensity (2.43 vs 190 km) and 58% sprint (650 vs 410 m) compared to the amateurs [14,36]. Therefore, young football players need good endurance, developed through general training integrated simultaneously with technical training.

Regarding fundamental skills, coaches should innovate and implement varied training techniques, including drills, massed and distributed practices, games experience learning, multilateral development, and part-whole approaches [8,14,29,37–39]. These contribute positively to the development of fundamental skills in football players. Besides, it is essential to reiterate that peak performance is achieved at the senior age. This implies that achieving success at a young age is not necessarily a benchmark for becoming a champion at the senior level. Therefore, understanding of pedagogical principles by coaches plays a key role in helping athletes explore potential and gain broad knowledge for individual, social, and health benefits [40].

Conclusions

In conclusion, significant differences were observed between first and second-semester test results for physical abilities, including flexibility, coordination, speed, power, and endurance as well as fundamental skills, comprising dribbling, receiving, shooting, and passing. Additionally, this study identified a simultaneous difference between physical abilities and fundamental skills of the young Real Madrid Foundation UNY football players, with second-semester tests producing better results.

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ORIGINAL ARTICLE

Mediating role of physical activity levels on physical fitness in overweight and obese children when Body Mass Index is not a determining factor

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Abstract

Background and Study Aim Physical fitness is a crucial health indicator in children and adolescents. Despite the global rise in overweight and obesity, the impact of Body Mass Index (BMI) on physical fitness remains unclear. This cross-sectional study aims to investigate: (R1) the differences in physical fitness components and physical activity levels among children according to gender and BMI, and (R2) the mediating role of physical activity in the relationship between BMI and physical fitness components.

Material and Methods The sample was made of 180 students aged 11-14 years (n=90 – male; n=90 - female) divided according to BMI cutoff in normal weight, overweight and obese. Physical fitness components were assessed with several tests: Standing Long Jump (SLJ), Medicine Ball Throw 2Kg (MBT), Shuttle Run 10x5m (10x5), and One Mile Walk Test. Physical activity levels were evaluated with a self-reported questionnaire. A two-way factorial MANOVA was conducted to assess the effects of gender and BMI on physical fitness. Additionally, a mediation analysis was performed to explore the effect of physical activity on the relationship between BMI and physical fitness.

Results Results revealed significant differences in the Standing Long Jump (SLJ), 10x5 Shuttle Run, One Mile Walk Test, and physical activity levels, with moderate to large effect sizes observed. Males demonstrated higher levels of physical fitness and physical activity levels (PAL) compared to females. Individuals of normal weight were generally more active and stronger than their overweight and obese peers. Mediation analysis revealed that physical activity completely mediates the relationship between BMI and physical fitness components.

Conclusions Results from the present study suggest that the development of physical fitness is not solely determined by BMI, but also depends on the daily practice of physical activity. Future research is needed to assess the effect of physical activity in mediating and moderating the relationship between obesity and physical fitness.

Keywords: obesity, overweight, physical fitness, physical activity, children.

Introduction

Physical inactivity among children and adolescents is a growing global health concern, particularly given its association with various negative health outcomes. The importance of physical activity for enhancing the health status of young populations cannot be overstated. The international literature has extensively documented the positive effects of physical activity on both physiological and psychological aspects of health in young people [1, 2]. Moreover, the World Health Organization (WHO) recommends that children and adolescents engage in at least 60 minutes of moderate to vigorous physical activity daily. This should include activities aimed at developing muscle strength at least three times per week, which have been shown to confer numerous benefits across organic systems as well as cognitive, psychological, emotional, and social domains [3, 4].

Nevertheless, in recent decades there has been a gradual and progressive increase in sedentary levels with a worrying increase in the percentage of overweight and obese children and adolescents. According to the WHO (2024) adult obesity was more the double since 1990, and quadrupled in adolescents, with 37 millions of children under 5 years who were overweight [5]. This negative trend, despite picturing the state of art about the reduction in levels of physical activity and poor eating habits in children and adolescents worldwide, is particularly worrying if considered in relation to the impact that could have on the costs and efficiency of the health system in the coming years. As predicted by the World Obesity Federation measures to combat and prevent overweight and obesity will be necessary, otherwise the economic impact on healthcare system could be higher than 4.32 trillion dollars annually by 2035 [6]. The costs for the management of chronic-degenerative diseases resulting from physical inactivity,

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overweight and obesity are around $173 billion a year in America [7] and 70 billion Euro per years in Europe [8]. Considering the rapid global increase of this negative trend, the numbers could be even higher over the next few years.

Overweight and obesity during childhood are strongly linked to comorbidities development, such as hypertension, metabolic syndrome, diabetes, dyslipidemia and low quality of life [9]. In this context, physical activity, exercise and lifestyles represent important measure to maintain heathy weight and healthy [10] .The concept of physical fitness as health indicator is not new in educational research and public health. By 1988 Lamb et al. [11] recognized the positive role of components of physical fitness as health-indicator in terms of agility, strength, flexibility, speed, aerobic endurance, body composition and posture.

Caspersen et al. [12] pointed out the difference between the five health-related – important for public health - components of physical fitness (i.e., cardiorespiratory endurance, muscular endurance, muscular strength, body composition and flexibility) and skills-athletic related fitness (i.e., agility, balance, coordination, speed, power and reaction time). The concept of physical fitness is strictly related to that of health-related fitness as a multidimensional construct linked to the development and/or maintenance of healthy and positive state of being as a consequence of physiological adaptation to increased overload [11, 12, 13].

Health-related physical fitness components are briefly described as follows [12]:

- cardiorespiratory endurance defines the ability of both the circulatory and respiratory system to contrast and eliminate fatigue during sustained physical activity;
- muscular endurance defines the ability of muscle to external force that muscle can exert;
- muscular strength defines to the amount of external force that a muscle can exert;
- flexibility defines to the range of motion available during movement performance;
- body composition defines the relative amounts of muscle, fat, bone and other body parts.

According to recent findings, overweight and obese children showed lower levels of absolute muscular strength [14, 15], aerobic endurance [16, 17], and speed and agility [18, 19]. Cross-sectional studies conducted on Italian children showed that both lower levels of physical activity and increased BMI negatively affected children's physical fitness and health status [20, 21, 22]. Moreover, physical inactivity results in an increase of adiposity and weight status in children, suggesting that recommended levels of physical activity and active lifestyles may reduce the risk of higher adiposity [23, 24].

According to Ortega et al. moderate to vigorous physical activity is positively associated with lower total and central adiposity in children and adults, and, despite the inverse relationship between physical fitness and body fat, active overweight and obese show similar fitness levels to normal weight peers [25]. This is particularly alarming when considered the emergence of progressive reduction in moderate to vigorous physical activity of overweight and obese children aged >6 years [26].

Starting from literature review on this topic, the researcher's interest is focused on the following research questions:

(R1) differences in physical fitness components and physical activity level in children according to gender and BMI;

(R2) the mediating role of physical activity between BMI and physical fitness components.

Based on literature review, the hypothesis tested are that normal-weight children should show better motor performances and higher PAL compared to overweight and obese groups, while better adherence to physical activity and active lifestyles could affect positively all physical fitness components, independently of gender.

Materials and Methods

Participants

The University of Salento (Lecce, Apulia) coordinated the study procedure. The sample was randomly recruited by first grade of secondary schools that joined the "Regional Observatory of Motor Development Project" in Apulia. 180 children aged 11-14 years (Male= 90, F= 90) were involved in this cross-sectional design study. Before data collecting, informed consent was obtained by all children as required by project management. G*Power software was used to calculate adequate sample size to run analysis. Medium effect size *f2* (V) = 0,15 [27], and α level at 0.05 were set as reference value. Results suggested a sample size of 54 that is met by the sample involved in the present study that is 180.

Research Design

Children were randomly selected from Lecce Apulian Province to increase the representativeness in the target population and reduce variability. After detecting weight and height, participants were classified as normal weight, overweight or obese according to Cole's Scale [28].

A multistage sampling procedure was applied to recruit study population (*N*= 180) according to gender and BMI Cutoff (M= 90, Nw= 30, Ow= 30, Ob= 30; F= 90, Nw= 30, Ow= 30, Ob= 30) from children involved in the "Regional Observatory of Motor Development Project" with no disability or mental/physical impairments or disorders.

Physical fitness assessment provided the Standing Long Jump (SLJ) and Medicine Ball Throw

2Kg (MBT) to evaluate lower and upper limbs strength, respectively [29,30]. Shuttle Run 10x5m (10x5) was proposed as indicator of speed and agility [31], and One Mile Walk Test for aerobic endurance [32].

Levels of Physical Activity (PAL) were assessed with a digitalized version of the Physical Activity Questionnaire for Older Children – Italian [33, 34, 35] to evaluate self-reported daily practice of physical activity during the last week, with values range from 1 (low physical activity) to 5 (high physical activity). Children are usually classified into 3 categories based on their total averages of physical activity results: scores ranging from 1 to 2.33 correspond to low levels of physical activity, from 2.34 to 3.66 to moderate physical activity, and from 3.67 to 5 to high levels of physical activity, respectively.

Assessment was conducted by physical education (PE) teachers and a team of Graduate in Motor and Sports Science involved in the Regional Observatory Project during curricular PE lessons from October to December 2023.

Statistical Analysis

In addition to descriptive statistic (mean ± standard deviation), a two-way factorial MANOVA was performed to assess main and interaction effects of gender and BMI Cutoff on physical fitness components. Factorial MANOVA was robust (participants per group > 10) to any divergence from multivariate normality, and multivariate homogeneity of variance-covariance matrix assumption was assessed with Levene's test. Due to small and unequal sample size, Pillai's *F* statistic was used to evaluate main effect of gender and BMI Cutoff on dependent variables (SLJ, MBT, 10x5 and Mile). The effect of Gender was analyzed in simple effects MANOVAs for each BMI Cutoff and vice versa. Partial eta squared (η^2) has been used to estimate effect size, interpreting results as follows: 0.01= small effect, 0.06 = medium effect, and 0.14 or higher = large effect [27]. Furthermore, independent t-test have been performed to assess significant differences according to gender and Bonferroni correction has been applied for multiple-comparison adjustment. Cohen's *d* was used as effect size value: 0.2 = small effect, 0.5 = medium effect, and 0.8 = large effect [27]. Mediation analysis was conducted according to Preacher and Hayes methods [36], setting BMI as independent variable, physical fitness components (SLJ, MBT, 10x5 and Mile) as DV, PAL as mediating factor and gender as confounders. The following indices were carried out:

- total effect of the independent variable (IV) on dependent variable (DV);
- the direct effect of IV on DV controlled per mediation variable (MV),
- indirect effect, that is product of IV on MV effect and the MV on DV effect.

If the indirect effect was significant, mediation was defined as partial, and total if indirect effect was non-significant. All significant indexes were set at p <.05. SPSS (ver. 26) was used to perform all statistical analysis.

Results

Sample's descriptive profile of anthropometric characteristics, physical fitness components and physical activity levels are reported in Table 1 divided by gender and BMI Cutoff. Descriptive analysis generally reveals physical fitness and physical activity levels in both male and female normal weight sample, compared to overweight and obese peers.

Multivariate analysis of variance highlighted significant main effect for both gender (F= 11.529, Pillai's trace = 0.274, *p*< .001) and BMI Cutoff (F= 13.886, Pillai's trace = 0.621, *p*< .001). Interaction effect (F= 2.864, Pillai's trace = 0.17, *p* = 0.002) was also significant. Since both main and interaction effect were significant, post-hoc analysis was performed for all variables considered (Table 2).

Results from ANOVA (Table 3) revealed that both gender and cutoff were significant predictors in SLJ (F_{gender} = 27.985, *p*< .001; F_{cutoff} = 42.791, *p*< .001), 10x5 (F_{gender} = 34.930, *p*< .001; F_{cutoff} = 29.050, *p*< .001), One Mile Wt (F_{gender} = 20.654, *p*< .001; F_{cutoff} = 28.734, *p*< .001) and PAL (F_{gender} = 22.031, *p*< .001; F_{cutoff} = 3.149, *p* = 0.045), while MBT showed significant difference according to gender (F_{gender} = 11.455, *p*< .001). Moreover, large effect size (η^2 > .06) emerged for all variables involved in the running analysis. Post-hoc test highlighted better male performance in SLJ (*p*< .001, Cohen's d = -. 791), MBT (*p*< .001, Cohen's d = - .505), 10x5 (*p*< .001, Cohen's d = .903), Mile (*p*< .001, Cohen's d = .685), and PAL (*p*< .001, Cohen's d = -. 710), with absolute value of effect size ranging from .505 to .903. Moreover, normal weight showed higher lower limbs strength (*p*< .001) and aerobic endurance (*p*< .001) compared to overweight and obese peers. Normal weight showed better performance than obese children in 10x5, but no difference were highlighted for MBT. Finally, overweight children were generally more physically active than obese peers (*p* = .043). All analysis showed moderate to large effect size.

Results of mediation analysis are summarized in Table 4. As confirmed by previous analysis, finding revealed significant total effect of BMI on SLJ (*p* < .001), 10x5 (*p* < .001) and One Mile Wt (*p* < .001), while indirect effect was non-significant for all variables considered. Furthermore, since the direct effect of BMI on physical fitness components controlled per PAL was significant for SLJ, 10x5 and One Mile Wt, it can be assumed that PAL totally mediate their relationship.

Table 1. Anthropometric and physical fitness components measures

Measures		Normal Weight					Overweight					Obese				
Group		N	Min	Max	Mean	SD	N	Min	Max	Mean	SD	N	Min	Max	Mean	SD
Female	Age	30	13.00	13.00	13.00	0.00	30	12.00	13.00	12.73	0.45	30	11.00	13.00	12.37	0.85
	Weight (Kg)	30	34.00	65.00	49.59	7.36	30	46.00	75.00	61.07	6.99	30	54.00	100.0	76.73	11.56
	Height (m)	30	1.44	1.76	1.59	0.08	30	1.45	1.73	1.60	0.07	30	1.41	1.72	1.59	0.07
	BMI	30	14.15	25.08	19.94	2.38	30	21.50	27.14	23.82	1.31	30	25.65	36.36	30.15	3.36
	SLJ	30	1.10	1.90	1.47	0.20	30	0.95	1.53	1.26	0.15	30	0.60	1.55	1.06	0.21
	MBT	30	3.00	7.20	5.01	1.03	30	3.10	5.98	4.64	0.71	30	2.90	8.40	5.24	1.35
	10x5	30	15.27	28.60	21.61	3.01	30	19.96	27.11	23.86	1.61	30	21.24	29.39	25.93	1.87
	Mile	30	7.46	14.20	10.27	2.02	30	7.57	15.50	11.21	2.09	30	7.30	19.78	13.15	3.55
	PAL	30	1.01	2.61	2.04	0.41	30	1.44	2.98	2.09	0.47	30	1.00	3.19	2.07	0.61
Male	Age	30	13.00	13.00	13.00	0.00	30	12.00	13.00	12.47	0.51	30	11.00	13.00	12.40	0.56
	Weight (Kg)	30	31.00	63.00	48.22	9.14	30	46.00	71.00	60.38	6.62	30	55.00	96.00	77.27	9.44
	Height (m)	30	1.46	1.79	1.60	0.08	30	1.44	1.78	1.61	0.09	30	1.43	1.80	1.63	0.10
	BMI	30	14.54	22.64	18.62	2.34	30	20.9	26.31	23.60	1.55	30	26.08	30.47	28.33	1.11
	SLJ	30	1.07	2.20	1.70	0.26	30	0.95	1.99	1.43	0.27	30	0.60	2.10	1.26	0.37
	MBT	30	3.10	8.50	5.80	1.31	30	3.25	8.13	5.59	1.19	30	0.21	9.70	5.43	1.79
	10x5	30	18.25	24.46	21.25	1.50	30	15.45	27.82	20.07	3.07	30	16.53	28.50	23.41	2.77
	Mile	30	6.27	12.29	8.45	1.61	30	6.50	12.78	9.69	1.38	30	7.30	16.13	11.80	2.34
	PAL	30	1.74	3.09	2.40	0.44	30	1.57	4.21	2.70	0.61	30	1.51	3.67	2.24	0.62

Note: SLJ - Standing Long Jump; MBT - Medicine Ball Throw; 10x5 - Shuttle Run 10x5m; Mile - One Mile Walk Test; PAL - Levels of Physical Activity

Table 2. Multivariate Test

MANOVA						
Variables	**df**	**F**	**Pillai's Trace**	**Num df**	**Den df**	**p**
Gender	1	11.529	0.274	5	153.000	< .001
BMI Cutoff	2	13.886	0.621	10	308.000	< .001
Gender x BMI Cutoff	2	2.864	0.170	10	308.000	0.002

Discussion

The aim of this study was to assess (R1) the effect and incidence of gender and BMI in determining the components of physical fitness, and (R2) the mediation analysis between physical activity, BMI and physical fitness.

As reported in results, MANOVA highlighted that both main effect for gender and BMI Cutoff were significant, as well as interaction effect (R1). In fact, ANOVA analysis revealed significant differences in SLJ, 10x5, One Mile Wt, and PAL with moderate to large effect size, and post-hoc test showed higher levels of physical fitness and PAL in male than female, and normal weight were generally more active and stronger than overweight and obese peers.

These results are confirmed by other findings in literature, suggesting gender differences [37, 38] and the inverse relation between BMI and physical fitness [14, 39]. Higher body weight and BMI lead to negative consequences on muscle strength and explosive power [22], cardiorespiratory fitness and muscles endurance [40, 41].

The research question n2 concerns the analysis of the mediating role of PAL between BMI and health-related physical fitness. Results highlighted that PAL is a total mediator the relation between BMI and physical fitness components, suggesting that the development of physical fitness is not linked and determined exclusively by BMI, but it deepens on daily practice of physical activity.

Recent findings seem to support these evidence.

Table 3. Independent t-test and post-hoc analysis.

Main differences between Groups													
Tests	**Variables**	**SS**	**df**	**MS**	**F**	**p**	**η^2**	**Group**	**MD**	**SE**	**t**	**Cohen's d**	**p**
SLJ	Gender	1.78	1	1.78	27.985	< .001	0.097	F - M	-0.200	0.038	-5.290	-0.791	< .001
	Cutoff	5.46	2	2.73	42.791	< .001	0.297	Nw – Ow	0.239	0.046	5.164	0.947	< .001
								Nw – Ob	0.426	0.046	9.228	1.685	< .001
								Ow- Ob	0.186	0.046	4.025	0.738	< .001
MBT	Gender	18.63	1	18.63	11.455	< .001	0.061	F - M	−0.643	0.190	−3.384	−0.505	< .001
	Cutoff	2.82	2	1.41	0.869	0.421	0.009	Nw – Ow	0.293	0.233	1.259	0.230	0.420
								Nw – Ob	0.068	0.233	0.292	0.053	0.954
								Ow- Ob	−0.225	0.233	−0.967	−0.177	0.599
10x5	Gender	221.47	1	221.47	34.930	< .001	0.135	F - M	2.274	0.385	5.910	0.903	< .001
	Cutoff	368.38	2	184.19	29.050	< .001	0.225	Nw – Ow	−0.617	0.477	−1.293	−0.245	0.401
								Nw – Ob	−3.346	0.473	−7.078	−1.329	< .001
								Ow- Ob	−2.730	0.464	−5.887	−1.084	< .001
Mile	Gender	106.67	1	106.67	20.654	< .001	0.082	F - M	1.557	0.343	4.545	0.685	< .001
	Cutoff	296.80	2	148.40	28.734	< .001	0.229	Nw – Ow	−1.095	0.422	−2.595	−0.482	0.028
								Nw – Ob	−3.122	0.419	−7.459	−1.374	< .001
								Ow- Ob	−2.027	0.418	−4.843	−0.892	< .001
PAL	Gender	6.45	1	6.44	22.031	< .001	0.110	F - M	−0.384	0.082	−4.694	−0.710	< .001
	Cutoff	1.84	2	0.92	3.149	0.045	0.032	Nw – Ow	−0.176	0.101	−1.750	−0.325	0.190
								Nw – Ob	0.065	0.101	0.640	0.119	0.798
								Ow- Ob	0.241	0.099	2.425	0.445	0.043

Note: SS - Sum of Square; MS - Mean Square; MD - Mean Difference; SLJ - Standing Long Jump; MBT - Medicine Ball Throw; 10x5 - Shuttle Run 10x5m; Mile - One Mile Walk Test; PAL - Levels of Physical Activity

Table 4. Mediation Analysis

Effect Type	**BMI Effects**	**Estimate**	**Std. Error**	**z-value**	**p**	**95% Confidence Interval**
Direct Effect	BMI → SLJ	-0.036	0.004	-9.079	< .001	[-0.044, -0.028]
	BMI → MBT	0.015	0.020	0.760	0.448	[-0.024, 0.054]
	BMI → 10x5	0.298	0.041	7.191	< .001	[0.217, 0.379]
	BMI → Mile	0.254	0.036	6.993	< .001	[0.183, 0.325]
Indirect Effect	BMI → PAL → SLJ	0.0005	0.001	-0.435	0.663	[-0.003, 0.002]
	BMI → PAL → MBT	-0.002	0.005	-0.435	0.664	[-0.012, 0.008]
	BMI → PAL → 10x5	0.004	0.008	0.432	0.666	[-0.013, 0.020]
	BMI → PAL → Mile	0.004	0.008	0.432	0.666	[-0.012, 0.019]
Total Effect	BMI → SLJ	-0.036	0.004	-8.864	< .001	[-0.044, -0.028]
	BMI → MBT	0.013	0.021	0.632	0.527	[-0.027, 0.053]
	BMI → 10x5	0.302	0.042	7.154	< .001	[0.219, 0.385]
	BMI → Mile	0.258	0.037	6.946	< .001	[0.185, 0.330]

Note: SLJ - Standing Long Jump; MBT - Medicine Ball Throw; 10x5 - Shuttle Run 10x5m; Mile - One Mile Walk Test; PAL - Levels of Physical Activity.

According to Ortega et al. being normal weight or not being obese is not enough for manteinig health, and adequate physical fitness levels are unavoidable to gain and achieve health [42].

A recent study classified cardiometabolic risk factors categories in adolescents according to physical fitness, physical activity, and body composition [43]. Results highlighted that being fat and unfit lead to develop the highest cardiometabolic risk, rather than adolescents who had high BMI and higher cardiorespiratory fitness and muscular strength. Moreover, despite the well-known relation between parental physical activity and weight status on children's BMI [44, 45], leisure-time physical activity (> 3 times a week) significantly contributes to reduce prevalence of obesity in children, even if their parents were overweight/obese [46]. Another study demonstrated that children's adherence to international guidelines on physical activity (60 minutes of PA per day) could reduce the risk of being overweight and obesity by about 7% [47].

However, findings revealed that children with high body weight and high health-related physical fitness showed higher cardiometabolic risk compared with children with high physical fitness and low body weight [48]. On the contrary, Gomes et al. suggested that muscle strength was an important indicator for reducing the risk of developing cardiometabolic risk, regardless of physical activity [49].

These results are even more important if considering that higher aerobic endurance and muscle strength have the potential to enhance quality of life in children and adolescents [50]. Moreover, aerobic endurance and speed-agility mediate the negative association between excessive body weight and academic performance in children [51]. A recent study of) has highlighted the fundamental role of cardiorespiratory fitness as a fully mediator between motor competence and daily physical activity in both boys and girls, while according to González-Gálvez et al. cardiorespiratory fitness is a full mediator between obesity and PAL [52]. Moreover, cross sectional studies have already shown that the incidence of overweight and obesity is strictly related with lower levels of physical activity [53, 54].

Conclusions

The assessment of health-related physical fitness components in early adolescence is an unavoidable prerogative for national and international institutional policies in public health. The present study highlights the importance of physical activity and body weight management in determining adequate levels of physical fitness.

The proposed mediation models can be useful for teachers and educators to carried out methodological and didactic implication in the field of physical activity and in the light of growing increase of overweight and obesity during developmental age. On the one hand, the need to enhance the quantitative and qualitative opportunities for being physically active at school, and on the other hand the need to involve institutions and families to promote physical activity interventions during extra-curricular physical activity and leisure time. In fact, despite school-based interventions can have important potential for health promotion of children in terms of obesity, physical fitness and obesity prevention, other interventions should engage and involve families and group of peers in leisure time to best increase time spent in physical activity and moderate to vigorous intensity.

Furthermore, future research could analyze the mediating role of physical activity between anthropometric characteristics and physical fitness considering different/multiple methods for assessing overweight and obesity, age and sport participation as covariates, and assess the effectiveness of structured experimental interventions in modifying the relation between obesity and physical fitness.

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REVIEW ARTICLE

What are physical exercise interventions in older age? Literature review for physical and cognitive function

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Abstract

Background and Study Aim The elderly represent a growing age group and an integral part of modern society. The aging process introduces significant health challenges, making exercise an essential component in maintaining quality of life and well-being among the elderly. This study reviews the impact of physical exercise interventions on the physical and cognitive functions of the elderly population.

Material and Methods The search for this study was conducted using the ScienceDirect and PubMed databases. The search strategy employed a combination of keywords ("Elderly Physical Exercise" AND "Physical Exercise Intervention" AND "Elderly Fitness and Cognitive" AND "Physical Exercise for Physical and Cognitive Functions" AND "Physical and Cognitive Benefits" AND "Elderly Physical Exercise Prevalence"). This search adhered to the PRISMA guidelines. Initially, 1,854 publications were identified through the database searches (ScienceDirect: 981 articles; PubMed: 873 articles). After applying the exclusion criteria, only 11 articles remained.

Results It has been found that physical exercise interventions for the elderly significantly impact their physical and cognitive functions. In the first group, exercises such as home-based e-Health programs, multicomponent exercises, moderate aerobic exercises, dance training, and balance training have been identified. All these have been shown to provide substantial benefits. These programs enhanced not only physical function but also cognitive performance and the overall quality of life for older adults without physical and cognitive health complaints. This showcases the potential of physical exercise interventions to prevent morbidity and reduce disability. The second group focused on physical exercise interventions for older adults with degenerative disease complaints, such as type 2 diabetes and multiple sclerosis. Dual-task exercise programs and tai chi chuan exercises have demonstrated improvements in cognitive function for this demographic. They also improved physical fitness. The research also points out some limitations related to the implementation and budgeting for these programs.

Conclusions The literature review suggests that physical exercise interventions play a crucial role in maintaining physical and cognitive functions in older adults. Exercise programs tailored to the specific health conditions of individuals can significantly improve the quality of life and reduce the risk of declining physical and cognitive functions in the elderly population.

Keywords: physical exercise, physical function, cognitive function, older age

Introduction

Understanding the critical role of physical and mental health maintenance with aging is vital for both individual well-being and the sustainability of healthcare systems and societies. These issues underscore the necessity of finding effective ways to support healthy aging. With the backdrop of aging-related challenges, the importance of targeted exercise interventions becomes more pronounced, offering a lens through which the potential of physical activity in fostering a healthier, more vibrant aging population is understood.

Maintaining physical and mental health is crucial as individuals age, supported by evidence that regular, age-appropriate exercise is effective

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in achieving this goal [1, 2]. The elderly, defined as those 65 years of age or older, encounter aging-related health challenges, including diminished strength, flexibility, and mobility, necessitating the need for tailored exercise programs [3, 4, 5]. Research, such as the study by Yarmohammadi, demonstrates that physical activity can significantly enhance the strength and flexibility of older adults, underlining the importance of selecting the right exercise to maintain these attributes [6].

Moreover, proper exercise and physical activity are recognized not only as methods to maintain physical capabilities but also as sources of strength and vitality. Ruegsegger's findings further emphasize that exercise and physical activity serve as powerful tools in preventing and treating various chronic diseases due to their ability to improve whole-body health [7]. The role of exercise extends beyond mere physical health maintenance, playing a crucial part in fostering healthy aging by developing and preserving the functional abilities vital for well-being in old age [8]. Acknowledging the benefits of exercise, alongside the identification of suitable types of physical activities for this age group, is essential for raising awareness and encouraging fitness among older adults. This encouragement could lead to longer, healthier, and more active lives. Given the more complex healthcare needs arising from additional functional decline, physical illnesses, and psychosocial needs, older adults require specialized attention [9]. The onset of aging in the elderly often results in reduced skeletal muscle mass, strength, and function, which highlights the critical need for targeted exercise interventions designed to counteract these effects.

Continuing from the emphasis on targeted exercise interventions for the elderly, recent data underscores the health challenges this demographic faces, particularly with non-communicable diseases. According to Riskesdas, hypertension, dental and joint disorders, oral health issues, diabetes mellitus, heart disease, stroke, and infectious diseases like acute respiratory infections, diarrhea, and pneumonia are notably prevalent among the elderly [10]. This situation is exacerbated by a high occurrence of type 2 diabetes mellitus (T2DM) and hypertension (HTN) within this age group, especially those aged 60 and above, pointing towards a critical need for preventive measures [11, 12].

With aging comes a natural decline in functional capacity, which is further impacted by lifestyle factors contributing to the rising incidence of hypertension and, subsequently, an increase in degenerative illnesses [13, 14]. Recognizing these challenges, the World Health Organization (WHO) advocates for a combination of physical activity and a nutritious, well-balanced diet as essential components of a healthy lifestyle for the elderly. Such practices are not only crucial for disease prevention but also for promoting successful aging, enhancing quality of life, and extending healthy life years [15].

The importance of physical activity extends beyond disease prevention. Andrieieva highlights the role of physical exercise in improving overall health, increasing functional capacity in daily tasks, slowing the aging process, and delaying the onset of age-related decline among the elderly [16]. Engaging in physical activity, therefore, is presented as a multifaceted approach to combatting the health challenges faced by the aging population, underscoring its significance in fostering a healthier, more vibrant aging community.

Building on the significance of physical activity in addressing health challenges among the elderly, it's imperative to pinpoint the kinds of exercises that are both suitable and beneficial for this demographic. Engaging in activities like walking, cycling, gymnastics, and yoga has proven to be immensely advantageous for older adults, enhancing muscle strength, maintaining balance, and boosting cardiovascular health [17]. Thomas et al.'s research supports this, demonstrating that adapted physical activities and Wii Fit training significantly improve balance in elderly individuals, with improvements ranging between 16% and 42% [18].

Moreover, strength training, such as lifting light weights, plays a critical role in preventing the loss of muscle mass — a common occurrence as one ages [19, 20, 21]. It is crucial to recognize that with advancing age comes a natural decline in performance, which can be mitigated through consistent physical activity. Such activity not only enhances the quality of life for the elderly but also contributes to their physiological resilience, reducing their vulnerability to health issues and enhancing overall well-being [22]. This suggests that a tailored, multifaceted approach to physical activity can significantly contribute to successful aging, highlighting the need for inclusive fitness programs that cater to the diverse needs of the elderly population.

Further emphasizing the importance of physical activity for the elderly, guidelines suggest older adults should engage in regular physical activity, totaling at least 150 minutes of moderate intensity or 75 minutes of high intensity per week. This recommendation aligns with the guidelines set forth by the American College of Sports Medicine (ACSM) and the World Health Organization (WHO), which advocate for 150-300 minutes of moderate intensity aerobic activities weekly, alongside two sessions dedicated to muscle strength training [23, 24, 25]. Additionally, engaging in 30 minutes of light activity daily, coupled with 20 minutes of moderate to vigorous physical activity, has been shown to positively affect overall health, reducing the risk of various diseases [26, 27].

Such physical activities encompass cardiovascular exercises, strength training, and exercises aimed at improving flexibility and balance, presenting a comprehensive approach to maintaining and enhancing physical fitness in the elderly [25]. The inclusion of aerobic exercises and moderate to high-intensity strength training not only improves physical fitness but also contributes significantly to the overall well-being and health of older adults, reinforcing the critical role of a well-rounded physical activity regimen in the process of healthy aging [28]. This holistic approach to exercise underscores the potential of regular, structured physical activity to serve as a cornerstone in the promotion of longevity and quality of life among the aging population.

Physical activity extends beyond the preservation of physical health, exerting a significant positive influence on the mental well-being of the elderly. Engaging in regular physical activity can mitigate the risk of depression, elevate mood, and bolster cognition and brain function. This correlation is supported by findings indicating that heightened levels of physical activity can alleviate some of the adverse symptoms associated with depression and anxiety in the elderly population [29]. Furthermore, physical activity serves as a protective measure against non-communicable diseases, including those related to cardiovascular health, stroke, diabetes, and delayed onset of dementia. It also plays a crucial role in enhancing mental health, quality of life, and overall well-being among the elderly [30, 31, 32].

With the aim of fostering a deeper comprehension of the multifaceted benefits of exercise for older adults, this systematic review is dedicated to examining the recommended types of physical exercise, identifying the benefits achievable through regular engagement, and understanding the significance of physical exercise in sustaining an optimal quality of life in old age. This exploration seeks to inspire both society at large and older adults to adopt and maintain active lifestyles throughout their senior years.

Materials and Methods

Search Strategy

In this study, the databases Science Direct and PubMed were utilized for the literature search. The search commenced with Science Direct, followed by PubMed, which is recognized as one of the premier indexing systems for citations and is the most frequently consulted source by researchers worldwide. The search strategy employed a combination of keyword variations, including "Elderly Physical Exercise" AND "Physical Exercise Intervention" AND "Elderly Fitness and Cognitive" AND "Physical Exercise for Physical and Cognitive" AND "Physical and Cognitive" AND "Elderly Physical Exercise Prevalence." This search was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [33, 34, 35]. Furthermore, PRISMA is known for emphasizing review reports that evaluate randomized trials, which can also serve as a foundation for reporting systematic reviews of other types of studies [36].

Exclusion Criteria

The exclusion criteria for this systematic review were delineated to ensure the relevance and quality of the included studies. The criteria applied were:

1) Articles not indexed in Scopus or Web of Science, to ensure the inclusion of only those studies recognized for their academic credibility;

2) Articles not written in English, given the need for accessibility and standardization in reviewing the literature;

3) Articles published outside the designated timeframe of the last five years, from 2019 to 2024, to focus on the most current research and developments in the field;

4) Articles that did not directly address the impact of physical exercise interventions on both the physical and cognitive functions of the elderly population, to maintain a clear focus on the review's objectives.

Procedure

The initial search through the databases yielded a total of 1,854 publications, with ScienceDirect contributing 981 articles and PubMed adding another 873 articles. Upon applying the exclusion criteria, the pool of potential articles was significantly narrowed down to just 11 articles that met the study's stringent requirements. The predominant reason for excluding articles was their lack of mention or focus on physical exercise interventions aimed at enhancing physical and cognitive functions in the elderly. To streamline the review process and eliminate any redundancies, all identified articles were meticulously extracted and analyzed using Mendeley software, which facilitated the removal of duplicate entries. The systematic filtration and selection process, including the dramatic reduction from the initial search results to the final selection of articles, is detailed in Figure 1. This provides a clear visualization of the methodological rigor applied throughout the study.

Results

The five categories identified, apart from "Author" and "Year," are detailed in Table 1. Omission of the "Country" category is due to the uniform focus across all articles on physical exercise interventions aimed at enhancing both physical and cognitive functions in the elderly. The comprehensive results of this categorization are meticulously presented in Table 1. Upon reviewing the methodological approaches and types of research employed, it was found that eleven articles utilized experimental research designs. This

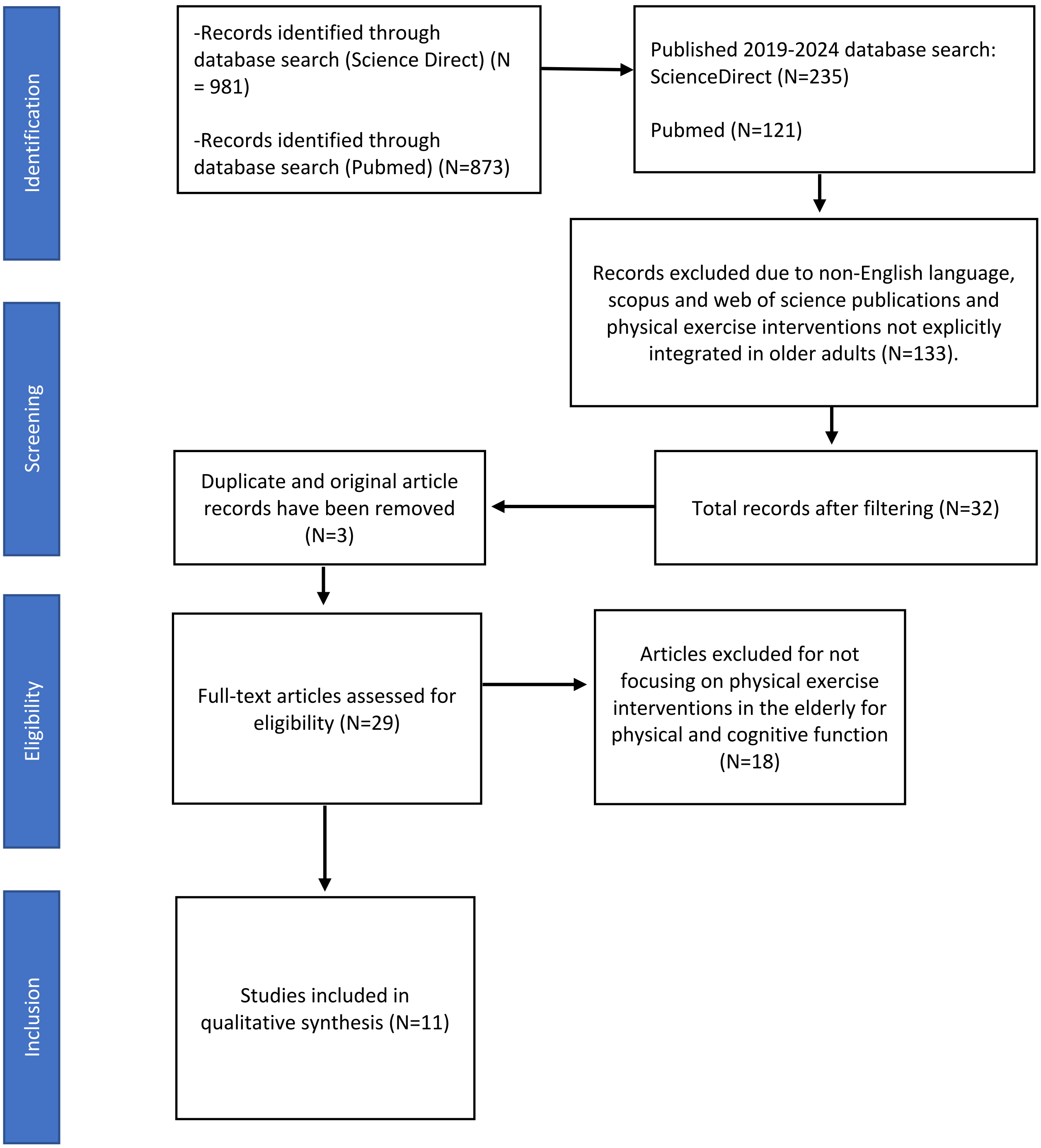

Figure 1. PRISMA Research Flowchart

includes various types of randomized controlled trials: four articles reported on simple randomized controlled trials [37, 40, 44, 47], one on randomized and single-blind controlled trials [42], another on a double-blind multicenter randomized controlled trial with two arms [38], a double-blind randomized clinical trial [39], a standard randomized clinical trial [46], randomized selection criteria [41], and one article where participants were randomly divided into three groups [43]. Predominantly, the reviewed articles adopted experimental research methods and utilized various measurement instruments for collecting data.

Discussion

The primary aim of this article was to investigate the effectiveness of physical exercise interventions among older adults, distinguishing between those with and without degenerative diseases. Initial findings from our comprehensive review reveal a diverse range of exercise programs that demonstrate beneficial impacts on both physical and cognitive health outcomes. This will further delve into the significance of these results, comparing them with existing literature to highlight the contributions of our study to the field of health and exercise science.

Table 1. Summary of Articles About

Author and Year	Research Methods and Types	Content	Research Objectives	Research Results
[37]	Experimental research (a randomized controlled trial)	Home-based e-Health intervention involving cognitive	Describes the protocol of the MOVI-ageing randomized controlled trial, a home-based e-Health intervention of cognitively engaging exercises for older adults with the aim of improving global cognitive function and baseline cognitive function, cardiorespiratory fitness, and muscular fitness.	The results of the program of activities carried out have an impact on the quality of life and welfare of community groups, especially the elderly through the prevention of morbidity and the reduction of years lost due to disability. These results are reflected in reduced economic expenditure by reducing demand for health and social services.
[38]	Experimental research (a two-arm single-blinded multicenter randomized controlled trial)	Muticomponent exercise intervention in nursing home residents	Determine the feasibility and effectiveness of a multicomponent exercise intervention in improving physical and cognitive function and quality of life in nursing home residents.	The results showed positive effects of a structured exercise program during long-term care on physical function, cognition, and psychosocial well-being.
[39]	Experimental research (a double-blind randomized clinical trial)	Exercise program to strengthen cognitive and physical health in the elderly	Identified two 24-week aerobic and cognitive exercise programs in older adults at risk of aerobic decline and balance.	Results show two low-cost exercise programs can improve physical and cognitive function in older adults with active participation.
[40]	Experimental research (a randomized controlled trial)	Combined exercise and cognitive training intervention in individuals with RRMS	Studying the effects of combined cognitive and physical rehabilitation (dual task) compared to physical exercise on walking and cognitive performance in individuals with relapsing-remitting multiple sclerosis (RRMS).	Results showed that a combination of exercise training and cognitive training (dual task) resulted in a significant improvement in cognitive ability and walking in individuals with relapsing-remitting multiple sclerosis (RRMS).
[41]	Experimental research (a random selection criteria)	Moderate aerobic exercise in improving cognitive performance	Analyzing the neuro-protective and anti-inflammatory activities of moderate aerobic exercise in improving cognitive performance in adults and the elderly.	Results showed that 12 weeks of aerobic exercise had a positive effect on cognitive performance of older adults through modulation of stress and pro-inflammatory cytokines.
[42]	Experimental research (a single-blinded, randomized controlled trial)	Training for people with osteoarthritis	To determine the therapeutic effect of WBV training on the neuromuscular function of KOA patients.	Results indicated that 8 weeks of WBV training had an improved effect on knee extensor isokinetic strength compared to ST or DIA, as well as a positive effect on improved physical function.

Table 1 (continued)

[43]	Experimental research (randomly divided into three groups)	Dance training and balance training	(1) To compare 12 weeks of dance training with balance training on fall risk, physical and cognitive functioning. (2) To evaluate the relationship between physical and cognitive function and markers of neurodegeneration and cognitive impairment in the elderly.	Results explained that the dance training intervention provided multiple benefits to physical and cognitive function in the elderly. However, the training altered the concentration of distributed proteins associated with neurodegenerative and cognitive disorders.
[44]	Experimental research (a randomized controlled trial)	Community-based exercise with action observation therapy in the elderly	To investigate the effect of community-based gymnastics with action observation therapy (AOT) on the physical and cognitive performance of older adults experiencing isolation during the pandemic.	Results showed that community-based exercise enhanced with action observation therapy improved physical and cognitive performance among the elderly.
[45]	Experimental research (randomized control trial)	Aerobic exercise, endurance, and balance in elderly women with type 2 diabetes (T2D)	To determine the effect of combined exercise on blood biomarkers, physical fitness, and cognitive function in elderly women with type 2 diabetes (T2D).	The results showed that a combination of aerobic, resistance, and balance training could improve physical fitness and diabetes-related surrogate factors, as well as cognitive function, but had no significant effect on cognition-related biochemical factors (BDNF) in elderly women with type 2 diabetes (T2D).
[46]	Experimental research (a randomized clinical trial)	Exercise tai chi chuan	To compare the effectiveness of tai chi chuan, a mind-body exercise in improving cognitive function in elderly people with type 2 diabetes (T2D) and mild cognitive impairment (MCI), by walking.	Results showed tai chi chuan had a better effect on improving global cognitive function in older adults with type 2 diabetes (T2D) and mild cognitive impairment (MCI).
[47]	Experimental research (a randomized controlled trial)	Low physical activity exercise	To increase the number of steps in the elderly with low physical activity levels on strength, balance, and aerobic capacity, as well as cognition.	Results showed that there was an improvement in physical fitness and cognition in the elderly who achieved an increase in physical activity of at least 35%.

The results revealed a broad spectrum of content relating to physical exercise interventions for the elderly. In one categorization, exercises were grouped by the type of activity and its relation to specific diseases. This group included home-based e-Health physical exercise [37], multicomponent exercise [38], moderate aerobic exercise [41], 12 weeks of dance and balance training [43], community-based gymnastic training combined with action observation therapy (AOT) [44], and activities ranging from low to moderate physical activity [47]. The second categorization encompassed a variety of programs such as a 24-week dual-task aerobic and cognitive exercise program [39], ai chi chuan training [46], walking-based physical exercise [40], and whole-body vibration (WBV) exercise.

Objectives and Results of the Physical Training Intervention Study in the First Group

This summary categorizes the research findings into two primary groups based on the nature of physical exercise interventions for the elderly, particularly distinguishing between those with and without physical and cognitive health complaints. The first group comprises six articles that explore a range of physical exercises designed for elderly individuals without complaints or a history of disease. These exercises include home-based e-Health physical exercise [37], multicomponent exercise [38], moderate aerobic exercise [41], 12 weeks of dance and balance training [43], community-based gymnastic training incorporating action observation therapy (AOT) [44], and activities classified as low to moderate physical activity [47]. Specifically, the first article investigates the effects of eHealth virtual physical exercise on cognitive guidance for older adults, aiming to improve basic and global cognitive functions, cardiorespiratory fitness, and muscular fitness. The findings indicate that a virtual eHealth home-based physical exercise program can significantly benefit the elderly and their relatives by preventing morbidity and reducing disability [37].

The second article evaluates the efficacy of a multicomponent exercise program tailored for nursing home residents, with an emphasis on enhancing physical and cognitive functions as well as quality of life. This comprehensive program, incorporating strength, balance, and dual-task exercises, was found to effectively support cognitive-motor maintenance, thereby aiding in the preservation of mental and physical functions among elderly individuals in nursing homes [38].

The third article investigates the neuroprotective and anti-inflammatory benefits of 12 weeks of moderate aerobic exercise for elderly individuals without disease complaints, specifically its impact on cognitive performance. The study concluded that moderate aerobic exercise positively influences cognitive performance in the elderly, potentially through the modulation of stress levels and pro-inflammatory cytokines, which are implicated in cognitive decline [41].

The fourth article explores the comparative effects of 12 weeks of dance training versus balance training on fall risk, physical and cognitive functions. It also examines the relationship between physical and cognitive functions and markers of neurodegeneration and cognitive impairment in the elderly. Findings suggest that both dance and balance training significantly enhance physical and cognitive functions. Importantly, these forms of exercise might influence the levels of circulating proteins related to neurodegenerative and cognitive disorders, presenting a promising avenue for further research [43].

These articles collectively underscore the multifaceted benefits of physical exercise in the elderly, highlighting its significant impact not only on physical health but also on cognitive function, thereby contributing to an improved quality of life and enhanced well-being for older adults.

The fifth study focused on assessing the effects of minimal physical activity interventions aimed at improving step frequency among the elderly, with a special emphasis on strength, balance, aerobic capacity, and cognition. The findings suggest that while there was an increase in physical activity levels, significant improvements in cognitive and physical fitness were not observed across the board. Notably, participants who managed to increase their physical activity by 35% or more exhibited noticeable improvements in aerobic capacity, walking speed, verbal memory, executive function, and overall cognition, compared to those who did not achieve this level of increased activity [47].

The sixth and final study reviewed aimed to investigate the outcomes of a community-based, multi-component exercise program designed for elderly individuals experiencing reduced levels of physical activity due to the Covid-19 pandemic. The study's results highlighted improvements across two groups. The first group, which participated in action observation therapy (AOT) alongside physical exercise, showed more significant improvements in various physical performance measures, including the Five Times Sit-to-Stand Test (5XSST), Tinetti Balance and Gait Scale, and the Timed Up and Go test. The second group, engaged in exercise alone, also saw significant improvements but particularly in the Tinetti Balance and Gait Scale and the Activity-Specific Balance Confidence Scale [44].

These studies collectively affirm the potential of targeted physical exercise interventions to not only enhance physical capabilities among the elderly but also to make meaningful improvements in cognitive functions and overall quality of life, especially when tailored to the individual's current activity level and health status.

Objectives and Results of the Physical Training Intervention Study in Group Two

The first article in this category evaluates the efficacy of a 24-week dual-task program combining aerobic and cognitive exercises, specifically designed for older adults at risk of cognitive decline. The program's comprehensive approach aimed at stretching and balance exercises demonstrated significant positive outcomes across several dimensions. These included improvements in both general and specific cognitive functions, gait stability, blood pressure levels, and carotid intima-media thickness, which collectively contributed to an enhanced quality of life for the elderly participants. Despite its promising findings, the study acknowledges limitations related to its budget, suggesting the need for further research with potentially more resources [39].

The second study delves into the impact of a combined exercise regimen on elderly women with type 2 diabetes, focusing on its effects on blood biomarkers, physical fitness, and cognitive function. Although no significant changes were observed in the levels of brain-derived neurotrophic factor between the exercise and control groups at the mid-point of the study, the exercise group showed notable improvements in several health markers by its conclusion. These included reductions in fasting blood sugar levels and glycated hemoglobin, alongside enhancements in cardiorespiratory fitness, dynamic balance, and strength in both upper and lower body regions. Additionally, a significant improvement was noted in the Montreal cognitive assessment index for the exercise group, indicating a potential benefit to cognitive function, despite the absence of differences in other cognitive assessments when compared to control groups [48].

These studies underscore the nuanced and multifaceted benefits of carefully designed physical exercise programs for the elderly, especially those battling degenerative diseases. They highlight the importance of incorporating physical activity as a cornerstone in the holistic management and improvement of physical and cognitive health conditions in aging populations.

The third article in the discussion centers on the effects of tai chi chuan, a form of mind-body exercise, on cognitive function among elderly individuals with type 2 diabetes and mild cognitive impairment, in comparison to fitness walking. This study strategically divided participants into three groups: those practicing tai chi chuan, those participating in fitness walking, and a control group with no specific intervention. The outcome indicated that individuals in the tai chi chuan group experienced more significant improvements in their Montreal Cognitive Assessment (MoCA) scores than those in the fitness walking group, showcasing an average difference of 0.84 in the intention-to-treat analysis. Further detailed analysis, both per protocol and within sub-groups, aligned with these findings. Despite reporting 37 non-serious adverse events in the tai chi chuan group—higher than in the fitness walking (8 events) and control (16 events) groups—these incidents were determined to be unrelated to the study interventions, with no statistically significant differences in safety outcomes observed across the groups [46].

The fourth study explores the comparative effects of combined cognitive and physical rehabilitation versus exercise training alone on walking ability and cognitive function in individuals diagnosed with relapsing-remitting multiple sclerosis (RRMS). The findings illustrate that although the control group, which likely received standard exercise training, showed improvements in the Mini-Mental State Examination (MMSE), concentration tests, and the 10-meter walking test, the study group subjected to combined rehabilitation exhibited enhancements across all evaluated parameters. This included improvements in the Expanded Disability Status Scale (EDSS), MMSE, logical reasoning, concentration, and walking ability. This suggests that a holistic approach encompassing both cognitive and physical rehabilitation exercises could offer more comprehensive benefits to individuals with RRMS compared to traditional exercise training alone [40].

These studies further validate the potential of tailored physical activity regimens, including traditional exercises like tai chi chuan and innovative combined rehabilitation programs, to significantly improve cognitive and physical functions in elderly populations, even among those with specific health challenges.

The fifth article delves into evaluating the therapeutic effects of whole-body vibration (WBV) training over a period of 8 weeks, comparing it against lower extremity strength training and health education in terms of muscle strength and proprioception impact on neuromuscular function in patients with knee osteoarthritis (KOA). The study's findings revealed no significant differences among the groups in aspects such as pain levels, proprioception accuracy, performance in the Timed Up and Go (TUG) test, and distances covered in the 6-minute walking distance test (6MWD). However, a notable interaction effect was observed concerning isokinetic muscle strength, with the WBV group demonstrating a more significant increase in extensor peak torque (PT) isokinetic muscle strength compared to both the health education and strength training groups. This suggests that while WBV training might not influence all aspects of knee osteoarthritis symptoms, it could offer specific benefits in enhancing muscle strength, potentially contributing to improved neuromuscular function in KOA patients [42].

This investigation underscores the nuanced benefits of different physical intervention strategies in managing symptoms and improving the quality of life for individuals with KOA, highlighting the need for a tailored approach based on specific therapeutic goals and patient conditions.

In conclusion, the discussion has illuminated the vast spectrum of physical exercise interventions and their significant impact on the elderly, especially those with and without specific degenerative diseases. From enhancing cognitive function and physical fitness to mitigating symptoms of chronic conditions, the evidence underscores the multifaceted benefits of tailored physical activity programs. These findings not only reinforce the importance of incorporating physical exercise into the daily regimen of the elderly but also highlight the potential for such interventions to improve overall quality of life and health outcomes.

Future studies could explore more diverse populations and longer-term impacts of physical exercise interventions to understand their sustained effects better. Additionally, investigating the mechanisms behind the therapeutic benefits of different types of exercise could provide insights into developing more effective, personalized exercise programs. The integration of technology in monitoring and enhancing the efficacy of exercise routines presents another promising avenue for research, potentially leading to innovative solutions that could further improve the health and well-being of the elderly population.

Conclusions

Physical exercises, encompassing aerobic, strength, balance, dance, and multicomponent routines, have been underscored as beneficial for improving the well-being of older adults across various health spectrums.

For those without health complaints, exercise interventions have been instrumental in enhancing cardiorespiratory fitness, muscle strength, balance, and cognitive performance. Similarly, in older adults facing degenerative diseases, such exercises have contributed to better blood sugar control, physical fitness, and cognitive functioning. Notably, dual-task exercises, incorporating both aerobic and cognitive training, alongside tai chi chuan, have demonstrated promising outcomes in augmenting cognitive function, balance, and overall quality of life.

The insights gained from this review advocate for the personalized development of exercise programs, tailored to the unique needs and conditions of the elderly, to optimize their efficacy. The imperative for such targeted interventions highlights the potential of physical exercise as a key strategy in preserving and enhancing the physical and cognitive functions of older individuals. Ensuring the adaptation and specificity of these programs can significantly elevate the quality of life and independence among the elderly population.

Looking forward, the field stands to benefit from expanded research endeavors, employing a wider array of keywords and databases to deepen the understanding of physical exercise's impacts. A comprehensive global exploration, potentially incorporating bibliometric and scientometric analyses, alongside in-depth investigations into health-oriented sports activities for older adults, represents a pivotal direction for future studies. This ongoing research is essential for refining exercise interventions, making them more accessible and effective for aging populations worldwide.

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Conflict of interests

There is no conflict of interest.

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ORIGINAL ARTICLE

Effects of Altitude training on Ethiopian endurance athletes recovery heart rate and hematological variables

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Abstract

Background and Study Aim A recent study indicates that Ethiopian middle- and long-distance athletes originate from diverse geographical regions, including areas of varying elevation. This study aimed to analyze the impact of altitude training on hematological parameters and recovery heart rates among young male endurance trainees training at sites located at different altitude levels.

Material and Methods The study employed a quasi-experimental, counterbalanced approach involving 15 male trainees. Five individuals from each training center experienced the standard training program across three distinct geographical locations and elevations. Pre- and post-test data were collected on red blood cells, hemoglobin, hematocrit, platelet count, and recovery heart rate before and after six months, from 6:00–8:00 AM. ANCOVA was utilized to analyze the data.

Results Following the intervention, the mean Red Blood Cell (RBC) count was observed to be higher in trainees from low altitude (5.18±0.33) compared to those from moderate altitude (4.48±0.14 and 5.21±0.22), with a significance level of $p<0.05$. The mean Hemoglobin (HGB) count was found to be higher in moderate altitude trainees (17.00±0.70 and 16.31±0.65) than in low altitude trainees (15.82±1.37), although this difference was not statistically significant ($p>0.05$). Similarly, the mean Hematocrit (HCT) count was low for both low altitude (46.04±3.49) and moderate altitude trainees (46.46±3.9 and 45.42±1.54), with no significant difference noted ($p>0.05$). The mean Platelet (PLT) count was 226.8±75.88 for low altitude trainees and 265.8±23.18, 276±53.96 for moderate altitude trainees, with no significant difference between the groups ($p>0.05$). As for the recovery heart rate, mean values showed no significant difference between the pre-and post-test groups. In the pretest, the mean recovery heart rate was 30.00±14.70 for low-altitude trainees and 43.20±8.90, 43.20±13.68 for moderate-altitude trainees ($p>0.05$). In the post-test, the mean recovery heart rate was 25.20±7.82 for low-altitude trainees and 32.40±10.04, 36.00±7.35 for moderate-altitude trainees ($p>0.05$).

Conclusions The findings indicate that training at different altitudes impacts the hematological and cardiovascular systems of endurance athletes in varied ways. This underscores the importance of developing tailored training programs to optimize performance and recovery. These results are particularly relevant for coaches and athletes seeking to enhance endurance training outcomes through altitude training strategies.

Keywords: altitude training, red blood cell, Hemoglobin, hematocrit, recovery heart rate

Introduction

The 1968 Summer Olympics were held in Mexico City at an altitude of approximately 2300 meters. This event sparked an interest in altitude and altitude training that persists today [1]. During the 1968 Olympics, the completion speed of endurance races was notably slower than usual, but records were broken in sprint-oriented games [2]. Before the 1968 Olympics, training at moderate to high altitudes was not considered a significant factor in enhancing athletic performance or competition [1, 3]. However, subsequent research has demonstrated that the 1968 Olympic Games and the 1970 FIFA World Cup, hosted in Mexico City, prompted athletes to train at 2,300 meters above sea level [4, 5]. The inception of this initiative marked a significant turning point in the history of sports by paving the way for establishing

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international standards for sporting events. Specifically, elevation limits were set to below 3,500 meters [1], a crucial development that has enabled athletes and coaches to recognize and embrace the benefits of high-altitude training. By optimizing their performance through this approach, athletes can gain a competitive advantage in the world of sports. This milestone has profoundly impacted the athletic community and helped establish a new era of excellence in sports.

Athletes have various ways to train and improve their physical fitness [1, 6] and have suggested combining various hypoxic training techniques, including intermittent hypoxic training, live low train high, live high-train low, and live high-train high approaches [6, 7, 8]. Endurance athletes use these methods to adapt better and improve their sea-level performance [6,7,9]. These methods also help improve hematological variables [8, 10, 11]. The optimal altitude range for these methods is between 1800 to 2700m and 2000 to 3000 meters above sea level and 1800 to 2,700masl [8, 12], respectively. Endurance running is a sport dominated by East African athletes, especially those from the middle and long-distance disciplines [13]. Depending on the length and duration of the endurance training, several elements, including hematological, environmental, sociological, psychological, physiological, anthropometrical, genetic endowment, inspiration, and training features, might affect endurance running performance [13, 14, 15, 16, 17, 18, 19]. Successful endurance runners share several traits, including a metabolic solid economy, a traditional diet, altitude training, and lifestyle, favorable skeletal-muscle-fiber composition, an oxidative enzyme profile, high maximum oxygen uptake, relatively high Hct and Hgb, and a drive for financial success [16, 20, 21, 22, 23].

Scheinfeldt et al. discovered that Ethiopian highlanders had different genes and genetic variants that contribute to adaption than those from other high-altitude places [24]. The Ethiopian runners tend to have a mesomorphic somatotype, demonstrate exceptional physiological economy, and appear independently through convergent evolution due to the strong selectivity of hypoxia, which is a potential factor contributing to their success [23, 25]. The elevation of several places in Ethiopia ranges from 1500 to 4550 meters, and the population is highly concentrated in plateau areas, especially at icy and moderate altitudes [26]. About 80% of the population mainly inhabits the highlands, where the athletes emerge from specific altitude areas, and the population is mainly from Arsi and Shewa or the central part of the country [23]. Depending on the subjective responses of these athletes, endurance training is carried out relatively at high altitudes.

Although many Ethiopians live in high altitudes, athletes grow at a precise area of altitude and population, mainly from Arsi and Shewa or the central part of the country [17, 23]. A recent study shows that Ethiopian middle- and long-distance athletes come from more than one geographical location or elevation [27]. However, the research investigation assessment focused only on live-high train-high approaches [11, 28] within the framework of Ethiopian athletics. As far as we know, no study has compared Ethiopian athletics training center trainees' hematological and recovery heart rate variables at a project level in moderate-train and low-train settings. Therefore, this study aimed to compare the hematological and recovery heart rate variables of Bekoji and Hagereselam from moderate altitude and Jinka athletics training center from low altitude. We hypothesized a significant difference between moderate and low-altitude trainees on selected hematological and recovery heart rates between Jinka, Bekoji, and H/selam athletics training centers of long-distance trainees.

This study aimed to compare the hematological parameters and recovery heart rates of athletes training at Bekoji and Hagereselam (moderate altitude) and the Jinka athletics training center (low altitude). We hypothesized significant differences in selected hematological parameters and recovery heart rates among long-distance trainees from Jinka, Bekoji, and Hagereselam training centers due to the varying altitudes.

Materials and Methods

Participants

The study involved 15 young male long-distance trainees, with five participants from each of the following training centers: Jinka, Bekoji, and Hagereselam.

Ethical Approval and Consent to Participate

This study involves human participants and the study was reviewed and approved by the College of Natural and Computational Sciences Institutional Review Board (CNS-IRB) of Addis Ababa University with reference number CNCSDO/669/14/2022 dated June 02/2022. Informed consent was obtained from the parents or legal guardians of each participant.

Study Design

The study was conducted in the South Ethiopia Region, which has Jinka athletics training center; the Sidama Region, which has Hagereselam athletics training center; and the Oromia Region, which has Bekoji athletics training center. The Jinka Athletics Training Center is in Jinka, a town in Southern Ethiopia. It is situated at a low altitude in the capital city of South Omo region [29] and is 1383masl. The Bekoji Training Center can be found in the Arsi Zone Oromia Region, 159 kilometers from Addis Ababa, and at a moderate altitude of 2810 masl [17]. The Hagereselam training center is located in the Sidama Region, 284 km South of Addis Ababa, with an altitude of 2759 masl [30, 31]. A comparative quasi-experimental, particularly counterbalanced design [32] was employed to compare the hematological and recovery heart rate quantities of moderate-altitude and low-altitude trainees.

Procedures

The study data was taken twice: once at the start of the training period and again six months later, or by the end of the winter training session when athletes were starting to taper or ready for their final annual internal competition seasons, which EAF organized. All measurements and estimations of individuals' hematological and recovery heart rate variables were held during early morning sessions from 6:00–8:00 AM in their respective training centers to minimize variations. Recovery heart rate was measured using the portable FT1; Polar Heart Rate Monitor Kemple, Finland, and it was recorded after a submaximal 3-minute step test on the bench of 30 cm height for three minutes at the rate of 96 steps per minute [33]. The first minute's pulse rate immediately after stopping the step test was recorded as the recovery heart rate [34]. Blood was drawn under the guidelines provided by [35]. Before sampling, participants were allowed to sit for fifteen minutes. A tourniquet was applied, the area was cleaned, and then 5 ml of venous blood was extracted using a syringe from the ulnar vein of the non-dominant hand. Using a hematology analyzer (DIRUI BCC-3000B; China), the drawn blood was placed into a vacuum tube containing EDTA to measure the concentration of RBC, HGB, HCT, and PLT. The blood samples of Jinka trainees were transported to Jinka General Hospital Jinka Town, the Hgereselam trainees to Hula Primary Hospital Hagereselam Town, and the Bekoji trainees to Bekoji General Hospital Bekoji Town.

Table 1 represents the weekly training schedule based on the FITT principle. The training was twice a day, five days a week. The training intensity was between 50 and 74% in each training center. Each session lasted at least 60 minutes and a maximum of 120 minutes. The type of training was endurance-based in all training centers. Hence, the frequency, intensity, time, and type of training were almost similar in all training centers.

Statistical Analysis

The Pearson normality test was used to determine whether all data were normal. For continuous and categorical variables, descriptive statistics were stated as mean ($\bar{X}$) ± standard deviation (SD) and frequency (percentage), respectively. Statistical analysis was conducted using the software SPSS version 26.0 to examine how altitude affects recovery heart rate and hematological markers. The analysis included an analysis of covariance (ANCOVA) with LSD adjusted post hoc to evaluate the similarity of variance, source of variance, sum of squares, degree of freedom, mean sum of squares, and F-ratio. Any variable with a p-value of less than 0.05 was considered statistically significant.

Results

Table 2 presents the participants' mean age, height, weight, and BMI.

Table 3 compares the hematological parameters, including RBC, HGB, HCT, and PLT counts, and the recovery heart rate between low and moderate-altitude trainees. In the pretest, there were no significant differences observed in mean RBC count between low-altitude trainees and moderate-altitude trainees ($p>0.05$). However, the mean HGB count was higher in moderate altitude trainees than

Table 1. Comparison of the FITT principles and their application between Jinka (low altitude) and Hagerselam and Bekoji (moderate altitude) training center

Variables	Jinka	Hgereselam	Bekoji
Frequency	2*/day 5days/week	2*/day 5days/week	2*/day 5days/week
Maximum Heart rate	50-74%	50-74%	50-74%
Time	60'-120'	70'-110'	70'-120
Type	Endurance type	Endurance type	Endurance type

Table 2. Demographic characteristics between low-altitude and moderate-altitude trainees

Variables	Jinka		Hgereselam		Bekoji	
	Mean	St.Dev	Mean	St.Dev	Mean	St.Dev
Age	17.8	0.44	18.4	0.89	17.8	0.44
Height	162.4	11.11	170.2	6.72	166.4	6.54
Weight	58.4	8.14	60.2	4.20	59	4.24
BMI	19.87	0.57	20.11	0.39	19.91	0.75

Table 3. One-way ANOVA result for the comparison of RBC, Hgb, Hct, platelet count, and RHR between study groups

Variables	Jinka			Hagereselam			Bekoji			P-value	P-value
	Pretest (Mean ± SD)	Post-test Mean ± SD)	p-value	Pretest Mean ± SD)	Post-test Mean ± SD)	p-value	Pretest Mean ± SD)	Post-test Mean ± SD)	p-value	Pretest	Post-test
RBC in (x106 / μL)	5.08±.25	5.18±.33	.267	4.47±.6	4.48±.14	.972	4.99±.25	5.21±.22	.002	.074	.001
HGB in g/dL	13.88±1.14	15.82±1.37	.002	17.4±1.51	17±.7	.648	15.82±.80	16.31±.65	.080	.002	.196
Hct (%)	44.14±2.63	46.04±3.49	.027	39.52±5.18	46.46±3.9	.118	44.26±2.26	45.42±1.54	.026	.100	.873
PLT in (x103/ μL)	243.4±13.57	226.8±75.88	.618	236.4±12.93	265.8±23.18	.108	247.4±88.39	276±53.96	.194	.945	.365
RHR	30.00±14.70	25.20±7.82	.242	43.20±8.90	32.40±10.04	.009	43.20±13.68	36.00±7.35	.109	.206	.165

RBC: red blood cell count, HGB: hemoglobin count, HCT: hematocrit, PLT: platelet, RHR: Recovery heart rate

in low altitude trainees ($p<0.05$). The mean HCT count showed no significant difference between the groups ($p>0.05$). Likewise, the mean PLT count did not significantly differ between low-altitude and moderate-altitude trainees ($p>0.05$). In the post-test, the mean RBC count was higher in low-altitude trainees than in moderate-altitude trainees ($p<0.05$). The mean HGB count was higher in moderate altitude trainees than low altitude trainees, but no significant difference was found ($p>0.05$). The mean HCT count did not significantly differ between the groups ($p>0.05$). Similarly, the mean PLT count did not significantly differ between low-altitude and moderate-altitude trainees ($p>0.05$).

For the recovery heart rate, mean values showed no significant difference between the pre-and post-test groups. In the pretest, the recovery heart rate for low-altitude trainees and moderate-altitude trainees did not differ significantly ($p>0.05$). Similarly, in the post-test, there was no significant difference in the recovery heart rate between low-altitude and moderate-altitude trainees ($p>0.05$).

Discussion

In this study, we sought to evaluate the effects of altitude training on hematological parameters and recovery heart rates among young male endurance athletes from Ethiopia, who adhered to a regular training regimen across three distinct locations and altitudes. Our findings revealed that athletes training at both low and moderate altitudes experienced an increase in mean red blood cell count post-training. This result aligns with previous research conducted on elite endurance athletes, including Swiss national team cross-country skiers participating in Live High-Train Low (LHTL) programs [36], well-trained competitive runners from collegiate track and cross-country teams in the USA Track and Field circuit [37], and comparisons between athletes from the Guna Athletics Sports Club and the Ethiopian Youth Sports Academy [11].

However, junior Ethiopian long-distance athletes showed no significant change in red cell mass after participating in Live High-Train High (LH-TH) and Live High-Train Low (LH-TL) programs [28]. Similarly, studies on French international swimming competitors and US collegiate track and cross-country runners revealed no significant alterations in mean values of hematocrit (Ht) and hemoglobin (Hb) in response to training [38, 39]. Despite these varied results, a meta-analysis indicated that elite athletes undergoing hypoxic training experienced more significant enhancements in red cell mass compared to those training at sea level. Additionally, short-term intermittent hypobaric hypoxia significantly increased red cell mass in moderately to highly trained individuals [40, 41]. Overall, this study reinforces the concept that altitude training, particularly LH–TH, substantially benefits long-distance athletes' red blood cell mass compared to a live low train low (LL-TL) approach [8].

Our research further explores the influence of altitude training on hemoglobin mass, with a particular focus on the outcomes of live-high train-high (LH-TH), live-high train-low (LH-TL), and combined live-high train-high train-low (LH-TH-TL) protocols. Our findings revealed that trainees at moderate altitudes exhibited higher mean hemoglobin levels compared to those training at lower altitudes. This observation aligns with results from [37], where the Swiss national orienteering teams saw an increase in Hgb levels following LH-TL training. Similarly, extensive research involving Australian endurance cyclists [43, 44], competitive cyclists [45], well-trained female cyclists [46], and Tokyo-based long- and middle-distance runners

[47], has consistently shown an enhancement in the hemoglobin mass of endurance athletes following LH-TL training.

Our results corroborate those of previous research, which has identified increased hemoglobin concentrations in highly-trained biathletes [10] and US endurance athletes [48], as well as among highly trained cyclists following altitude training [49]. Supporting these observations, a meta-analysis by [40] revealed that elite athletes training under hypoxic conditions at altitude showed more significant improvements in hemoglobin levels compared to those training at sea level, aligning with our findings. Contrarily, our study diverges from the results presented by [50], where no enhancements in hemoglobin levels were noted in trained athletes after altitude exposure. In contrast, studies by [51, 52] on live-high train-low protocols indicated hemoglobin mass increases even among well-trained athletes, a finding echoed by [53] in their investigation of elite or well-trained male and female distance runners undergoing LHTH training, which resulted in increased hemoglobin mass. Our study lends further support to the effectiveness of altitude training, particularly live-high train-low (LH-TL) and live-high train-high (LH-TH), in augmenting red blood cell mass in long-distance athletes.

The results of our study demonstrate an increase in hematocrit (Hct) levels among athletes training at both altitude and low/moderate altitudes. This enhancement in Hct count aligns with the findings of previous research [46, 47], which observed that elite endurance runners and cyclists, residing or training at altitude, exhibit elevated Hct counts. Furthermore, a meta-analysis by [40] revealed that elite athletes training at altitude could significantly improve their Hct levels compared to their sea-level counterparts, a conclusion that mirrors our observations. Chen et al. (2014), along with studies on male long-distance track and field athletes [54], highly-trained biathletes [10], intermittent hypoxic trainees [50], and the application of the live-high train-low (LH-TL) strategy in competitive off-road cyclists, have reported findings similar to ours, further validating the beneficial effects of altitude training on hematocrit levels.

Our research focused on investigating the impact of live-high train-high (LH-TH) altitude exposure on hematocrit (Hct) counts in elite distance runners [52]. We discovered that this specific altitude exposure significantly increased the Hct count. However, our results diverge from those reported by [55], where moderate altitude training sessions, or living and training at moderate altitudes, did not alter the hematocrit levels in male cyclists at the elite level. This discrepancy is further echoed by findings from a study on Ethiopian endurance runners engaged in LH-TH and live-high train-high train-low (LH-THTL) programs, which indicated no significant hematocrit differences between experimental and control groups [28]. Conversely, our findings align with those of [48], which demonstrated a significant correlation in hematocrit levels between athletes training at lowland and those at high altitude, particularly among high-class long-distance cyclists with innate high-altitude training.

The results of our study indicate that trainees at moderate altitudes exhibit higher platelet counts compared to those training at lower altitudes. This observation is in line with findings from a previous study [56], which investigated the effects of altitude on platelet count among healthy, sports-engaged volunteers and reported an increase in platelet counts. Similarly, research conducted on young, healthy Bolivian airmen [57] found that short-term exposure to high altitude (just 48 hours) led to an increase in platelet count. Additionally, a study on healthy male volunteers [57] observed that strenuous exercise resulted in increased platelet aggregation, a result that mirrors our own. Exercise's effect on platelet activation was further supported by findings [58] that suggest training and exercise status influence platelet activation, with active individuals showing higher total platelet counts than their sedentary counterparts. Subsequent studies [59, 60, 61, 62] have consistently shown that physical activity can positively impact platelet function or counts. Despite these correlations, to date, no research has specifically demonstrated that altitude training variations for long-distance runners can enhance the athletes' platelet count, marking a notable area for future investigation.

The current study also investigated the mean recovery heart rate among trainees at low and moderate altitudes, finding that individuals in the low-altitude group exhibited a quicker recovery rate. This aligns with findings from previous studies involving well-trained male cyclists undergoing high-intensity training, physically active individuals across varying training intensities, and endurance athletes [63, 64, 65]. Additional research confirms that well-trained endurance athletes display more rapid heart rate recovery [66], and similar improvements in exercise capacity have been observed among recreational runners, physically active adults, and first-division soccer players [65, 67]. Moreover, studies focusing on young, healthy male soccer players [68], well-trained male basketball players [69], and participants engaging in maximal aerobic power exercises [70] have all demonstrated that aerobic training can significantly enhance the performance and recovery heart rate of endurance athletes, including elite cyclists.

In summary, the observed improvements in both hematological parameters and recovery heart rate among the athletes at the training centers may be attributed to the unique characteristics of Ethiopian distance runners. These include genetic predispositions, a mesomorphic body type, and an outstanding physiological efficiency, which collectively contribute to their exceptional athletic performance.

Conclusions

Based on the empirical evidence gathered, this study concludes that endurance athletes undergoing training regimens at both low (live-low train-low) and moderate (live moderate-train-moderate) altitudes exhibit statistically significant enhancements in hematological indices and recovery heart rate. The observed similarity in training intensity, frequency, duration, and type across both groups underscores the effectiveness of these training strategies. This research highlights the capability of both low and moderate altitude training to improve athletic performance and accelerate recovery, suggesting their valuable application in endurance sports training.

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Conflict of interests

The authors have declared no conflicts of interest.

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ORIGINAL ARTICLE

Assessment of cardiorespiratory function in adolescent athletes affected by COVID-19: a comparative analysis

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Abstract

Background and Study Aim Given the global spread of COVID-19 and its profound effects on public health, understanding its impact on the physical health and performance of young athletes is crucial for developing guidelines to support their recovery and well-being. The goal of this research was to assess the impact of the COVID-19 infection and possible consequences on the functional abilities of schoolchild athletes, and determine whether there are differences compared to their peers who did not suffer the infection.

Material and Methods This study involved 100 teenagers (median age 15.7±1.167), who engage in two different sports (basketball and soccer), divided into two groups. The first group comprised young athletes (n=53, age 15.79±1.854) who had contracted COVID-19 and underwent 14 days of home isolation. The second group consisted of healthy child athletes (n=47, age 15.60±1.313). Participants underwent a comprehensive pre-participation sports medical examination, which included a cardiopulmonary exercise test (CPET) on a treadmill. CPET assessed various physiological parameters: maximum oxygen consumption (VO2max); heart rates at the first and second ventilatory thresholds (HR at VT1 and HR at VT2); respiratory exchange ratio (RER); maximal pulmonary ventilation (VEmax); ventilatory efficiency (VE/VCO2); oxygen pulse (O2/HR); maximum heart rate (HRmax); three-minute heart rate recovery; and potential electrocardiographic changes.

Results The results indicate that COVID-19 infection has led to statistically significant impairments in the cardiorespiratory functions of child athletes. Notably, there were significant reductions in maximum oxygen consumption (VO2max), maximal pulmonary ventilation (VEmax), oxygen pulse (O2/HR), as well as heart rates at the first ventilatory threshold (HR at VT1), maximum heart rate (HRmax), and heart rate recovery following maximal effort, all demonstrating p-values less than 0.05.

Conclusions The assessed parameters demonstrated that the functions were statistically significantly impaired in child athletes who had recovered from COVID-19 compared to their healthy peers of the same age. However, the infection appeared to have a minimal impact on heart rate variability at ventilatory thresholds. These findings offer valuable insights for coaches and sports medicine physicians in adjusting training programs and supporting the rehabilitation process for young adolescent athletes resuming their training after recovering from COVID-19.

Keywords: VO_2max, SARS-CoV-2, aerobic capacity, heart rate, pulmonary ventilation, oxygen pulse

Glossary

- VO_2max – Maximal Oxygen Consumption.
- VE/VCO_2 – Ventilatory Efficiency.
- VE max – Maximal Pulmonary Ventilation.
- RER – Respiratory Exchange Ratio.
- O_2/HR – Oxygen Pulse.
- HR max – Maximal Heart Rate.
- HR VT_1 – Heart Rate at First Ventilatory Threshold.
- HR VT_2 – Heart Rate at Second Ventilatory Threshold.
- Velocity at VT_1 – Speed at First Ventilatory Threshold.
- Velocity at VT_2 – Speed at Second Ventilatory Threshold.
- RCP – Respiratory Compensation Point.

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Introduction

The COVID-19 virus pandemic, which began in 2020, had enormous consequences for the life and health of young athletes [1]. For the first time in their careers, young athletes had to face a different approach to the organization of their training during the competition season itself [2]. All these circumstances and an unusually long break without organized training or only training at home, affected the physical abilities of young athletes [3]. During the eight-week quarantine, young athletes could maintain their level of physical fitness with only limited training at home. In some cases, this led to a decrease in functional abilities, as well as a decrease in speed among young soccer players, with a simultaneous increase in body fat and muscle atrophy [4, 5]. At the same time, young athletes were not exempt from infection with the COVID-19 virus, and some, just like non-athletes, were exposed to hospitalization due to more severe symptoms, as well as heart problems during the pandemic [6, 7]. To avoid any risk of an athlete training and competing while infected, PCR tests, as well as cardiopulmonary exercises tests (CPET) were often performed to evaluate cardiovascular health prior returning to training and competition [8]. CPET is a standard protocol for the direct measurement of functional abilities, primarily maximum oxygen consumption (VO_2max), as a direct measure of aerobic capacity. In healthy adolescent athletes aged 15 to 18 years, according to some authors, VO_2max ranges from 45 to 62 mL/kg/min, depending upon the sport [9, 10, 11, 12, 13, 14]. Previous research that has dealt with the topic of young athletes and COVID-19 infection is quite limited. Some works have shown that, post COVID-19 recovery, the maximum consumption of oxygen was similar compared to healthy young athletes, but a drop in respiratory reserves (42%), as well as abnormal spirometry (42%), were observed when compared to peers who had not suffered from COVID-19 [15].

Most of the papers that dealt with the impact of quarantine and cessation of training for eight weeks on functional and motor skills showed a drop in the training efficiency of young athletes [16, 17, 18, 19, 20]. No research detailing the specific assessment of the functional abilities of young adolescent players after a prolonged COVID-19 infection.

As such, the goal of this research is to explain the new challenges related to the COVID-19 infection of young athletes, as well as the consequences that remain on their functional body responses to the infection. The study will also show the importance of diagnostics among young athletes to enable the safest participation in training and competitions and will provide useful advice on protocols for a gradual return to sports for young athletes after a COVID-19 infection.

Hypotheses. H° The null hypothesis of this research is that there will be no statistically significant difference between young players who are healthy and who are infected by Covid 19 infection. H^1 An alternative hypothesis states that the impact of COVID-19 on cardiorespiratory abilities will be more pronounced in kids with infection in terms of parameters such as VO_2max, VEmax, O2/HR, HR at VT1, HRmax, and heart rate recovery upon maximal effort, compared to heart rate variability at ventilatory thresholds.

This study aims to evaluate the impact of COVID-19 infection on the functional abilities of teenage athletes, with a specific focus on cardiorespiratory parameters. By comparing the performance metrics of athletes who have recovered from COVID-19 with those of their healthy peers, the study seeks to uncover insights into the potential consequences and discernible differences in aerobic capacity, heart rate, pulmonary ventilation, and oxygen pulse.

Materials and Methods

Participants

One hundred male children athletes (N=100) from two sports, soccer and basketball, with an average age of 15.70±1.85, from Serbia participated in this longitudinal experimental study and were divided into two groups. The experimental group comprised athletes who had tested positive for COVID-19 via PCR and underwent home isolation for 14 days (n=53, age 15.79±1.854). The control group included healthy adolescent athletes of the same age who had not contracted COVID-19 and had no interruption in training (n=47, age 15.60±1.313).

All subjects and their parents provided written informed consent to participate in the study after the testing procedures were explained verbally and in writing. The conducted research does not violate the rights of the players examined, according to the ethical standards of the Helsinki Declaration of the Human Rights Committee (VMA Declaration of Helsinki, 2013). The Ethical Committee of Sports Cardiology Association of Serbia approved all the performed procedures (Decision No. 2/21, adopted on September 28, 2021).

Research Design

All athletes usually performed 4-6 training sessions per week (about 90-120 minutes each), participating in an official game during the weekend. The criterion for inclusion in the study for COVID-19 athletes was the age < 18, as well as a positive PCR test for COVID-19, and a minimum of 14 days' break from training and competition. All tests were performed during the competitive season.

Athletes infected with the COVID-19 virus were asymptomatic or had mild-symptomatic complaints in the forms of fever, malaise for a maximum of

2, 3 days, as well as loss of smell and/or taste. Before performing CPET, all subjects filled out a survey concerning their basic data, personal, and family history. A pre-participation sports medical examination was performed in the outpatient sports medicine clinic "Vita Maxima" in Belgrade, Serbia, which allowed for insight into their health condition, while an assessment of the health capacity for participation in the study, i.e., for the application of the maximum CPET, was carried out.

The basic sports medical examination included: determination of body height, assessment of complete body composition (body weight, height-to-weight ratio (BMI), body fat percentage (FAT%)), and a 12-channel electrocardiogram (ECG) at rest with determination of heart rate. Physical examination was performed by measuring arterial blood pressure on both arms and auscultating the heart and lungs.

During the study a pre-participation sports medical examination and CPET of young athletes between October 2021 and June 2022 were conducted. The goal of the sports medical examination was to determine the general health capacity of non-COVID-19 athletes, as well as athletes after infection with the COVID-19 virus. An appropriate sports medical examination was a prerequisite for participation in the study and performance of CPET on a treadmill. CPET was used to determine maximal oxygen consumption (VO_2max), respiratory exchange ratio (RER), maximum pulmonary ventilation (VEmax), ventilatory efficiency (VE/VCO_2), oxygen pulse (O_2/HR), heart rates achieved at first and second ventilatory thresholds (HR at VT1 and HR at VT2), maximum heart rate (HRmax) and three-minute heart rate recovery after CPET.

All participants received medical clearance and a negative PCR test for COVID-19 within 48–72h before testing.

Test Protocol

A treadmill (HP-COSMOS®) was used to perform a CPET. An electrocardiogram of the heart at rest was performed using a 12-channel ECG (Fukuda). Maximum oxygen consumption (VO_2max), maximum minute ventilation (VEmax), and respiratory exchange ratio (RER), as well as ventilatory equivalents for oxygen (O_2) and carbon dioxide (CO_2) were assessed by monitoring breath-by-breath gas exchange (O_2 and CO_2) using the Quark CPET system (Cosmed®, Rome, Italy). To conduct the test, a standard protocol for young athletes was used with an initial speed of 5 km/h and an elevation of 0°. After the introductory part of the test, which serves as a warm-up, the speed of the treadmill was increased by 1 km/h every 60 seconds in order to achieve the maximum effort. Subjects were equipped with face mask and mobile ECG device (Quark C12x-T12x) during the CPET to evaluate respiratory and cardiological parameters. The CPET was considered maximal when three of four parameters below are accomplished:

- the value of the achieved maximum heart rate is ⩾ 90% or more of the predicted theoretical maximum heart rate for gender and age, which is calculated based on the formula: 220 – number of years,
- respiratory exchange ratio (RER) > 1.10,
- plateau in maximal oxygen consumption, despite increased loads (differences in VO_2max values less than 150 mL/min at the end of the CPET),
- a subjective feeling of exhaustion.

The cardiopulmonary exercise test was performed by trained and expert persons, as was the calibration, which was done according to the so-called STPD criteria (ST-standard temperature/standard gas temperature: 0°; P-pressure/pressure: 760 mmHg; D-dry equivalent/dry air) after every fifth test to adequately determine the measured parameters.

Statistical Analysis

To describe parameters of importance, depending on their nature, the following were used: frequency, percentages, sample mean, sample median, sample standard deviation, rank, and 95% confidence intervals. To test the normality of the distribution, Kolmogorov-Smirnov tests were used, as were graphs: histogram and normal QQ plot. To test for differences in maximum oxygen consumption between young athletes in two groups, as well as to examine the differences between them in aerobic and anaerobic capacity and heart rate response, we use the Independent T test and the Mann Whitney U test. To analyze the power of the study sample, a post hoc calculation of the power of the sample was performed for the results of the comparison between the two study groups (n=27). Two-way dependent t-test was used, with α=0.05. The effect size was determined by the mean of each group (COVID-19 vs. healthy group) for the variable VO_2pred (%) for adolescents' basketball and soccer athletes [10, 12] (COVID-19 participants: 83.9±9.87% and healthy group participants: 93.1±11.77 %) and standard deviation of the groups. Thus, the value of sample power was (1-β) = 0.989, which is considered a large sample power. The sample size calculation was performed using G*Power 3.1. Statistical data processing was performed using the statistical package SPSS 22.0 for Windows. Differences were considered significant when the p value was less than 0.05.

Results

Descriptive statistics of all participants in the study are presented in Table 1. Results showed that

Table 1. Descriptive statistics of functional abilities of all participants in the study.

Variables	Participants	N	Mean	Standard deviation
VO_2max (mL/kg/min)	COVID-19 infection	53	45,58	4,65
	healthy group	47	56,52	6,19
VE/VCO2	COVID-19 infection	53	24,77	4,24
	healthy group	47	25,17	2,88
RER (CO_2/O_2)	COVID-19 infection	53	1,16	0,064
	healthy group	47	1,13	0,059
O_2/HR (mL/beat)	COVID-19 infection	53	17,23	4,00
	healthy group	47	21,90	4,25
VEmax (L/min)	COVID-19 infection	53	113,02	27,30
	healthy group	47	143,14	26,65
HR at VT1 (bpm)	COVID-19 infection	53	143,90	13,85
	healthy group	47	150,70	12,08
HR at VT2 (bpm)	COVID-19 infection	53	171,98	12,06
	healthy group	47	173,27	9,49
HRmax (bpm)	COVID-19 infection	53	191,94	5,78
	healthy group	47	190,89	6,39
HR recovery 1st minute (bpm)	COVID-19 infection	53	160,39	14,72
	healthy group	47	160,70	12,60
HR recovery 2nd minute (bpm)	COVID-19 infection	53	136,52	14,73
	healthy group	47	132,23	12,71
HR recovery 3rd minute (bpm)	COVID-19 infection	53	125,11	13,67
	healthy group	47	120,55	11,74

Abbreviations: VO2max - maximum oxygen consumption; VE/VCO2 – ventilatory efficiency; RER (CO2/O2) – respiratory exchange ratio; O2/HR – oxygen pulse; VEmax – maximum minute ventilation; HR (beats per minute) – heart rate; VT1 – first ventilatory threshold; VT2 – second ventilatory threshold.

adolescent athletes who had suffered a COVID-19 infection had statistically significantly lower values of aerobic capacity or VO_2 max ($p<0.001$) compared to their peers from the control group (Figure 1). Also, a significant difference was recorded in young players after COVID-19 infection in the area of maximal pulmonary ventilation and Oxygen pulse compared to their healthy peers ($p<0.001$) (Figure 2, and Figure 3).

Furthermore, anaerobic capacity, the respiratory gas exchange ratio (RER), as a measure of lactate tolerance, was much higher in COVID-19 group of adolescents ($p < 0.05$). This means that young athletes who had suffered from COVID-19 infection were exposed to much greater anaerobic metabolic fatigue at the end of the CPET (Figure 4). No statistically significant difference was observed in terms of ventilatory efficiency (VE/VCO_2) ($p=0.589$) (Figure 5).

Discussion

Aerobic and Anaerobic Capacity

The primary findings of this research showed that adolescent athletes after a COVID-19 infection suffered visible consequences from the effects of the virus on their cardiorespiratory abilities. Decreased values of vital parameters compared to healthy peers were observed ($p < 0.001$). The virus and de-training for 14 days had a greater effect on the decline in ability during the competition season than the summer break without training. Adolescent athletes from this study who had suffered a COVID-19 infection had statistically significantly lower values of aerobic capacity or VO_2 max (45,58 mL/kg/min), compared to their peers from the control group (56,52 mL/kg/min), but also lower values than young players from earlier studies prior to the pandemic, who had a range of VO_2 max values from 51.7 mL/kg/min to

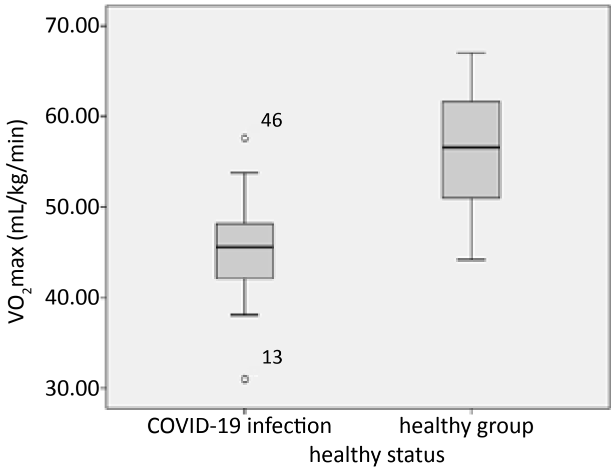

Figure 1. The aerobic capacity (VO_2max) of adolescent athletes after COVID-19 infection compared to their healthy peers. Abbreviation: VO_2max (mL/kg/min) - maximum oxygen consumption

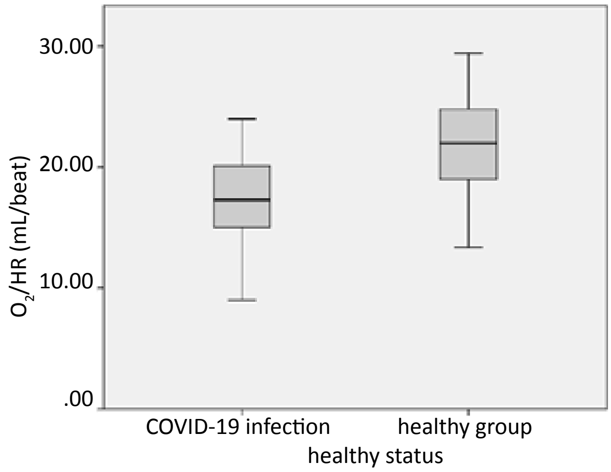

Figure 2. Oxygen pulse of adolescent athletes after COVID-19 infection compared to their healthy peers. Abbreviation: O_2/HR (mL/beat) - oxygen pulse.

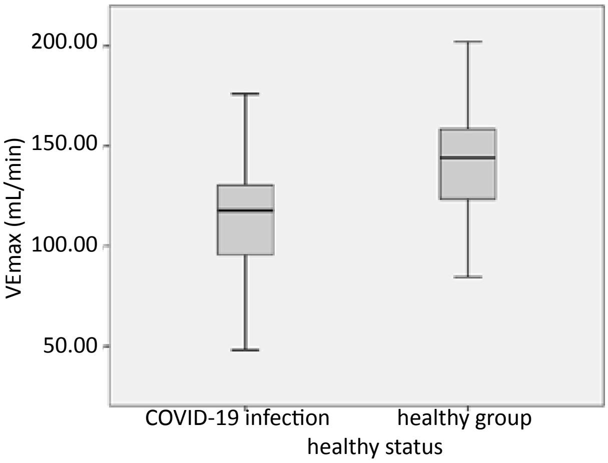

Figure 3. Maximum minute ventilation, of adolescent athletes after COVID-19 infection compared with their healthy peers. Abbreviation: VEmax (mL/min) - maximum minute ventilation.

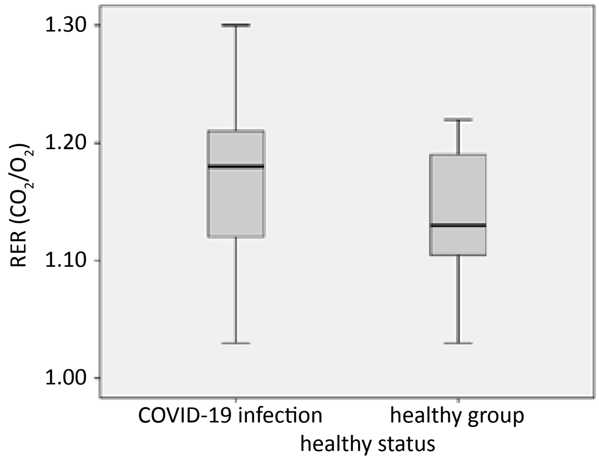

Figure 4. Respiratory exchange ratio (RER) of adolescent athletes after COVID-19 infection compared with their healthy peers. Abbreviation: RER – Respiratory exchange ratio

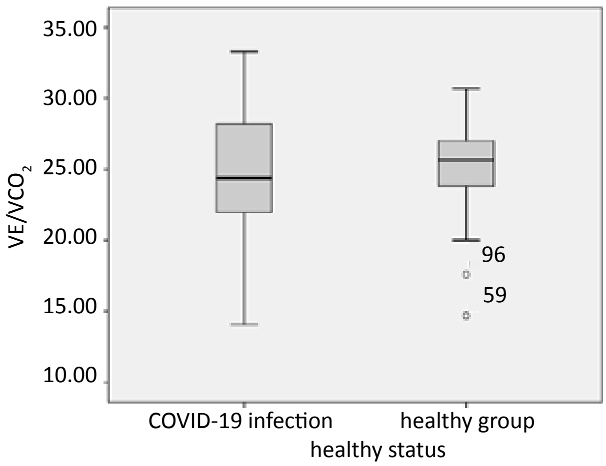

Figure 5. Ventilatory efficiency (VE/VCO_2 slope) of adolescent athletes after COVID-19 infection compared to their healthy peers.

59,4 mL/kg/min [21, 22, 23, 24 25]. At the same time, in terms of anaerobic capacity, the respiratory gas exchange ratio, as a measure of lactate tolerance, was much higher in COVID-19 group of adolescents ($p < 0.05$). This means that young athletes who had suffered from COVID-19 infection were exposed to much greater anaerobic metabolic fatigue at the end of the CPET. Furthermore, an early transition from aerobic to anaerobic metabolism pathways for energy production was seen, which can explain higher maximal RER values. Even though the greater anaerobic fatigue was seen in COVID-19 group of participants, the results in both groups, in terms of RER, are within the parameters expected for gender and age, as well as sports disciplines [26].

Pulmonary ventilation and oxygen pulse

In the area of maximal pulmonary ventilation, our research showed that post COVID-19 adolescent athletes obtained a far lower level of VEmax compared to the control group ($p < 0.001$). However, results from both research groups also coincided with the results of student basketball players from Russia [27]. Furthermore, the adolescent COVID-19 athletes from our study had a lower maximal pulmonary ventilation than healthy athletes from other sports disciplines aged 18-24 [28]. The virus affected the respiratory system of adolescent athletes at the cellular level, more so than detraining itself, since one study showed that, among young athletes aged 15,4 years, there was no drop in VO_2max, VE/VCO_2, VEmax after 42 days of detraining [29].

In terms of the oxygen pulse variable (O_2/HR), as an indirect indicator of the work of the left ventricle of the heart, a significant difference was recorded in young players after COVID-19 infection (18,66 mL/beat) compared to their healthy peers (23,13 mL/beat). This is an indication that it is possible that the virus had affected the function of the left ventricle of the heart, whose task is to deliver oxygen-enriched blood to active muscles. Even though the values from both study groups were within normal limits for age and gander, it was obvious that oxygen delivery to the working muscles was decreased, which can explain the lower VO_2max values in COVID-19 group of athletes [30].

No statistically significant difference was observed in terms of ventilatory efficiency (VE/VCO_2), even though the numerical difference was present. The VE/VCO_2 values coincide with the results from earlier research on this topic for both our study groups, which means that COVID-19 did not affect ventilatory efficiency of young athletes and respiratory function [31, 32].

Heart rate response

Regarding heart rate response parameters, our research observed that COVID-19 infection significantly affected the heart rate response at the first ventilatory threshold. After recovering from a COVID-19 infection, the young athletes faced with a decrease in cardiac capacity, since they reached VT1 at the lower heart rates, indicating that they had entered anaerobic fatigue earlier than their healthy peers during CPET. Yet, at the same time, there was no statistically significant difference in terms of achieved heart rate at VT2 between the groups, even though the numerical difference was observed.

Furthermore, the results of this study coincide with the results of elite athletes from earlier studies [33,34]. However, it is interesting that heart rate recovery after maximum effort was much weaker and, statistically, significantly lower in adolescent athletes after COVID-19 infection, compared to their healthy peers. The difference was observed in the second and third minutes of heart rate recovery after CPET ($p < 0.05$), which may indicate that the COVID-19 infection affects cardiac muscle in terms of decreased exercise tolerance and slower recovery.

The limitation of this study relates primarily to the small number of respondents who had had COVID-19. Further research could be extended to other young athletes from other disciplines, while research could also go in the direction of continuing to monitor young athletes with new medical examinations several months after their recovery from COVID-19. The duration of follow-up or observation period may have been relatively short, which could limit the understanding of long-term effects of COVID-19 infection on cardiorespiratory fitness in young athletes. Addressing these limitations and conducting further research with larger, more diverse samples and longer follow-up periods can provide a more comprehensive understanding of the impact of COVID-19 on the cardiorespiratory fitness of young athletes.

Conclusions

Research has shown that the COVID-19 infection has left certain consequences on the cardiorespiratory fitness of young adolescent athletes. It does so first of all in maximum oxygen consumption, pulmonary ventilation, and oxygen pulse, which is to be expected given that COVID-19 infection has proven to be a virus that affects both cardiovascular and respiratory functions, especially at the cellular level. For healthy athletes, detraining for several weeks did not cause such a big drop as it did in athletes after infection from the coronavirus and a break of 14 days. Infection did not greatly affect respiratory efficiency or heart rate variability, which was at level for sex, age and sport discipline. At the same time, heart rate recovery after maximal effort was lower in the second and third minutes of recovery. These findings can be useful to coaches and doctors of sports medicine when calculating training and returning to the training process of young athletes after their recovery from COVID-19 infection. Naturally, much more research is needed on this topic to gain a broader and better picture of the effects of the virus on the cardiorespiratory functions of athletes.

Within the pediatric sports population, young athletes are at risk of injury during the return to training following a COVID-19 infection and deconditioning. It is necessary to be careful and properly dose individual training for a young athlete after coronavirus disease.

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Conflicts of Interest

The authors declare no conflict of interest.

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REVIEW ARTICLE

Gender stereotypes in physical education: state of the art and future perspectives in primary school

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

Abstract

Background and Study Aim Given the recent mandate by the Budget Law 2022 for compulsory two hours of physical education (PE) in IV and V classes of Italian primary schools, understanding the dynamics of gender stereotypes during movement activities becomes crucial. This review aims to summarize the scientific evidence of the gender gap in PE lessons and identify barriers to female participation in movement activities.

Material and Methods The methodology employed was a systematic literature review guided by the PRISMA 2020 guidelines. The literature search was conducted in April 2023, utilizing a range of databases including Web of Science and Scopus. The search strategy applied MeSH terms and text words, connected by AND: "gender stereotypes" OR "gender gap", "PE" OR "physical education" OR "school" OR "children". Additionally, relevant articles were manually selected from Google Scholar to supplement the database findings. The inclusion criteria were centered on studies within the school context. Only articles published in English within the time frame of 2012 to 2023 were considered. Exclusion criteria ruled out conference proceedings, literature reviews, articles published before 2012, and non-English language publications.

Results Thirteen items met the inclusion criteria. The main barriers included personal beliefs of pupils towards sporting activities, particularly highlighting concerns from the female gender. Other significant barriers were attitudes of teachers and the perpetuation of gender stereotypes in PE textbooks. Several interventions were conducted, primarily focused on co-educational methodologies. These interventions proved effective in dismantling some gender stereotypes.

Conclusions The results demonstrated the presence of gender stereotypes during PE lessons. There was a need to improve teacher training, which was perceived as inadequate to work on gender inequality from primary school onwards.

Keywords: perceptions, gender gap, teaching methods, strategies, barriers

Introduction

In recent decades, the pursuit of gender equality has become a cornerstone of educational reform worldwide, reflecting a broader commitment to social justice and equitable opportunities for all students. Despite considerable progress, disparities persist, particularly in the realm of school education.

The contrast of the gender gap in school education is one of the main priorities on which education policies have been focusing in recent years, as it significantly affects learning outcomes [1]. This concern is directly aligned with the objectives of the 2030 Agenda for Sustainable Development. Specifically, Goals 4 and 5 of the UN Global Agenda 2030 emphasize the importance of providing quality, equitable, and inclusive education for all and achieving gender equality, respectively. Goals 4.1 and 4.5 call for the elimination of gender disparities in education by 2030, ensuring that every child has access to quality and equitable education. Similarly, Goal 5.1 focuses on ending discrimination against women and girls as a fundamental step towards equality. However, the attainment of these objectives faces significant challenges, exacerbated by the COVID-19 pandemic, which has adversely affected educational systems and widened existing inequalities [2, 3]. This backdrop underpins the critical examination of gender stereotypes in physical education within primary schools, spotlighting both the current state of affairs and future prospects for gender equality in education.

Gender stereotypes significantly influence individuals' perceptions and behaviors. These stereotypes are normalized and embedded in social practices from an early age, even before a child is born, illustrated by the common practice of assigning pink or blue colors based on the child's gender. As a result, children internalize gender distinctions through socialization, forming their gender identity [4]. This process affects all aspects of their lives, including their educational experiences. Physical education (PE) is a domain where the gender gap is particularly pronounced. PE has historically perpetuated notions of hegemonic masculinity [5], often sidelining girls either directly or through self-exclusion from activities. It's noteworthy that

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the discipline was initially introduced in schools as 'gymnastics,' exclusively for boys to prepare for military service. Only subsequently was it made available to girls and gradually adopted a more inclusive, educational focus [6, 7].

Historically, sports were deemed unsuitable for women, who were traditionally seen as caregivers, focused on domestic responsibilities. Despite this, an increasing number of women have shown interest in sports over time. Nonetheless, the sports sector remains characterized by significant gender inequalities, with men's participation and sports receiving more economic and cultural recognition. According to the World Health Organization [8] and other research [9], women tend to be more sedentary and less active than men. Typically, women engage more in non-competitive, health-oriented activities, such as gym workouts. This shift has the potential to mitigate gender disparities by blending traditionally masculine traits with those traditionally feminine.

Schools, as institutions, often appear ill-equipped to counteract the mechanisms that foster gender inequalities [10]. They are frequently criticized for systematically producing and reinforcing disparities [11]. One of the most visible manifestations of this issue within educational settings is the perpetuation of stereotypical gender roles, notably through sexism in textbooks. Such materials frequently emphasize traditional roles, casting women primarily as mothers and caregivers, and men as the economic providers for their families [12]. Moreover, teachers may unintentionally propagate gender stereotypes through their teaching practices and content, affecting the quality of instruction in subjects like physical education (PE). Historically, PE instruction has disproportionately favored boys, to the detriment of girls, who often report decreased interest and enjoyment in PE classes [11]. This discrepancy extends beyond the classroom, influencing daily life activities where females tend to be less physically active compared to males.

Considering that attitudes and habits formed during childhood significantly shape behaviors and choices in adulthood, addressing gender stereotypes in PE from the earliest stages of education, starting with pre-school and early primary classes, becomes imperative. Doing so can begin to dismantle the entrenched biases that contribute to gender disparities in physical activity and beyond.

In Italian primary schools, until the 2021/2022 academic year, the teaching of Physical Education (PE) was delegated to generalist teachers. According to several studies conducted in recent years [13, 14], these teachers did not feel adequately prepared to conduct PE lessons, potentially leading to diminished attention to gender policies due to concerns over the content and modalities of a PE lesson. From the academic year 2023/2024, only for Classes V and IV, PE teaching has been assigned to specialist teachers with a master's degree in sports science [15]. This change was made in recognition of the generalist teachers' insufficient competence in promoting children's health and well-being through movement.

Hypothesis and Purpose

Our hypothesis (H1) posits that gender stereotypes remain prevalent in the school context, manifesting themselves during PE lessons. This assumption is based on the observation that the importance of PE in the overall development of children has not been fully acknowledged. Historically, PE was considered a lesser subject, taught by generalist teachers who received general training for all subjects and thus lacked specific expertise in PE.

The purpose of this review is to summarize the scientific evidence demonstrating the presence of the gender gap phenomenon during PE lessons and to identify the barriers that particularly hinder female participation in movement activities. Additionally, it aims to identify variables that should be considered to dismantle this phenomenon and provide actionable guidance for both generalist and specialist teachers responsible for PE in primary schools.

Materials and Methods

Information Sources

The literature search was conducted in April 2023, utilizing various databases and sources: Web of Science; Scopus; Google Scholar (for manual selection of articles). Additional sources included manually selected articles via Google Scholar.

Eligibility Criteria

Inclusion Criteria: Studies were included if they focused on the school context, analyzed teachers' and pupils' perceptions of gender stereotypes in PE, evaluated interventions aimed at breaking down gender stereotypes in PE, and analyzed variables that may influence the reproduction of gender stereotypes in PE. Only publications in English and those published from 2012 to 2023 were considered.

Exclusion Criteria: Exclusions were made for publications in conference proceedings, literature reviews, articles published before 2012, and non-English language articles.

Search Strategy

The search strategy employed MeSH terms/text words combined with AND/OR operators: "gender stereotypes" OR "gender gap", "PE" OR "physical education" OR "school" OR "children".

Selection Process

The selection process was guided by the PRISMA 2020 flowchart to decide whether a study met the inclusion criteria (Figure 1). This involved screening

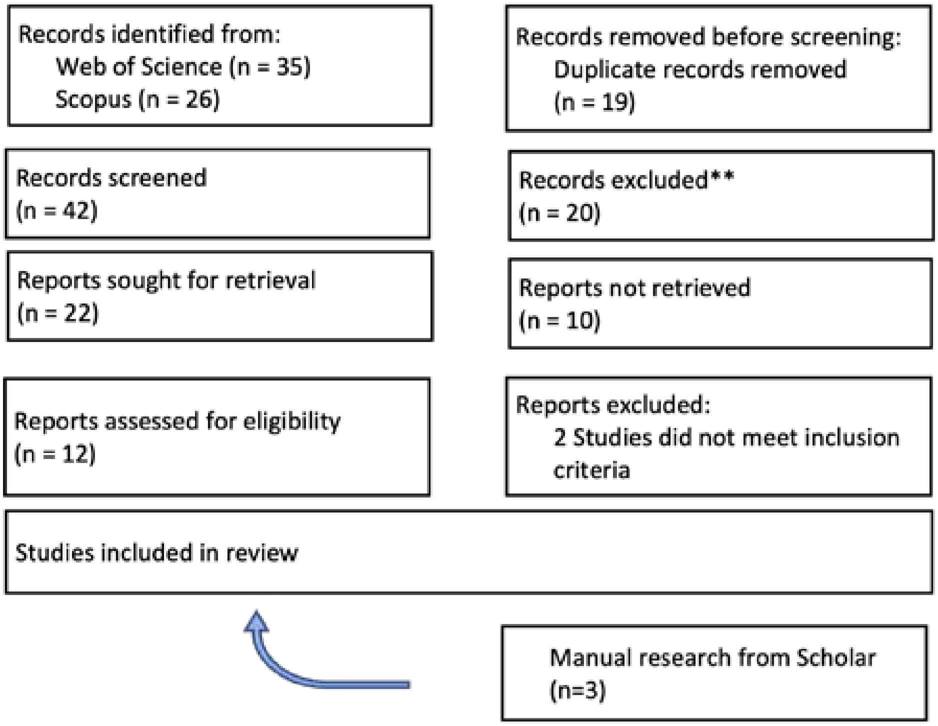

Figure 1. PRISMA 2020 Flowchart Illustrating the Study Selection Process

each record and retrieved report for eligibility, with details of the process to be further specified.

Data Items

Outcomes Sought: Data were sought for outcomes related to the presence of gender stereotypes during PE lessons, barriers hindering female participation in movement activities, and effective interventions breaking down gender stereotypes.

Other Variables: Data were also sought for variables such as participant characteristics, intervention details, and study settings. Assumptions were made for any missing or unclear information, to be further specified.

Results

A search in the Scopus and Web of Science databases yielded a total of 61 articles matching the search criteria. After the removal of 19 duplicates, 42 articles remained for further analysis. Screening of titles and abstracts for relevance to the inclusion criteria led to the exclusion of an additional 20 articles. Full-text review of the remaining 22 articles identified 2 more articles that did not meet the inclusion criteria. Additionally, 3 articles from Google Scholar were included in the study. Consequently, a final sample of 13 relevant articles was identified for analysis, as detailed in Table 1.

Table 1. Gender stereotypes during PE classes.

Sources	Aim	Design	Sample	Tools and intervention	Results
Cárcamo et al. [9]	To understand the gender beliefs, value and participation of Colombian boys and girls in PE.	Qualitative	30 pupils (50% M; 50% F; age 8-10) of primary school	Interview	Gender stereotypes were still present in PE. Topics were beliefs on sports ability, intrinsic and extrinsic motivation, kind of sports, kind of activities preferred.
Gubby [25]	To understand if mixed-sports such as korfball could provide an opportunity for successful mixed PE.	Qualitative	Junior korfball players (aged 11-13) of primary school	Interview	Korfball seemed to reduce the gender gap.

Table 1. (Continued)

Sources	Aim	Design	Sample	Tools and intervention	Results
López-Morales et al. [17]	To investigate how teachers perceived their teaching on gender equality during their PE.	Qualitative	191 PE secondary teachers in Spain	12 questions	PE teachers considered they had proper co-educational behaviour (regarding gender equality).
Martin et al. [16]	To investigate the barriers girls face during PE classes and the benefits of an activist approach on gender issue.	Experimental	20 girls and 28 boys (age 10 -12) and PE teachers of primary school	Focus group, interviews, specific activities	Several barriers were identified focus on the male dominance in games. The programme led to an improvement in the girls' participation.
Martínez et al. [26]	To test the effects of co-educational physical education in improving students' gender beliefs.	Quasi-experimental	91 primary school pupils (age, 11.5 ± 0.7)	Didactic intervention of 4-Colpbol sessions, 2 questionnaire.	The intervention was useful to promote gender equality in PE.
Mateo-Orcajada et al. [19]	To establish differences in gender stereotypes in sport among teachers and trainers.	Qualitative	127 PE teachers and trainers	CEGAFD	The gender stereotypes in trainers and teachers were still present.
Moya-Mata et al. [23]	To analyze the link between gender issue and textbooks of PE in primary school.	Qualitative	34 PE textbooks (Spain)	SAIMEF	PE textbooks reflected gender stereotypes.
Moya-Mata et al. [24]	To analyze the existence of gender stereotypes in PE Brazilian textbooks.	Qualitative	10 PE books containing 1327 images (Brazilian)	SAIMEF	PE textbooks reflected gender stereotypes.
O'Reilly et al. [27]	To investigate the effect of a Girls Active program on girls during PE classes.	Experimental	46 (EXP) and 58 (CON) girls (age, 12-15) from secondary school	Focus group and interviews , Girls Active program	Girls Active was useful to promote PE.
Peterson et al. [22]	To assess physical educators' (N = 162) ability and performance expectations, attributions, and attitudes toward overweight and non-overweight students.	Qualitative	162 PE teachers	Students' photos, questions on ability and performance expectations, Fat Phobia Scale.	PE teachers had lower ability expectations for overweight students than for non-overweight.
Preece and Bullingham [4]	To explore gender stereotypes and their impact upon perceived roles and practice of PE teachers.	Qualitative	21 PE teachers	An online story	Teachers' perceptions largely conformed to typical gender stereotypes.
Vera et al. [21]	To design a Spanish instrument to measure gender stereotypes in PE.	Qualitative	73 primary school students	An ad-hoc questionnaire (24 items + 5 dimensions)	There were prejudice and stereotypes in PE classes related to gender. The tool was valid and reliable.

Xiang et al. [28]	To investigate the presence of gender stereotypes about running during PE.	Qualitative	32 boys and 114 girls of primary school	Ad hoc questions; Run for Your Life program	Running was perceived to be a gender-neutral activity.

CEGAFD, gender beliefs and stereotypes towards physical activity and sport; CON, control; EXP, experimental; SAIMEF, Physical Analysis Images Analysis System

Discussion

The results of the present study demonstrated the persistence of gender stereotypes in the school context during PE lessons. The stereotypes were primarily derived from personal beliefs on the part of the pupils with regard to sports activities. Cárcamo et al. [9], through qualitative research, sought to understand the gender beliefs, value and participation of Colombian boys and girls in PE lessons and concluded that gender stereotypes were still present. Their findings reveal a prevailing perception of male superiority in sports, with most students attributing higher performance to males, except for a minority who believe abilities depend more on individual characteristics and task complexity. Additionally, the study notes differing motivations between genders, with females placing a higher value on psychological well-being from PE. Sports preferences were also gendered, with traditional "masculine" and "feminine" categorizations for activities like football and volleyball, respectively. The research underscores the need for educational strategies that promote gender equality, suggesting adjustments in activity selection and space usage to provide balanced experiences for all students.

Another critical aspect discussed was the barriers to participation in PE lessons, as perceived by females. These barriers included a self-perceived lack of skill, particularly in invasion games; the dominance of boys in activities and the assignment of passive roles to girls; the prominence of male-centric sports in media; the pressure felt by girls when making mistakes; and a lack of self-criticism among boys [16]. To address these perceptions, Martin et al. [16] devised a protocol incorporating two teaching units focused on volleyball and colpbol—comprising six volleyball sessions to explore the barriers, interests, and motivations of girls in PE, followed by nine colpbol sessions implementing an 'activist phase' with reflective spaces aimed at enhancing girls' empowerment and fostering communication between teachers and pupils.

For effective application of these strategies, teachers should consider: 1) selecting and adapting game content to reduce the emphasis on physical contact or activities that require prior knowledge, thereby making participation less daunting; and 2) creating opportunities for reflective discussions. Training for teachers is essential for the successful implementation of this approach. Adopting these practices can help schools move away from perpetuating hegemonic masculinity, ensuring a safer and more positive learning environment for all students.

The third aspect addresses the perceptions and beliefs of primary and secondary school teachers regarding gender stereotypes in PE, as well as the adequacy of their training to address this issue in practice. On one hand, a subset of teachers believes they employ teaching methods that avoid perpetuating these stereotypes. They report not holding higher expectations for male students, employing inclusive language, and providing examples of both male and female athletes in their lessons [17]. On the other hand, a significant number of teachers have expressed a lack of confidence in their training concerning the most effective methodologies to counter gender inequality in PE. This highlights a crucial need for enhanced training programs, especially considering that many educators rely on self-directed learning to fill these gaps.

The REFLECT program, highlighted in the literature, was designed to enhance secondary school teachers' competences in reflective co-education [18]. However, research by Mateo-Orcajada et al. [19] indicated that gender stereotypes persist among PE teachers, particularly among the older cohort. This finding is in line with the study by Preece and Bullingham [4], which observed that PE lessons often mirror prevailing stereotypes: female teachers were of the opinion that males receive preferential treatment in sports, to the detriment of females, while male teachers pointed to developmental differences as a basis for this disparity.

A recent narrative review [20] has highlighted the profound influence of teachers on female students' dissatisfaction in PE, especially in programs that predominantly feature traditional sports. Similarly, Vera et al. [21], by validating a questionnaire designed to explore the existence of gender stereotypes in PE classes, affirmed the continuance of such stereotypes. They underscored the critical need to challenge and change sexist attitudes among educators. Further, Peterson et al. [22] investigated PE teachers' expectations, attributions, and attitudes, with a particular focus on how these are shaped by the gender and weight of the students. Their research revealed that teachers generally have lower expectations for overweight students' abilities, with this bias being more pronounced towards female students. This body of evidence calls for immediate action to address and rectify the misconceptions prevalent among PE teachers.

A significant barrier in the fight against gender stereotypes in sports and physical education (PE) is their perpetuation in educational textbooks. Moya-Mata et al. [23] revealed that textbooks used in Spanish primary schools depict a stereotypical portrayal of sports, characterized by a predominant representation of male sports figures. Activities such as orienteering were predominantly associated with males, while climbing was linked with females. The study suggests a need for textbooks to present role models that challenge these gendered expectations. Reflecting on the content of textbooks could foster more egalitarian and co-educational practices among students. In subsequent research [24], Moya-Mata et al. found similar trends in Brazilian textbooks, where combat sports were typically assigned to males and individual practices like gymnastics to females. These findings underscore the importance of educators actively working to counteract the promotion of hegemonic male sports models in both primary and secondary education.

Various innovative protocols have been successfully employed to tackle gender stereotypes in PE, yielding positive results towards narrowing the gender gap. These include korfball sessions, colpbol, 'girl active', and 'run for your life'. Gubby [25] highlighted korfball, a sport akin to basketball originating from the Netherlands, known for promoting gender equality through its mixed-gender teams and gameplay that ensures a balanced competition between genders. Martinez et al. [26] found that a co-educational intervention using colpbol effectively shifted students' gender perceptions, promoting more equitable views. O'Reilly et al. [27] introduced the 'girl active' initiative in secondary schools, underscoring the significance of teachers engaging with adolescent girls' perspectives to dismantle prevailing gender stereotypes, including the myth of girls' disinterest in sports. This calls for schools to enhance support for teachers in facilitating such discussions. Xiang et al. [28] reported on the 'run for your life' program, a running activity in PE that was deemed gender-neutral by both boys and girls, fostering increased interest and participation among students.

Teachers are instrumental in either perpetuating or dismantling gender stereotypes in physical education (PE) [29]. The effectiveness of their role hinges on their teaching approach and the thoughtful selection of content to foster a quality, inclusive educational environment. It's crucial for teachers to engage in active listening and seek creative alternatives, including content adaptations or variations, to promote inclusive education practices. The introduction of PE specialist teachers, with their targeted university training in sports sciences [30-32], represents a significant step forward compared to the more generalized approach of generalist teachers. Nonetheless, with generalist teachers still responsible for delivering PE in the early years of primary education (classes I, II, and III), there is a clear need for enhanced training and awareness initiatives for these educators.

Future research should aim to explore teachers' perceptions of gender equality and the extent to which their teaching practices in PE reflect gender stereotypes. This includes comparing the approaches of generalist and specialist teachers in primary schools and examining children's perceptions of their teachers' methods and views on gender equality within PE lessons.

Conclusions

This study has illuminated the enduring presence of gender stereotypes in physical education (PE) within both primary and secondary educational settings. Key barriers include pupils' personal beliefs towards sporting activities—with notable emphasis on female students' perceptions—the attitudes of teachers, and the perpetuation of these stereotypes through PE textbooks. Notably, the implementation of several protocols, such as colpbol, korfball, and running programs, has been effective in fostering a more inclusive environment. These sports, by virtue of their rules and adaptations, do not ascribe to traditional gender norms and thus promote inclusivity.

However, a significant challenge remains: many educators report a lack of adequate training to effectively address gender stereotypes in PE. This underscores an urgent need for educational institutions to offer comprehensive resources and materials to support teachers in this critical area. The findings from the reviewed studies suggest that coeducation represents the most effective strategy for overcoming gender biases and fostering an equitable and inclusive PE environment.

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REVIEW ARTICLE

Impact of physical exercise on behavioral and social features in individuals with autism spectrum disorder

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

Abstract

Background and Study Aim Physical exercise is linked with several physical and psychological health advantages. A range of investigations has revealed the presence of a significant association between physical exercise and indicative improvements in subjects with Autism Spectrum Disorder (ASD). This systematic review aims to update the literature about the impact of physical exercise interventions on social, behavioral, and other outcomes for individuals with ASD.

Material and Methods The study design followed the PRISMA guidelines. A systematic search of electronic databases—PubMed, Google Scholar, Science Direct, and Jane Publications—was performed from 2010 to December 2023. We searched for related research papers in English using keywords 'Autism Spectrum Disorder,' 'exercise,' and 'physical activity.

Results This systematic review employed a four-stage screening process, which resulted in the inclusion of 18 trial studies. The intervention period varied from three to forty-eight weeks, with a frequency of 3-7 times per week. The results demonstrated that physical exercise had a substantial positive impact on communication, social interaction, and motor skills in subjects with Autism Spectrum Disorder (ASD).

Conclusions This review supports physical exercise as a powerful tool in decreasing stereotypical behaviors, and in improving social communication and motor skills in subjects diagnosed with ASD. Regular physical exercise therapy can have a greater effect on improving the quality of life for ASD subjects.

Keywords: autism spectrum disorder, exercise, physical activity, psychological, health

Introduction

Autism Spectrum Disorder (ASD) is a multifactorial neurodevelopmental disorder typically identified at a very early age and usually persists throughout an individual's life. The hallmark symptoms of ASD include impaired speech skills, limited social engagement, and repetitive behaviors. The etiology of ASD remains largely unknown, and effective preventive measures have yet to be established [1]. Currently, no reliable early diagnostic biomarkers or definitive treatments are available for individuals with ASD [2]. While a limited number of treatment options exist, the therapeutic outcomes of various rehabilitation methods vary significantly, posing a considerable financial burden on the families of ASD patients and on social service systems [3].

Various behavioral intervention programs aimed at developing social, communication, and cognitive skills have been implemented, leading to positive outcomes for individuals with Autism Spectrum Disorder (ASD). Recent research suggests that incorporating therapeutic options such as exercise, sports, and additional physical activities alongside traditional behavioral therapies can significantly benefit the improvement of behavioral symptoms and the quality of life in individuals with ASD [4, 5, 6].

A variety of exercise programs, such as swimming, jogging, roller-skating, hydrotherapy, walking, cycling, weight training, horse riding, and exergames, have been implemented in individuals with ASD to mitigate the frequency of stereotypical behaviors [4, 7, 8], reduce hyperactivity, and address aggressive or self-injurious behaviors [9]. Hydrotherapy and horse riding therapies, in particular, aim to enhance balance and gross motor coordination in children with autism. Furthermore, these interventions have been utilized to curtail aggressive and antisocial behaviors, thereby improving social engagement and interpersonal relations in individuals with ASD [10, 11]. There is a robust body of research confirming the significant role of exercise therapies in enhancing behavioral, social, and motor skills in individuals with ASD [4, 12, 13]. Additionally, engagement in physical activities has been shown to bolster communication abilities,

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balance, and overall fitness levels in subjects with ASD [14, 15].

The benefits of physical exercise, including enhancements in cardiorespiratory function [6], motor skill performance [16], muscular strength [12], and a decrease in body mass index [17], have been well-documented for individuals with ASD. Overall, exercise plays a pivotal role in both physical and mental health, offering a holistic approach to well-being. Physical activities that engage both the body and mind have been shown to reduce stereotypical behaviors and improve cognitive functions [18] and perceptual-motor skills [19] in individuals with ASD. Additionally, exercise therapy has been effective in alleviating stress and anxiety, reducing reaction times, enhancing memory, and improving sleep quality [20].

In recent years, a multitude of review articles has emerged, examining the impact of exercise on various aspects, including social communication [21], the immune, musculoskeletal, and gut systems [22], stereotyped behaviors [23, 24], as well as academic and physical activity outcomes [25] in subjects with ASD.

Despite growing evidence supporting the behavioral and mental health benefits of physical exercise, research specifically addressing individuals with ASD remains limited. The clarity of outcomes from various studies is often obscured by significant variations in sample sizes, intervention durations, frequencies, and measurement methods. The primary objective of this systematic review is to update the existing literature on the effects of physical exercise interventions on social, behavioral, and other outcomes in individuals with ASD.

Methodology

Search Strategy

Search strategies adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [26]. This review considered all relevant research articles published in peer-reviewed journals between 2010 and 2023, focusing on the impact of physical exercise on individuals with ASD, and were available in English. A systematic electronic search was conducted across PubMed, Google Scholar, Science Direct, and Jane publications. Using keywords 'Autism Spectrum Disorder' and 'physical exercise/activity,' we identified 60 pertinent papers. The articles were initially selected based on their titles and abstracts, with a final selection made after a full-text assessment.

Data Collection and Extraction

Two independent researchers systematically extracted data from all selected articles. The following screening methods were employed to determine the relevance of articles from the initial search to the study objectives:

a) Topic identification was the first step, after which all duplicate articles were excluded.
b) The abstracts were assessed for sufficient data pertaining to the research topic, with inadequate articles being removed.
c) Full texts of the remaining articles were reviewed against the inclusion criteria, and those not meeting these criteria were excluded from the study.
d) Comprehensive information was extracted from each article, including study reference, number of participants along with their ages, type of intervention, duration, frequency, protocol, and outcomes, as detailed in Table 1.

From the search across Science Direct, Google Scholar, Jane Publication, and PubMed databases, a total of 60 studies were initially identified. After removing duplicates, 33 studies remained. Preliminary screenings of titles and abstracts further narrowed the selection to 28 studies. Ultimately, 18 studies were included in the review following a full-text evaluation (Figure 1).

Study Selection Criteria

The inclusion criteria for selecting studies were as follows:

a) Participants diagnosed with Autism Spectrum Disorder (ASD) according to the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) or another recognized diagnostic method, encompassing any age group.
b) Incorporation of physical exercise as an intervention tool within the study design.
c) Studies published within the timeframe of 2010 to 2023.

Exclusion criteria for the study selection included:

1) Review articles, animal studies, conference proceedings, and duplicate articles.
2) Studies that involved subjects with other physical diseases.

Study Characteristics

The key findings from the reviewed articles on this topic are summarized in Table 1. The studies incorporated a variety of exercise approaches—including jogging, running, jumping, ball tapping, cycling, balance trampoline training, games, sports, and more—to assess the impact of physical exercise on individuals with ASD.

Results

Table 1 displays the primary information, intervention characteristics, and outcomes of the included studies. Over the past decade, from 2015 to 2023, nineteen papers were published. These articles collectively involved a total of 870 subjects with ASD, with 757 participants in the ASD-specific groups and 117 in control groups.

Table 1. A summary of published studies examining exercise intervention and relevant outcomes in individuals with ASD

References	Study	No of Subjects (Age in years)	Intervention	Duration	Protocol/ tools	Outcome
1	2	3	4	5	6	7
27	RCT	n= 55 (8–12)	Jogging	30-min daily for 12–week,	Gilliam Autism Rating Scale	Significant improvements in sleep and behavioral functioning
28	RTC	n=27, A=15; C=12; (8-12)	jogging	12-week	Emotion Regulation Checklist and the Child Behavior Checklist	Significant improvement in emotion regulation and reduction in behavioral problems
29		n=20, A=10, C=10, (4 to 7)	Physical exercise	60-min, three times a week for 8 weeks	Abbreviated Development Scale -3	significant improvements in gross motor skills
30	C C T	n=30 (9–12)	Ball-tapping	20 min per session for 24 sessions (two sessions per week,)	video camera and Gilliam Autism Rating Scale (GARS-3)	Hand-flapping stereotypy was significantly reduced
31	Pilot study	n=24, male = 20, female = 4; (11 - 14)	Aerobic, resistive, and neuromuscular	8-week	Body composition and ATEC	Fat mass was significantly reduced, and behavior improved markedly.
32		n=64	Two-wheel cycling vs stationary cycling	-	-	significant improvements in cognition and self-regulation
33	RCT	n= 21, 17 males and 4 females; Mean age = 11.07 ± 1.44	Ball-tapping and jogging	10-min daily for 3 days	stereotypic behavior was videotaped	Hand-flapping, body-rocking and stereotypic behaviors were significantly reduced however, the behavioral benefit diminished at 45 min after the exercise.
34	RCT	n= 64, A = 46, C = 18; (6-12)	Physical Exercise	48-week	Multilevel regression modelling	Beneficial effects on metabolic indicators, autism traits, and parent-perceived quality of life
35	-	n= 20, Adolescents	Motor activities, games and sports	10 weeks	Bruininks-Oseretsky Test of Motor Proficiency (BOTMP)	significant effects on all of the variables except the speed of running and agility
36	RCT	n= 40 (mean = 9.95)	Physical activity	-	-	significant improvements in sleep and in inhibitory control
37		n= 28, A=14, C=14 (Mean: 10.07 ± 0.25)	Running speed and agility, balance, bilateral coordination, and the standing long jump. Handgrip strength (both sides),	Three 60-minute sessions per week for 12 week	of BOT-2, Reaction times, and flexibility tests	Significant improvement in gross motor proficiency with reaction times and flexibility in ASD

Table 1 (continued)

References	Study	No of Subjects (Age in years)	Intervention	Duration	Protocol/ tools	Outcome
1	2	3	4	5	6	7
38	-	n= 10 (mean: 10)	combination of aerobic exercise training and Motor skill training (Ball playing, Balance exercise, Cycle training)	60-minute, thrice-weekly for 3 weeks	sleep-encephalography, parents' questionnaire and standardized test batteries.	sleep efficiency increased, sleep onset latency shortened, and wake time after sleep onset decreased for 63% of the sample, Mood in the morning, improved
39	-	n=66, A=33, C= 33 (13.1 ± 2.97)	Virtual training and physical exercise	One hour 3 times a week for 6 weeks	Executive function tests	Executive functions (working memory, inhibition, flexibility) were improved However, after the intervention stopped, the executive functions decreased
13	RCT	n= 229 (2.3-17.3, mean = 7.8, ±3.2)	Moderate intensity exercise	30 min, twice a week for 48 weeks	Bayesian multilevel regression modelling	Decrease in social interaction problems, attention deficit, emotional reactivity, stereotypical verbal and motor behavior, and sleep disturbances.
40	RCT	n= 112 (4-6)	Games based exercise	1 hour twice a week for 16 weeks.	CAST, AQ-Child	Significant improvement in physical and psychological traits
41		n=16, 3 girls and 13 boys, A=8, C=8 (4–10)	Trampoline training standing long jump without run-up	32 weeks	Motor proficiency BOT2 test	improvement in both the strength of the inferior limbs and motor proficiency
42		n= 25 A=14, C=11 (6.9 ± 2.3)	Trampoline training, standing long jump without run-up	20-32 week	Motor proficiency BOT2 test	Motor pro ciency improved
43	RCT	n = 7, (mean = 13.0 - 1.4)	Aerobic exercise	60 minutes every day for five days	Heart rate (HR) and Borg Rating of Perceived Exertion (RPE)	Significant and large reductions in Stereotypical behaviors in ASD group

A= Autistic, C= Control, ATEC= Autism Treatment Evaluation Checklist, BOT-2=Bruininks-Oseretsky test-2, CAST=The Childhood Autism Spectrum Test, AQ-Child= The Autism Spectrum Quotient-Children's Version, (RCT= Randomized controlled trial, CCT= Controlled Clinical Trial

Regarding the frequency of physical activity, thirteen studies reported engaging in physical activity more than three times per week. Three studies indicated a frequency of physical activity three times or less per week, while the frequency of exercise was not specified in three other studies.

Among the selected papers, nine reported that each physical exercise session lasted between 30 and 60 minutes, and two papers indicated a duration of 10 to 15 minutes. However, the duration of exercise sessions was not specified in the remaining papers. The duration of physical activity interventions varied widely, ranging from 3 weeks to 48 weeks. There were six articles where the intervention period was eight weeks or shorter, and eight papers described interventions extending beyond eight weeks.

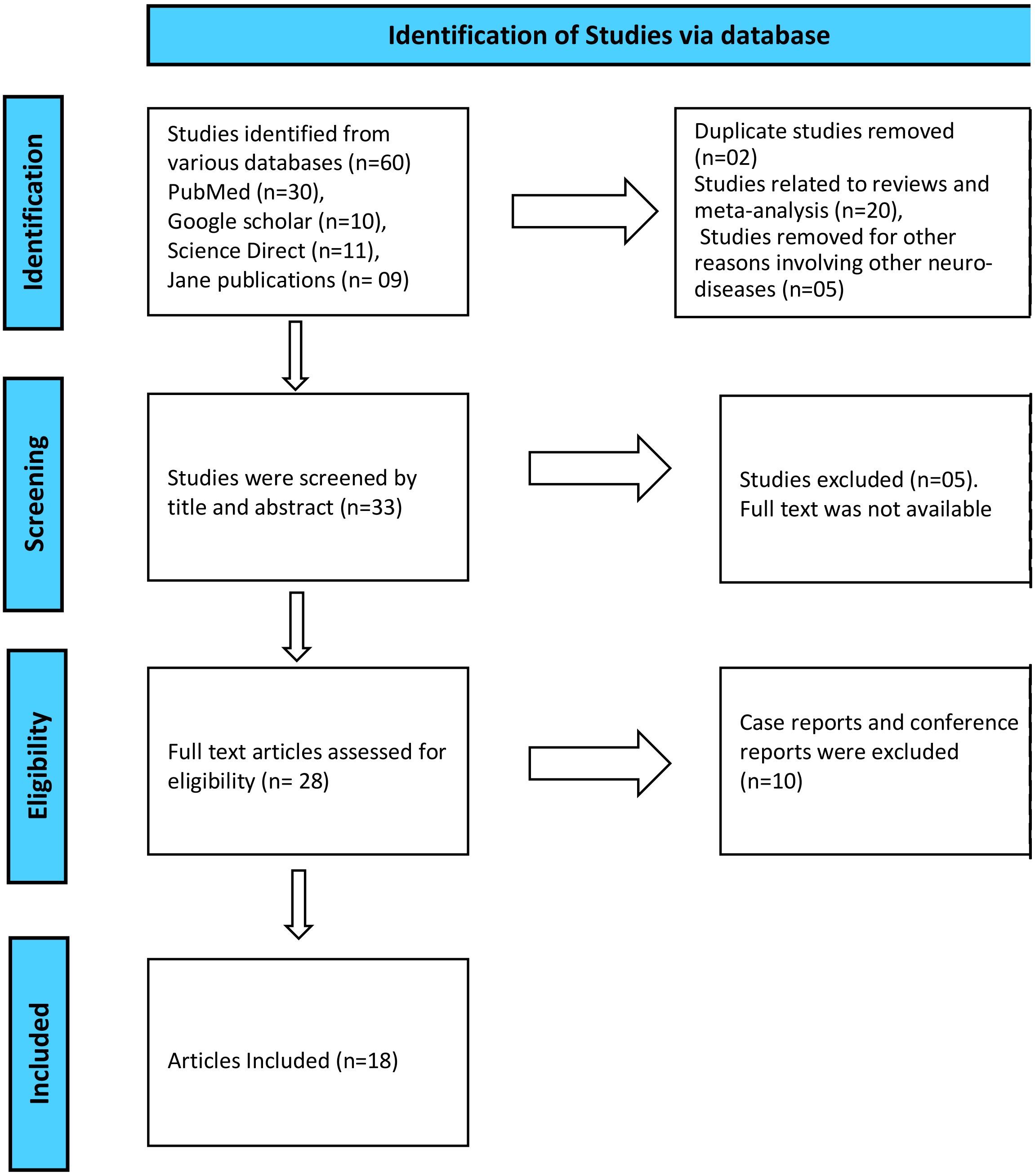

Figure 1. Scheme of information about the different phases of systematic search through the positioning PRISMA guidelines.

The 19 studies reviewed reported various physical exercises, including Jogging (n = 3), Ball playing and balance activities (n = 3), Cycling (n = 2), Aerobic, resistive, neuromuscular, and motor skill exercises (n = 3), Games and sports such as running and standing long jump (n = 2), Trampoline training (n=2), and other physical activities (n = 4). The outcomes of these exercise interventions primarily focused on the three core symptom areas of ASD—stereotypical behaviors, and motor, social, and communication skills—though some studies also explored effects on sleep quality, inhibitory control, emotional regulation, cognitive function, and executive functions.

Geographically, the studies were diverse: five originated from Hong Kong, three from the USA, two each from the UK, Columbia, and Portugal, and the remaining five from Iran, Turkey, China, Brazil, and Switzerland.

Table 1 summarizes all the included studies, detailing physical exercise variables, study type, number of subjects along with their ages, intervention methods, exercise duration, frequency, protocol, and outcomes. Figure 1 presents a flowchart that outlines the four stages of the systematic search process, following the PRISMA statement guidelines.

Discussion

Physical exercise has been employed as an intervention to address various health-related issues in individuals with ASD. The objective of this systematic review was to gather and analyze data from published studies on the impact of physical exercise on stereotypical behaviors, social and cognitive functioning, and physical fitness in subjects with ASD. The outcomes from eighteen studies were assessed through pre- and post-exercise intervention evaluations.

Moderate to Vigorous Physical Activity (MVPA) exercise programs were implemented as interventions for individuals with ASD, engaging them in a variety of activities, including Jogging [27, 28], Ball Playing and Balance [30, 32], Cycling [32, 38], Aerobic Resistive, Neuromuscular, and Motor Skill Exercise [31], Games and Sports like Running and Standing Long Jump [37, 42], Trampoline Training [41, 42], and other physical activities [13, 29, 40].

The studies reviewed herein have shown a significant link between physical exercise and the reduction of stereotypical behaviors [23, 44], along with notable improvements in motor, social, and communication skills [29]. Furthermore, exercise has been observed to positively affect sleep [36, 38], mood, emotion regulation [28], cognition, self-regulation [32], and executive functions [39] in individuals with ASD.

According to this review's findings, in thirteen papers, physical exercise occurred more than three times per week; in three articles, the frequency was three times or less per week; and in two papers, the duration of the intervention was not specified.

Regarding the duration of each physical activity intervention, nine papers reported periods ranging from 30 to 60 minutes, and two papers specified 10 to 15 minutes; the duration in the remaining papers was not clearly defined. The intervention periods for physical activities varied significantly, from 3 weeks to 48 weeks. There were nine papers reporting an intervention period of eight weeks or shorter, and another nine papers documented periods longer than eight weeks.

The frequency, duration, and period of exercise interventions are critical factors influencing the extent and sustainability of their effects [24]. Regarding the optimal duration for interventions, exercises spanning eight to twelve weeks are recommended [21]. Although there is a trend indicating diminishing returns over longer periods, studies have observed only minor differences in the total effect size between moderate and extended exercise durations [21]. Consequently, further research is essential to elucidate the optimal duration of exercise interventions. From the standpoint of session length, engaging in more than one hour of exercise per session is likely to yield better outcomes. This is particularly relevant for individuals with ASD, where brief periods of exercise may not significantly alter arousal levels or impact brain structure and function. Regarding the frequency of exercise, engaging in physical activities more than three times a week is deemed necessary to produce discernible effects [21]. There is a need for additional studies to investigate whether exercising more than five times per week offers superior benefits compared to a more moderate frequency.

Recent analysis by Su et al. [45] evaluated the impact of exercise interventions, indicating that extended sessions lasting 45–75 minutes, conducted 1–2 times per week for a duration of 12 weeks or more, are necessary to enhance motor skills. Additionally, they found that long-duration exercise sessions are more effective than shorter ones. For significant improvements in psychosocial functioning and to induce neurological changes, interventions should last for at least 50 minutes, 1–2 times per week, over a period of 10 weeks or more [45].

Exercise intensity plays a crucial role in triggering metabolic and associated neurological mechanisms. Lang et al. [9] posited that higher intensity exercise yields more pronounced effects compared to milder forms of exercise. Intensity is commonly gauged by heart rate, and the World Health Organization (WHO) recommends achieving 60–69% of the maximal heart rate (MHR = 220 – participant's age) to qualify as moderate to vigorous physical activity (MVPA) [46]. Conversely, Tse et al. [47] observed that for children with ASD, exceeding 50% of the maximum heart rate (MHR) should be deemed MVPA due to their generally lower levels of physical activity. Given the enhanced benefits of longer-term exercise interventions, maintaining consistent engagement in exercise is vital. It is advisable to gradually attain MVPA, taking into account the individual's perceived exertion rate (RPE), as physical fitness levels vary significantly among individuals.

The outcomes of this review yield several valuable insights. Firstly, exercise interventions may facilitate social integration in individuals with ASD by reducing the duration and intensity of stereotypic behaviors and associated behavioral issues. This could lead to a more positive perception of physical fitness and healthy living among individuals with ASD and their families. Secondly, physical exercise interventions could serve as a preventative behavioral therapy, offering an effective alternative to medications for mitigating maladaptive behaviors. Lastly, as an indirect practical implication, physical exercise is associated with mitigating several health comorbidities prevalent among individuals with ASD, such as those related to higher instances and increased risk of obesity [48] and enhancements in metabolic health [34].

Physical exercise plays a remarkable role in benefiting both the brain and body. According to heart-brain physiology, an increase in heart rate leads to more oxygen being delivered to the brain and a rise in hormones that support the healthy development of neurons and glial cells. Beyond fostering the growth of new brain cells, exercise enhances brain plasticity and stimulates new connections between the cerebral hemispheres. Aerobic exercises, in particular, impact the overall brain size and improve cognitive functions. Continuous aerobic activity is linked to growth in the hippocampus—the brain structure responsible for emotion regulation, memory, motivation, and overall learning abilities [49]. Many children with ASD, who experience challenges with short-term memory, have seen significant enhancements in hippocampal function and quality of life through aerobic exercise [50].

Various theories have proposed different mechanisms by which exercise ameliorates the principal symptoms of ASD, with regulation of metabolism highlighted as a key process. This metabolic regulation is crucial for transporting trophic factors and neurotransmitters [5, 52, 53], which may contribute to the alleviation of ASD's behavioral symptoms by normalizing brain function.

During physical activity, an increase in heart rate and breathing rate not only delivers more oxygen and nutrients to the muscles and organs but also enhances blood flow. This augmented circulation helps in the removal of waste products, such as lactic acid and carbon dioxide, that accumulate during exercise.

In the brain, physical activity triggers the release of various neurotransmitters and hormones, such as endorphins, serotonin, and dopamine, which are known to enhance mood and alleviate stress. Furthermore, exercise promotes neurogenesis and improves neural connectivity across different brain regions, contributing to enhanced cognitive functions.

This study enriches the existing body of research and clinical understanding within the field of ASD by deepening insights into the relationship between ASD and exercise interventions. The findings from this review will be instrumental in determining which exercises are most beneficial and suitable for individuals with ASD. Additionally, it sets forth several directions for future research, including: (a) evaluating the long-term impacts of physical activity; (b) elucidating the physiological or psychological mechanisms driving, contributing to, or hindering positive outcomes; and (c) discovering effective strategies for integrating exercise into daily routines and existing therapeutic interventions.

The paramount objective of this review is to pave the way for more personalized exercise programs, tailored to the unique needs of individuals with ASD. We are optimistic that the insights gained from this review will positively influence one of the most challenging public health issues faced globally. To comprehensively understand the role of various physical exercise programs in treating children with ASD, further experimental studies involving a larger cohort of ASD subjects are essential, with a particular emphasis on holistic outcomes.

Conclusions

Physical exercise emerges as a promising therapeutic strategy for individuals with ASD, offering diverse benefits across physical, cognitive, and social domains. Research has demonstrated that exercise can enhance physical fitness, motor skills, social interactions, and cognitive performance in the ASD population. Furthermore, it contributes to reducing symptoms of anxiety, depression, and sleep disturbances among these individuals. Optimal outcomes from exercise interventions are typically observed with early initiation, incorporating multi-component exercises, and employing protocols that feature moderate to high intensity, high frequency, prolonged duration, and group settings.

Effective collaboration between healthcare professionals and exercise experts is essential to devise comprehensive exercise programs tailored to the specific needs of individuals with ASD. These programs should consider all aspects of a patient's profile, including physical capabilities and interests, to ensure that the exercise regimen is not only appropriate but also enjoyable and sustainable over time. Further research is necessary to identify which types of exercise interventions are most effective in supporting individuals with ASD, paving the way for more targeted and beneficial therapies.

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Conflict of Interest

The authors have no conflicts of interest to report.

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