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Exome-Wide Association Study of Competitive Performance in Elite Athletes

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Abstract: The aim of the study was to identify genetic variants associated with personal best scores in Turkish track and field athletes and to compare allelic frequencies between sprint/power and endurance athletes and controls using a whole-exome sequencing (WES) approach, followed by replication studies in independent cohorts. The discovery phase involved 60 elite Turkish athletes (31 sprint/power and 29 endurance) and 20 ethnically matched controls. The replication phase involved 1132 individuals (115 elite Russian sprinters, 373 elite Russian endurance athletes (of which 75 athletes were with VO_{2max} measurements), 209 controls, 148 Russian and 287 Finnish individuals with muscle fiber composition and cross-sectional area (CSA) data). None of the single nucleotide polymorphisms (SNPs) reached an exome-wide significance level ($p < 2.3 \times 10^{-7}$) in genotype–phenotype and case–control studies of Turkish athletes. However, of the 53 nominally ($p < 0.05$) associated SNPs, four functional variants were replicated. The *SIRT1* rs41299232 G allele was significantly over-represented in Turkish ($p = 0.047$) and Russian ($p = 0.018$) endurance athletes compared to sprint/power athletes and was associated with increased VO_{2max} ($p = 0.037$) and a greater proportion of slow-twitch muscle fibers ($p = 0.035$). The *NUP210* rs2280084 A allele was significantly over-represented in Turkish ($p = 0.044$) and Russian ($p = 0.012$) endurance athletes compared to sprint/power athletes. The *TRPM2* rs1785440 G allele was significantly over-represented in Turkish endurance athletes compared to sprint/power athletes ($p = 0.034$) and was associated with increased VO_{2max} ($p = 0.008$). The *AGRN* rs4074992 C allele was significantly over-represented in Turkish sprint/power athletes compared to endurance athletes ($p = 0.037$) and was associated with a greater CSA of fast-twitch muscle fibers ($p = 0.024$). In conclusion, we present the first WES study of athletes showing that this approach can be used to identify novel genetic markers associated with exercise- and sport-related phenotypes.

Keywords: athletic performance; athletics; track and field; athletes; aerobic capacity; muscle hypertrophy; sports genetics; WES; EWAS; GWAS

1. Introduction

Whether pure talent or long-term experiences promotes athletic performance is one of the questionable issues [1]. Progression in the sport sciences has underlined that athletic performance was a phenomenon affected by lots of factors including physiology and environment [2]. Recent studies have also figured out the possible association of the genetic background of the athletes in their high personal performances, resulting in the rise of a novel scientific branch, called sport genetics [3,4].

Sport genetics could be defined as the investigation of the genes and their molecular mechanisms affecting athletic performance and the determination of the possible association of the variants, especially single nucleotide polymorphisms (SNPs), with diverse athletic parameters including branch or personal performances [5]. According to the studies on sport genetics, 66% of athletic performance has been linked to the genetic background [6]. Moreover, physical parameters were also associated with the genetic background. For instance, 44–68% of endurance and 49–56% of muscular force were shown to be affected by genetic variations [7,8]. Thus, both genetics and the environment, which would influence each other, have key roles in athletic performance [9,10]. For example, training periods to reach a performance level were proved to be linked to the genetic background of the athletes [9].

Recently, identification of candidate genes and/or variants associated with sports parameters has greatly attracted scientists. Until now, more than 235 genetic variants have been linked to the athletic parameters [10,11]. However, the results of the single-gene and/or variant approach may mislead, owing to the ignorance of the other related genes and/or variants. Consequently, it was realized that the results for the associations of each gene and/or variant were controversial [12]. Hence, multigenetic factors should be targeted to totally explore the possible associations. In parallel, several genome-wide association studies (GWAS) have been conducted on sports genetics. GWAS is a powerful technique to cover all known or unknown SNPs [13–15]. GWAS has proposed novel associated genes and/or SNPs for the athletic parameters such as endurance, aerobic capacity, metabolism, and muscle fiber composition [16,17]. However, the complexity and cost of GWAS limit such studies, and pilot experiments are suggested [18]. Exome-wide association studies (EWAS) could be an alternative to overcome the problems with GWAS. EWAS has also been previously chosen as a strategy to find the possible associations in the sports genetics [19].

The aim of the present study was to identify genetic variants associated with personal best scores in Turkish track and field athletes and to compare allelic frequencies between sprint/power and endurance athletes and controls using a whole-exome sequencing approach, followed by replication studies in independent cohorts of athletes and controls.

2. Materials and Methods

2.1. Ethical Approval

The study was carried out in accordance with the Declaration of Helsinki, and approval was obtained from the Gazi University Non-Interventional Clinical Research Ethics Committee (with the decision dated 5 April 2021 and numbered 09) and from the Ethics Committee of the Federal Research and Clinical Center of Physical-Chemical Medicine of the Federal Medical and Biological Agency of Russia (Approval number 2017/04).

2.2. Participants

2.2.1. The Turkish Cohorts

The Turkish study involved 60 elite athletes (sprint/power: 11 females (35.5%) and 20 males (64.5%); endurance: 10 females (34.5%) and 19 males (65.5%); mean age \pm SD:

25.1 ± 4.8; height (cm): 174.97 ± 7.9; body weight (kg) 72.5 ± 22.4; sport experience (year) = 9.4 ± 4.8; personal best (PB) = 1005.63 ± 94.55) licensed in different clubs and affiliated with the Turkish Athletics Federation. The number of controls (non-athletes) was 20 (6 females (30.0%) and 14 males (70.0%); mean age ± SD: 23.5 ± 7.1), and they were healthy unrelated citizens of Turkish descent without any competitive sports experience.

The athletes were categorized as either sprint/power or endurance athletes as determined by the distance, duration, and energy requirements of their events. All athletes were nationally ranked in the top ten in their sports discipline and had participated in international competitions such as the Olympic Games, European Championships, Universiade, Mediterranean Games, and Balkan Championship. The sprint/power group included sprint and power athletes whose events demand predominantly anaerobic energy production. The athletes in this group ($n = 31$) were 100–400 m runners ($n = 9$), jumpers ($n = 3$), and throwers ($n = 19$). The endurance athlete group ($n = 29$) included athletes competing in long-distance events demanding predominantly aerobic energy production. This group included 3000 m ($n = 12$), 5000 m ($n = 5$), 10,000 m ($n = 4$), and marathon ($n = 8$) runners. The informed voluntary consent and demographic information forms were obtained from the participants before the measurements. The International Association of Athletics Federations (IAAF) score scale was used to determine the performance levels of the athletes, depending on their personal best/competitive performance [20]. For instance, the IAAF score scale of a male athlete who runs 100 m in 10.05 sec is 1189, while that of a marathon runner who completes the race in 2 h 20 min 11 sec is 997. Thus, the performance scale of the marathon runner is less than that of the 100 m runner. The IAAF scales are useful for the determination of performances of athletes from diverse athletics events and genders.

2.2.2. The Russian Cohorts

The Russian case–control study involved 488 elite athletes (293 males and 195 females), of whom 115 were elite sprint/power athletes (29 100–400 m runners, 38 500–1000 m speed skaters, 22 sprint cyclists, 26 50 m swimmers), and 373 were elite endurance athletes (52 rowers, 32 biathletes, 7 long-distance cyclists, 30 kayakers and canoers, 37 middle- and long-distance speed skaters, 92 cross-country skiers, 63 middle- and long-distance runners, 31 middle- and long-distance swimmers, 8 race walkers, and 21 triathletes). The athletes were Russian national team members (participants and prize winners in international competitions) who had never tested positive for doping. Of 373 endurance athletes, 46 male endurance athletes (rowers, kayakers, speed skaters, biathletes, and cross-country skiers) and 29 female endurance athletes (rowers, kayakers, speed skaters, biathletes, and cross-country skiers) participated in the study of aerobic performance. Controls were 209 healthy and unrelated citizens of Russia without any competitive sport experience.

The Russian muscle biopsy study involved 148 physically active participants of Russian origin (99 males: mean age ± SD: 30.4 ± 7.9 years; 49 females: mean age ± SD: 27.1 ± 7.3 years).

2.2.3. The Finnish Cohort

The Finnish muscle biopsy study (replication phase) involved 287 individuals (167 males, age 59.5 ± 8.1 years; 120 females, age 60.7 ± 7.4 years) from the FUSION study as previously described [21].

2.3. Evaluation of Muscle Fiber Composition by Immunohistochemistry

2.3.1. Russian Study

Vastus lateralis samples were obtained from the left legs of the participants using the modified Bergström needle procedure with aspiration under local anesthesia using 2% lidocaine solution. Serial cross-sections (7 μm) were obtained from frozen samples. The sections were then incubated at RT in primary antibodies against slow or fast isoforms of the myosin heavy chains, as previously described [17,22].

2.3.2. Finnish Study

Muscle fiber composition in 287 Finnish individuals was estimated based on the expression of the myosin heavy chain 1 (MYH1), myosin heavy chain 2 (MYH2), myosin heavy chain 7 (MYH7), Ca²⁺ ATPase A1, and Ca²⁺ ATPase A2 genes, as previously described [21].

2.4. VO_{2max} Measurement

Maximal oxygen consumption rate (VO_{2max}) in rowers, kayakers, speed skaters and biathletes was determined using an incremental test to exhaustion on specific ergometers. VO_{2max} was determined breath-by-breath using a MetaLyzer II (Cortex Bio-physik, Leipzig, Germany), MetaMax 3B (Cortex Biophysik, Leipzig, Germany) or MetaMax 3B-R2 gas analysis systems (Cortex Biophysik, Leipzig, Germany), as previously described [23].

2.5. Whole-Exome Sequencing (WES)

The peripheral blood obtained from the participants was processed to isolate total DNA by DNeasy Blood and Tissue Kit (Qiagen, Hilden, Germany) according to the manufacturer's instructions. Next, qualities of isolated DNA were checked by 1% agarose gel, and the concentrations were determined by a NanoDrop (NanoDrop 1000 Spectrophotometer V3.8; Thermo Scientific, Waltham, MA, USA). WES was performed after library preparation by the Twist Human Comprehensive Exome Panel (Twist Biosciences, San Francisco, CA, USA) according to the supplier's instructions. Briefly, enzymatic DNA fragmentation was performed, and Twist Hybridization probes and Dynabeads™ MyOne™ Streptavidin T1 (Invitrogen, Carlsbad, CA, USA) were used for the hybridization. After the steps of library enrichment and determination of the library sizes, the samples were uploaded to the flow cells and the run was performed by Illumina NextSeq500 (Illumina Inc., San Diego, CA, USA). Average read depth was aimed as minimum 200×. Raw data were processed to by the Genome Analysis Toolkit (GATK)'s [24]. The HaplotypeCaller program was used to obtain Binary Alignment Map (BAM) files and subsequently produce an output Variant Call Format (VCF) file via the GRCh38/hg38 reference genome. Finally, variants were annotated by ANNOVAR [25].

2.6. Data Extraction

As the primary evaluation of the data, the VCF files were combined, and 511,061 variants were detected. Only SNPs were analyzed in the context of the present study. The variants with a minor allele frequency (MAF) < 0.01, incorrectly annotated, and non-autosomal were eliminated, and 219,232 SNPs were further evaluated.

2.7. Genotyping

DNA samples from Russian individuals were obtained from leukocytes (venous blood). DNA extraction and purification from blood samples were performed using commercial kits (Techno-sorb), according to the manufacturer's instructions (Techno-clon, Moscow, Russia). Genotyping of the candidate SNPs from the discovery phase was performed using microarray technology [26].

DNA samples from Finnish individuals were extracted from the blood, and the polymorphisms were genotyped using the HumanOmni2.5–4v1_H BeadChip array (Illumina, San Diego, CA, USA), as previously described [21].

2.8. Statistical Analyses

Association analyses of Turkish data were performed by a Chi-square test using the R program [27]. During the EWAS, the unified mixed-model method [27] was used.

$$y = X\beta + S\tau + e \quad (1)$$

where y is the phenotypic observation; $X\beta$ is the fixed effect; and $S\tau$ is the SNP effect [27]. The statistical significance probabilities of the SNP effects were converted to $-\log_{10}p$. The

results of EWAS analyses were presented as a Manhattan Plot. The exome-wide significance level was set at $p < 2.3 \times 10^{-7}$ (i.e., 0.05/219,232 SNPs).

Statistical analyses of Russian and Finnish data were conducted using GraphPad InStat Version 3.05 (GraphPad Software, Inc., San Diego, CA, USA) software. The PLINK 1.9 program (National Institutes of Health, Bethesda, MD, USA) was used to perform genetic data quality control, and PLINK 2.0 was used to perform principal component analysis and association testing via generalized linear models. Bcftools was used for vcf file conversion. The phasing and imputation of genotypes were completed using the shapeit2 and impute2 programs. Differences in phenotypes between groups were analyzed using regression analysis adjusted for covariates. The chi-square test (χ^2) was used to test for the presence of the Hardy–Weinberg equilibrium (HWE). Thereafter, the frequencies of genotypes or alleles were compared between sprint/power and endurance athletes and controls using Fisher’s exact test. All data are presented as means (SD). The p -values < 0.05 were considered statistically significant.

3. Results

3.1. Discovery Phase

None of the SNPs reached an exome-wide significance level ($p < 2.3 \times 10^{-7}$) in genotype–phenotype and case–control studies of Turkish athletes (Figure 1). The only SNP that was close to the threshold ($p = 1.0 \times 10^{-5}$) was rs8037843 in the Pyroglutamyl-Peptidase I Like (*PGPEP1L*) gene (Figure 1). Although rs8037843 correlated with personal bests in athletes, there were no allelic differences between the Turkish and Russian endurance and sprint/power athletes and controls with respect to this SNP ($p > 0.05$).

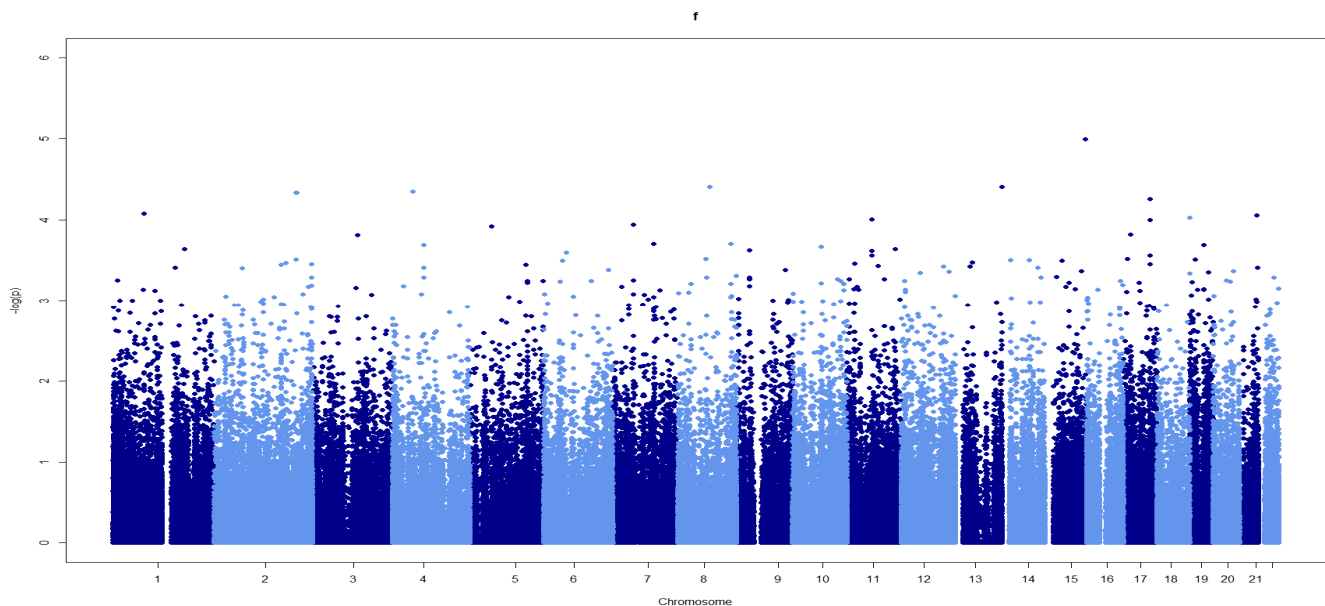


Figure 1. Manhattan plot showing associations between SNPs across chromosomes and personal bests in elite Turkish athletes. Light and dark blue: the illustration separating the consecutive chromosomes for comprehensibility.

The genotypic differences between the groups were evaluated by principal component analysis on an SNP matrix (PCA). PCA of the genotyping data pointed out no significant influence of sport disciplines (Figure 2) on genotype distributions.

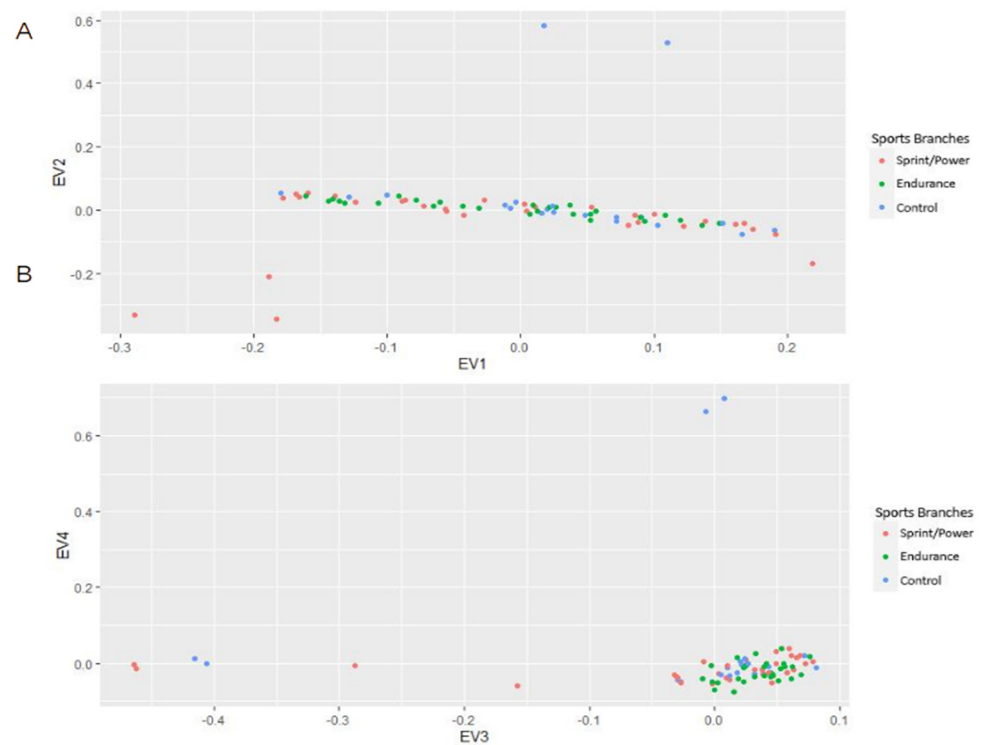


Figure 2. Principal component analysis on the SNP matrix showing genotype distributions across different groups in EV1–EV2 (A) and EV3–EV4 (B) planes.

Comparisons of allelic frequencies between three groups (endurance vs. sprint/power athletes; endurance athletes vs. controls; sprint/power athletes vs. controls) showed 53 SNPs whose frequencies were significantly differentiated between the sprint/power and endurance group (but not in the separate sub-groups of female and male athletes due to low sample sizes) (Supplementary Table S1). The genes in which these SNPs were located were further analyzed by the String database (v.11.5; <https://string-db.org/>, accessed on 10 December 2022) for the functional interaction and pathway analyses. The results showed minimal interactions between the proteins, and the Markov Cluster Algorithm (MCL) option in the database demonstrated five clusters (Figure 3).

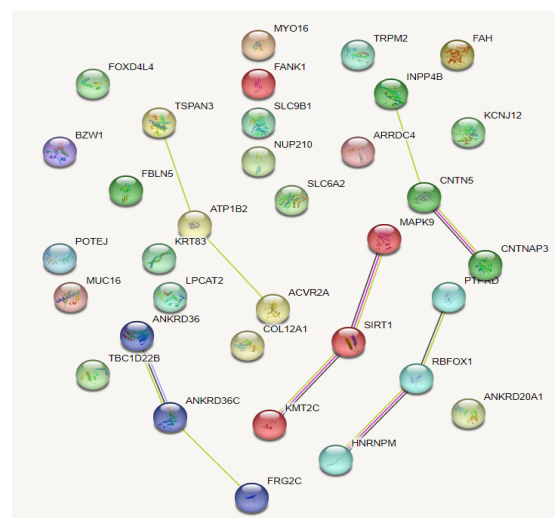


Figure 3. Interaction of and clustering of the protein-coding genes on which deviated frequencies of the SNPs were realized between the sprint/power and endurance groups.

3.2. Replication Studies

Of the 53 nominally ($p < 0.05$) associated SNPs, four variants were replicated in the following studies involving Russian and Finnish individuals. More specifically, the *SIRT1* rs41299232 G allele was significantly over-represented in Turkish (44.0 vs. 4.0%; $p = 0.047$) and Russian (63.5 vs. 55.4%; $p = 0.018$) endurance athletes compared to sprint/power ones and was associated with increased relative $\text{VO}_{2\text{max}}$ (C/C ($n = 9$): 63.2 (8.0) mL/min/kg, C/G ($n = 35$): 64.3 (7.0) mL/min/kg, G/G ($n = 31$): 66.2 (6.4) mL/min/kg; $p = 0.037$ adjusted for sex), and a greater proportion of slow-twitch muscle fibers in Finnish subjects (C/C ($n = 45$): 42.8 (12.7)%, C/G ($n = 147$): 44.4 (16.0)%, G/G ($n = 95$): 47.0 (13.7)%; $p = 0.035$ adjusted for age and sex).

The *NUP210* rs2280084 A allele was significantly predominant in Turkish (68.0 vs. 34.0%, $p = 0.044$) and Russian (59.2 vs. 50.0%, $p = 0.012$) endurance athletes compared to the sprint/power group. In addition, the rs2280084 A allele was over-represented in highly elite Russian endurance athletes ($n = 119$) compared to controls (64.1 vs. 52.9%, $p = 0.003$).

The frequency of the *TRPM2* rs1785440 G allele was significantly higher in Turkish endurance athletes compared to sprint/power athletes (57.0 vs. 18.0%, $p = 0.034$) and was associated with increased $\text{VO}_{2\text{max}}$ (A/A ($n = 1$): 58.3 (0) mL/min/kg, A/G ($n = 16$): 63.2 (6.9) mL/min/kg, G/G ($n = 58$): 65.6 (6.8) mL/min/kg; $p = 0.008$).

The *AGRN* rs4074992 C allele was significantly over-represented in Turkish sprint/power athletes compared to endurance athletes (83.0 vs. 44.0%, $p = 0.037$) and was associated with a greater CSA of fast-twitch muscle fibers in physically active Russian individuals ($p = 0.024$ adjusted for sex, age, type, and level of physical activity).

4. Discussion

Athletic performance and branches have widely been proved to be a result of the combination of environmental and genetic factors [1,28]. The latter, named as sports genetics, has attracted sports scientists since it was relatively a new branch [10]. The studies on sport genetics have focused on single-gene and/or SNP alteration between the sport branches, which may mislead [12]. Hence, studies aiming at the involvement of multigenetic factors are needed. Limited studies, but not on the Turkish population, have reported GWAS results in sports genetics [10,13,14,16,29]. Thus, the present study focused on the assessment of the multigenetic factors in the elite sprint/power and endurance athletes using the WES approach. Although WES is not a cumulative approach compared to whole-genome sequencing (WGS), it may be advantageous for a pilot study such as the presented one to eliminate the analysis efforts and cost problems.

In our present study, we could not detect any SNPs whose frequencies reached an exome-wide significance. The primary problem with such studies would be the limitations with the number of participants [28]. Sport genetics has been established on a population- and sport-branch-specific manner. However, the restricted number of elite athletes would be a challenge to conclude exact findings [5]. Still, by the fact that the number of participants in such studies could affect the results according to the literature [30], such studies are still needed as a pilot comprehensive report to guide both the geneticists and sport scientists.

By the lack of associations with a threshold of $p < 2.3 \times 10^{-7}$, we further compared the frequencies of the SNPs between the sprint/power and endurance groups with $p < 0.05$ using the Chi square test. The results pointed out 53 SNPs whose frequencies significantly differentiated between the sport groups ($p < 0.05$; Supplementary Table S1). Of the 53 SNPs, four functional (i.e., affecting gene expression) variants located on the (or near) *SIRT1*, *NUP210*, *TRPM2*, and *AGRN* genes were replicated in Russian and Finnish individuals with consistent effects.

The *SIRT1* gene encodes the sirtuin 1 protein which is considered as a functional regulator (through the deacetylation and activation) of peroxisome proliferator-activated receptor- γ coactivator (PGC-1 α) that induces a metabolic gene transcription program of mitochondrial fatty acid oxidation (one of the positive factors of aerobic capacity) [31]. In our study, we found that the *SIRT1* rs41299232 G allele was significantly over-represented

in Turkish and Russian endurance athletes compared to sprint/power ones and was associated with increased VO_{2max} and a greater proportion of slow-twitch muscle fibers. Both phenotypes are considered advantageous for endurance athletes. According to the GTEx portal [32], the *SIRT1* rs41299232 (intronic variant) is significantly ($p = 4.2 \times 10^{-33}$) associated with the altered expression of the *SIRT1* gene in the whole blood. Previously, the rs41299232 G allele was reported to be associated with an increased red blood cell count ($p = 0.0000015$), higher hemoglobin concentration ($p = 0.0032$), and higher physical activity ($p = 0.0031$) in the UK Biobank cohort [33], which is in line with our findings.

The *NUP210* gene encodes nucleoporin 210 (a membrane-spanning glycoprotein), which is a major component of the nuclear pore complex. Previously, the *NUP210* has been shown as a critical regulator of muscular and neuronal differentiation [34]. Muscle function experiments in mice have shown that *Nup210* is required for muscle endurance during voluntary running and muscle repair after injury [35]. In our study, we found that the frequency of the *NUP210* rs2280084 A allele was significantly higher in Turkish and Russian endurance athletes compared to sprint/power athletes, as well as in highly elite Russian endurance athletes compared to controls. According to the GTEx portal [32], the *NUP210* rs2280084 (missense variant) is significantly associated with changed expression of the *NUP210* gene in the brain ($p = 3.9 \times 10^{-11}$) and the whole blood ($p = 0.000032$).

The *TRPM2* gene encodes the transient receptor potential cation channel subfamily M member 2 protein. *TRPM2* plays an important role in a variety of cellular functions, including cell proliferation, insulin release, cell motility, and cell death [36,37]. Recently, it has been shown that *TRPM2*-mediated Ca^{2+} signaling is required for training-induced improvement in skeletal muscle mitochondrial functions and fiber-type transition in mice [38]. In our study, we found that the *TRPM2* rs1785440 G allele was significantly over-represented in Turkish endurance athletes compared to sprint/power ones and was associated with increased VO_{2max} in Russian athletes. According to the GTEx portal [32], the *TRPM2* rs1785440 (intronic variant) is significantly ($p = 2.5 \times 10^{-12}$) associated with an altered expression of the *TRPM2* gene in the skeletal muscle.

The *AGRN* gene encodes the agrin protein, which regulates the maintenance of the neuromuscular junction [39]. Previous studies have linked the *AGRN* gene variants with sarcopenia-related traits (muscle mass and strength) and congenital myasthenia [39,40]. Furthermore, *Agrrn* gene expression has been shown to be upregulated after progressive weighted wheel running in mice [41]. In our study, we found that the *AGRN* rs4074992 C allele was significantly over-represented in Turkish sprint/power athletes compared to endurance athletes and was associated with a greater CSA of fast-twitch muscle fibers in physically active Russian individuals. Muscle fiber size is a surrogate indicator of muscle mass and is positively associated with power and strength [42–44]. According to the GTEx portal [32], the *AGRN* rs4074992 (intergenic variant) is significantly ($p \geq 3.8 \times 10^{-8}$) associated with altered expression of the *AGRN* gene in multiple tissues. Previously, the rs4074992 C allele has been reported to be associated with increased appendicular lean mass ($p = 0.0031$) in the UK Biobank cohort [33], which is in line with our findings.

Like the present study, a study in diverse populations conducted in the literature reported that none of the SNPs reached genome-wide significance with the endurance athlete status [14]. Nonetheless, others reported the associations of the specific SNPs with different exercise-related parameters [15–17,45–48]. However, the number of participants in those studies was increased by the involvement of the athletes from close countries. Importantly, only one study was able to present a clear association between Tatar wrestlers and a specific SNP in an athletic group with limited participants [5]. Therefore, we can also underline that such studies are critically influenced by the populations, number of the participants, and sport branches.

The present study had some limitations that may be common in other sport genetics studies. These limitations could be the restricted number of participants in the discovery phase ($n = 80$), heterogeneity in the branches, diverse ethnicity in the Turkish population, lack of controllability of environmental factors, and ignorance of the epigenetic mech-

anisms. On the other hand, we regard that we were able to reduce the probability of obtaining false-positive results by replicating our initial findings—a widely used approach in sports genetics—in the larger cohorts of Russian ($n = 845$) and Finnish individuals ($n = 287$) [14,23,49]. Still, the present study figured out four important SNPs that would further be analyzed in the next studies.

5. Conclusions

In conclusion, by conducting the first comprehensive WES study on elite athletes, we showed that the *SIRT1* rs41299232 G, *NUP210* rs2280084 A, and *TRPM2* rs1785440 G alleles are associated with endurance athlete status, whereas the *AGRN* rs4074992 C allele is linked with sprint/power athlete status and muscle fiber hypertrophy. Our data indicate that the WES approach followed by replication studies can be used to identify novel genetic markers associated with exercise- and sport-related phenotypes.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/genes14030660/s1>, Table S1: SNPs were significantly associated with athlete status in the Turkish cohorts of endurance athletes, sprint/power athletes, and controls.

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

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Article

Evaluation of the Association of VDR rs2228570 Polymorphism with Elite Track and Field Athletes' Competitive Performance

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Abstract: The present study aimed to examine the vitamin D receptor (VDR), rs2228570 polymorphism, and its effect on elite athletes' performance. A total of 60 elite athletes (31 sprint/power and 29 endurance) and 20 control/ physically inactive, aged 18–35, voluntarily participated in the study. The International Association of Athletics Federations (IAAF) score scale was used to determine the performance levels of the athletes' personal best (PB). Whole exome sequencing (WES) was performed by the genomic DNA isolated from the peripheral blood of the participants. Sports type, sex, and competitive performance were chosen as the parameters to compare within and between the groups by linear regression models. The results showed no statistically significant difference between the CC, TC, and TT genotypes within and between the groups ($p > 0.05$). Additionally, our results underlined that there were no statistically significant differences for the association of rs2228570 polymorphism with PBs within the groups of the ($p > 0.05$) athletes. The genetic profile in the selected gene was similar in elite endurance, sprint athletes, and in controls, suggesting that rs2228570 polymorphism does not determine competitive performance in the analyzed athlete cohort.

Keywords: athletics; sprint/power athletes; endurance athletes; VDR; rs2228570 polymorphism



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1. Introduction

From the inception of humanity to the present date, the differences created by physical performance and related variables have been regarded as very important parameters in terms of the survival and continuity of generations. Particularly within the last century, in addition to factors that affect physical performance such as lifestyle and environmental-epigenetic interactions, changes in which polymorphisms resulting from genetics also play a role have become the focal point of the scientific world. Since new findings and locations of interaction have been revealed along with their causes as a result of the gradual decoding of human genome codes in the past 25 years, new methods and applications that will contribute to the scientific world within the framework of improving individual effort limits have started to gain momentum as well.

Elite athletes easily adapt to the interaction of genomic and epigenomic features; training applications; and the changes caused in organisms by nutrition, lifestyle, and environmental factors. In addition to genetic adaptation, the reshaping of muscles as a result of training and positive responses to training stimuli are the most apparent reflections of the ability to adapt. When used in athletes who exhibit elite levels of performance, candidate genes that reveal athletic ability serve as important clues that can reveal the reflections of the scope and severity of training applications, load, rest and recovery processes, nutrition, and injury risks on the field or podium [1,2].

In contemporary medicine, a new era titled “personalized medicine” is beginning. The necessity to address a variety of metabolic diseases and support individuals with an approach toward sports activities that are specified based on their genetic infrastructure has been increasingly emphasized in many countries and scientific communities [3]. Within this scope, with the discovery of approximately 250 candidate genes that affect athletic performance up to date, the regulation of methods and applications affecting competitive performance in consideration of the genetic features of individuals and particularly elite athletes, and the implementation of application-oriented exercises within this framework, have started to become increasingly common among trainers and athletes as well [4,5]. In this context, one of the candidate genes that has been considered by researchers in recent years in relation to the improvement of physical effort and athlete health is the vitamin D receptor (*VDR*) gene. The vitamin D receptor (*VDR*) is a member of the nuclear receptor group. The gene coding *VDR*, a member of the nuclear hormone receptor gene family, was defined for the first time in 1969. It is localized in 12q13.11 and has a size of 100 kb, and more than 100 polymorphisms were defined [6,7]. Exons 2 and 3 of the gene, which consist of 11 exons, code the DNA binding site, whereas exons 4 and 9 code the ligand binding site.

There are four functionally important polymorphic regions within the *VDR* gene. The most significant variations of these are polymorphisms such as rs1544410 (intron 8), rs2228570 (exon 2), rs731236 (intron 8), and rs7975232 (exon 9). These variations can cause various metabolisms [8,9]. The Fok1 polymorphism (rs2228570) is located at the 5′ end of exon 2 of *VDR* and corresponds to the start codon. As a result of the transition of T to C, ATG→ACG conversion occurs in the first codon and a 424 amino acid variant polypeptide is produced [6,9–12]. In the absence of this variation, a 427 amino acid polypeptide, which is regarded as normal, is synthesized. It is stated that the *VDR* protein has effects on parathyroid cells, hematopoietic cells, keratinocytes, pancreatic islet cells, reproductive organs, and the immune system. *VDR* also exhibits a wide tissue distribution involving endothelial, vascular smooth muscles, and cardiomyocytes [13].

Vitamin D, which carries out its functions through *VDR*, is a fat-soluble molecule derived from the steroidal hormone family [14]. Vitamin D metabolites adjust calcium homeostasis with the parathyroid hormone D [15]. Vitamin D synthesized in the human body from cholesterol plays a role in mechanisms affecting skeletal (mineral density, stress fractures, etc.) and muscular (resistance and power) structure [16] and is stored in fat cells to be transferred into circulation when needed. Vitamin D plays an important role in the maintenance of mineral balance [17] and the regulation of calcium metabolism and protein synthesis within muscle cells by enabling the absorption of phosphorus and calcium in the kidney and intestines [18]. In the functioning of vitamin D metabolism, it is thought that the functional polymorphisms on the receptor have different levels of impact on individuals [8,18]. Vitamin D plays an important role in the healthy development of muscles and bones and neuromuscular functions [19–21]. Vitamin D triggers muscle cells to receive the inorganic phosphate obtained from energy-rich phosphate compounds (ATP and CrP) that play a key role in muscular contraction mechanisms, whereas specific *VDRs* localized in the cell membrane enable the distribution and regulation of intracellular calcium [22,23].

It is known that an increase in vitamin D levels in an athlete has positive effects on the musculoskeletal system. As a result of increased vitamin D levels, ATP regeneration, protein synthesis [18], and a positive acceleration in the development of physical performance

aspects such as explosive muscle strength are observed, as well as a decrease in the risk of stress fractures. On the other hand, in the case of vitamin D deficiency, muscular atrophy linked with different sports branches, a decrease in muscular contraction rate, chronic muscle pain, and prolonged post-training muscle recovery time are observed. In consideration of the role of vitamin D in muscular contraction strength and stimulation processes, it can also have a direct effect on functional conditions [18,24,25]. Recent studies suggest that the 25 (OH) D level in athletes is above 40 ng/mL [26–28]. In another similar study, it was found that high serum 25 (OH) D3 levels were directly related to speed, power, vertical jump, and muscle strength [26,28,29]. In long-distance runners whose vitamin D concentrations were found to be below 32 ng/mL, it was observed that the tumor necrosis factor significantly increased following extensive training loads, and low levels of vitamin D as well as anti-inflammatory and pro-inflammatory cytokines that ensure recovery were found.

Vitamin D deficiency is caused by insufficient time and frequency of sunlight exposure [30]. However, in studies conducted in various climates and regions, cases of vitamin D deficiency were reported despite sufficient time and frequency of sunlight exposure. In certain studies, it was stated that even athletes who trained outdoors had low vitamin D levels [31], which could lead to over-training syndrome induced by overload, malnourishment, and insufficient rest in the later stages of training [32].

VDR polymorphisms can affect the vitamin D demands of the body at varying levels. Essentially, vitamin D can be acquired through dietary sources, but is predominantly synthesized endogenously from the ultraviolet-B radiation of the sun, and it reinforces muscle mass and strength levels by increasing the hormone levels in the body within the framework of enzymatic processes [33]. In a study investigating the effects of vitamin D intake on athletic performance under different seasonal and climatic conditions, the performances of athletes during the summer and winter seasons were compared, and it was stated that the physical efforts exhibited during the winter season were more efficient [34]. This situation explains the fact that vitamin D deficiency does not only occur through being deprived of solar rays, but genetic and epigenetic interactions can play a key role in vitamin D deficiency as well.

The present study aimed to examine the VDR rs2228570 polymorphism and its effects on the performance of elite athletes.

2. Methods

2.1. Participants

This study involved 60 elite athletes (sprint/power: 11 females (35.5%) and 20 males (64.5%); endurance: 10 females (34.5%) and 19 males (65.5%)) licensed in different clubs and affiliated to the Turkish Athletics Federation. The number of the controls (non-athletes) were 20 (female 6 (30.0%) and male 14 (70.0%)); they were healthy unrelated citizens of Turkey without any competitive sports experience. All the athletes and controls were of Caucasian ancestry. The individuals with any known and declared diseases were excluded from this study. The athletes were categorized as either sprint/power or endurance athletes, as determined by the distance, duration, and energy requirements of their events. All athletes were ranked in the top 10 in their sport disciplined nationally. Those in the elite group had participated in international competitions such as the Olympic Games, European Championships, Universiade, Mediterranean Games, and Balkan Championship. The sprint/power group included sprint and power athletes whose events demand predominantly anaerobic energy production. The athletes in this group were 100–400 m runners, jumpers, and throwers. The endurance athlete group included athletes competing in long-distance events demanding predominantly aerobic energy production. This group included 3000 m, 5000 m, 10,000 m, and marathon runners. The athletes in this group (n = 31) were 100–400 m 123 runners (n = 9), jumpers (n = 3), and throwers (n = 19). The endurance athlete group (n = 29) included athletes competing in long-distance events demanding

predominantly aerobic energy production. This group included 3000 m ($n = 12$); 5000 m ($n = 5$); 10,000 m ($n = 4$); and marathon ($n = 8$) runners.

2.2. Study Design

This study was carried out in accordance with the Declaration of Helsinki and approval was obtained from the Gazi University Non-Interventional Clinical Research Ethics Committee with the decision dated April 05, 2021 and numbered 09. The informed voluntary consent and demographic information forms were applied for the athletes and control groups before the measurements.

2.3. Personal Best (PB)

The International Association of Athletics Federations (IAAF; World Athletics) score scale was used to determine the performance levels of the athletes depending on their personal best/competitive performance [35]. For instance, the IAAF score scale of a male athlete who runs 100 m in 10.05 sec is 1189, whereas that of a marathon runner who completes the race in 2 h 20 min 11 sec is 997. Thus, the performance scale of the marathon runner is less than that of the 100 m runner. The IAAF scales are useful for the determination of performances of athletes from diverse athletics events and genders.

2.4. Whole Exome Sequencing

Total genomic DNA was isolated from the peripheral venous blood of the participants (4cc) for further genetic screenings using a DNeasy Blood and Tissue Kit (Qiagen, Germany) according to the supplier's instructions. The quality of the isolated DNA was verified using 1% agarose gel electrophoresis and NanoDrop (NanoDrop 1000 Spectrophotometer; Thermo Scientific, USA) according to optical density ratios, and the concentration was determined by NanoDrop.

Whole exome sequencing (WES) was performed after library preparation by Twist Human Comprehensive Exome Panel (Twist Biosciences, USA) according to the instructions of the supplier. Briefly, DNA was fragmented enzymatically, size selection was carried out, and hybridization was applied using Twist Hybridization probes and Dynabeads™ MyOne™ Streptavidin T1 (Invitrogen, USA), and the library was enriched by polymerase chain reaction (PCR). The concentration and size of the libraries were determined, and sequences were performed using Illumina NextSeq500 according to the manufacturer's standard protocol.

Raw data were processed to by the genome analysis toolkit (GATK) [36]. The HaplotypeCaller program was used to obtain binary alignment map (BAM) files and subsequently produce an output variant call format (VCF) file via the GRCh38/hg38 reference genome. Variants were annotated by ANNOVAR [37] and each single nucleotide polymorphism (SNPs) was analyzed manually. All molecular analyzes were performed in Gazi University Medical Genetics Laboratory.

2.5. Statistical Analyses

The SPSS statistical package version 25.0 for Mac was used to perform all statistical analyses. In the evaluation of the data, descriptive statistical methods (number, percentage, and mean) were used. Before performing any analysis on the data, the study determined whether they met the requirements for parametric tests. To that end, the variables were tested for normality, whereas Kolmogorov–Smirnov and Shapiro–Wilk ($p = 0.200$; 0.785, respectively) tests were used for homogeneity of variance. As result of these tests, parametric tests were performed for the variables distributed. Genotype and allele frequencies were calculated for the polymorphism, and the Hardy–Weinberg equilibrium (HWE) was assessed using the chi-squared (χ^2) test. Allele and genotype frequencies and any associations between the polymorphism and the athletic parameters were assessed by SNPStats (<https://www.snpstats.net/start.htm>, accessed on 11 October 2022) [38] using linear regression models, which were used to assess the score of variation in PB with linear regression

multiple inheritance models: co-dominant, dominant, recessive, over-dominant, and additive. To confirm the results obtained using the linear regression models, we also analyzed the data by means of the one-way analysis of covariance (ANCOVA), adjusting for sex and sports experience. Data were significant when $p < 0.05$.

3. Results

The present study aims to decipher any possible association of the rs2228570 polymorphism with the competitive performances of a group of elite athletes (mean age \pm SD: 25.1 ± 4.8 ; height (cm): 174.97 ± 7.9 ; body weight (kg) 72.5 ± 22.4 ; sports experience (year) 9.4 ± 4.8 ; personal-best (PB) = 1005.63 ± 94.55) in the presence of a control group (mean age \pm SD: 23.5 ± 7.1). Three groups (speed/throw/jump) and long-distance athletes and controls have been chosen to assess this aim.

The genotype and allele frequencies were determined. According to the results, there were not any statistically significant difference between the CC, TC, and TT genotypes within and between the groups (Table 1; $p > 0.05$). For allele frequencies, although the number of T alleles ($n = 112$) was higher than the C allele ($n = 48$), it was not statistically significant ($p > 0.05$; Table 1).

Table 1. Genotype and allele frequencies of VDR rs2228570 polymorphism in elite athletes and controls.

	Genotype			<i>p</i> -Value	Allele		<i>p</i> -Value
	CC	TC	TT		C	T	
Sprint/Power	1(3.2%)	17(54.8%)	13(42.0%)	0.717	19(30.6%)	43(69.4%)	0.618
Endurance	1(3.4%)	13(44.8%)	15(51.7%)		15(25.9%)	43(74.1%)	
Controls	2(10.0%)	10(50.0%)	8(40.0%)		14(29.6%)	26(70.4%)	

Statistically significant differences ($p < 0.05$); T: thymine, C: cytosine.

Additionally, when we compare the genotype or allele distribution for both sex and sports experience, no significant difference was detected (data not shown). Therefore, to increase the power of the statistical results, we decided to pool the sample.

VDR rs2228570 polymorphism was also evaluated to determine whether it was associated with personal bests (PBs) using different genetic models, codominant, dominant, recessive, and over-dominant. Our results underlined that there was not any significance for the association of rs2228570 polymorphism with PBs within the athlete group ($p > 0.05$; Table 2).

Table 2. Association analysis of the VDR rs2228570 polymorphism with competitive performance.

Model	Genotype	n	Mean Score (PB)	Difference (95% CI)	<i>p</i> -Value
Co-dominant	CC	28	1011	0.00	0.72
	TC	30	997	−18 (−65 to 28)	
	TT	2	1009	8 (−122 to 138)	
Dominant	CC	28	1011	0.00	0.48
	TC-TT	32	997	−17 (−62 to 28)	
Recessive	CC-TC	58	1003	0.00	0.79
	TT	2	1009	17 (−110 to 145)	
Over-dominant	CC-TT	30	1010	0.00	0.42
	TC	30	997	−19(−64 to 27)	

Statistically significant differences ($p < 0.05$); adjusted by sports experience + sex.

4. Discussion

A predisposition towards sports activities in humans is a large variable factor. Although muscle mass and function were initially listed among the main reasons behind

this variability, it has been stated within the framework of the scientific data reported in recent years that elite athletic performance ability originates from genetics. In this context, it is thought that high levels of effort can be achieved through the regulation of variables such as the type of nutrition, as well as the severity and duration of training programs planned in line with the properties of the related candidate genes in addition to the existing genetic infrastructure of the individual. In recent years, genetic tests and applications that reveal branch-specific athletic ability have been among the most frequently emphasized concepts, particularly in the field of the sports industry. In tests carried out within this scope, the presence of candidate genes that reveal capability is regarded as indicating the capability of individuals, and outstanding candidate genes are taken into consideration, particularly in elite athletes. Genetic differences allow certain individuals to reach their goals in a very short period of time, whereas others can achieve high performance following a very long period. Although there are various body types among humans, body type and physiological characteristics depend on the distribution in the genetic structure, which varies based on environmental and epigenetic factors. These differences determine the outcome for elite athletes [39].

Similarly, the type and efficiency of nutrition are also affected by genetic factors. For example, the microbiome is heavily affected by host genetics [40]. Polymorphisms in various genes, including *VDR* rs2228570, can differentiate individual responses to training loads by influencing muscle strength and resistance [41]. *VDR* can affect the vitamin D needs of an individual. Within this framework, differences between individuals that result from genetics, common environment, and epigenetic factors determine the functionality of primary nutritional sources and supplements within the metabolism. Similarly, vitamin D absorption levels originating from *VDR* gene polymorphisms differ among individuals. Therefore, functional polymorphisms on the receptor play a very significant role in terms of understanding the effects of vitamin D metabolites on athletic performance and a healthy lifestyle [42].

Vitamin D is among the bioactive molecules required for bone mineral density, as well as muscular contraction and regeneration. Additionally, it accelerates regeneration time by reducing the level of inflammation that occurs after exhaustive training loads. Within this framework, it was stated in previous studies that the daily level of vitamin D required for athletes should be at high values such as approximately 32–40 ng/mL (20 ng/mL for sedentary individuals). However, variables originating from individual differences (climate; geography; genetic structure; type, severity, and duration of the training; etc.) can affect levels of vitamin D use. Though sufficient levels of vitamin D intake allow for the maintenance and development of athletic performance, the reduction of said vitamin levels inhibits muscle relaxation required after training and increases muscle pain while also triggering injury risk and stress fractures by causing muscle power loss and reducing bone mineral density [21].

In the findings of a study comparing elite athletes who were found to have insufficient vitamin D levels ($n = 61$) and the control group ($n = 30$) (eight weeks/daily vitamin D intake of 5000 IU), it was found that 25(OH)D levels observed in serum improved exercise performance (sprint, vertical jump) (Close et al., 2013), whereas another similar study reported that serum 25(OH) D concentrations measured on dancers ($n = 98$) were low (73%) due to vitamin D deficiency [43]. Additionally, in another study conducted on lab rats, it was observed that vitamin D reduced injury risk in anaerobic training loads by increasing the volume and number of type II muscle fibers, making positive contributions to maximal sprint and power capabilities [44].

In another study conducted by Allison et al. [45] ($n = 506$), vitamin D levels and structural coronary parameters were compared within the framework of the effects of vitamin D on the cardiovascular system and it was found that the structural parameters of the athletes below the 25(OH)D levels observed in serum were lower compared to the others [45].

VDR is among the first polymorphisms studied in the determination of the link to athletic performance. In the studies carried out within this framework, it was observed that the *Fok1* polymorphism had a greater impact on bone mineral density along with exercise and nutrition in individuals with the CC homozygous genotype [46], and increased the risk of sarcopenia [9,47]. In addition to the impact of the related polymorphism on changes in bone mineral density linked with endurance training, it was reported to be related to environmental factors such as calcium intake [48,49]. Polymorphisms in different genes, including *VDR*, can impact muscle strength and alter responses to training stimuli [33].

Certain previous studies reported that the rs2228570 polymorphism increased the risk of stress fractures in athletes performing heavy exercise and that it is necessary to analyze the said genetic variable to create healthy training programs [50]. In a similar study conducted with young soldiers consisting of males and females ($n = 385$), 268 single nucleotide polymorphisms (SNP), including the *VDR* gene and 17 gene regions, were analyzed, and it was stated that the *VDR* gene is an important determinant in the onset of stress fractures [51]. In the findings of another similar study conducted on military personnel, it was found that patients with stress fractures were much more likely to possess the rs2228570 polymorphism [52]. In a previous study investigating the impact of *VDR* gene polymorphisms on the longitudinal changes in hormones related to bone mass, bones, and calcium in adolescent football players ($n = 46$; 11.8–14.2 years old), it was stated that the *VDR* gene polymorphism affected bone mass in adolescent football players (41.3% on the CC genotype rate, 47.3% on the CT genotype rate, and 10.9% on the TT genotype rate) and that its impact on bone mineralization likely occurred in early stages of puberty during bone maturation [53]. As in chronic obstructive pulmonary disease (COPD) patients, it was observed that individuals with systemic diseases had weaker quadriceps muscles in the CC alleles compared to the CT and TT genotypes [54].

Similarly, the study conducted by Eken et al. [6] stated that CC genotypes and C alleles were more dominant in elite athletes [6]. In contrast with the said study, in the present study, although the frequency of the T allele ($n = 48$) was higher compared to the C allele among all participants, no statistically significant intragroup and intergroup difference was observed (Table 1; $p > 0.05$). By contrast, another study ($n = 206$ men and women; 50–81 years old) reported that the *Fok1* polymorphism had a greater effect on bone mineral density in lengthy and low-intensity aerobic and strength training applications, although the said interaction was unrelated to the development of aerobic resistance training levels [55]. Supporting the findings of the present study, in the study conducted by Morucci et al. [56] on gymnasts ($n = 80$), it was stated that there was no relationship between *VDR* genotypes and athletic performance in terms of genotype [56]. Similarly, in another study conducted by Gavin et al. [57] on female athletes ($n = 62$), the relationship between *VDR* and muscle strength was examined; however, no relation was found [57].

In the vertical jump performance tests carried out by Massidda et al. [58] on professional male football players ($n = 90$), the percentage of participants with the CC genotype (46.3%) was found to be higher compared to the CT (38.8%) and TT (14.8%) genotypes [58]. Differently from the results of the present study, in another study similar to that of Micheli et al. [59], the rate of young male football players ($n = 125$) with the CC genotype was found as 52%, whereas this percentage was 34% for the CT genotype and 14% for the TT genotype, stating that these genotype results can serve as important indicators in terms of the predisposition towards football [59].

The fact that the rate of football players with the CC genotype was found to be higher in both of the aforementioned studies compared to the competitive performance findings in the present study can be interpreted as notable differences between sports disciplines in terms of performance level, individual features, and the rate of use of energy sources. Though both studies show similarities with the analyses performed in the present study, this is not adequate to explain the reasons why the frequencies of the C or T alleles were high or low. The present study found no significant intragroup or intergroup difference (speed/throw/jump, long distance, and control) between the CC, TC, and TT genotypes.

This was also the case in genotype or allele distributions within the framework of both genders and sports experiences, and in the light of the findings obtained within this scope, no correlation was found between the *VDR* rs2228570 polymorphism and the personal bests (PBs) in the athlete groups (Table 2; $p > 0.05$). The fact that the number of studies and data on the cellular effects of this polymorphism are insufficient may lead to the conclusion that the T or C alleles provide a predisposition toward the status of elite athletes. However, the impact of either allele on a molecular level is not clearly known, which will cause their contribution or ineffectiveness toward individual performance to remain unclear.

With approximately three billion nucleotides in the human genome, the number of nucleotide combinations that can affect gene activity is essentially infinite. Beyond the aforementioned studies, many studies show that genes play an important role in the determination of athletic performance. Considering the improvements achieved in the past 20 years, it can be foreseen that the genetic elements affecting athletic performance phenotypes and training stimuli will become more comprehensible in the following years with multigene and multifactorial approaches. On the other hand, based on the available data, it is certain that the effects of the candidate genes involved in athletic performance development as the desired phenotype are not very clear, and that further studies are needed.

Although the present study underlined the insignificance between the related polymorphism and athletic parameters, there were some limitations that could affect the results. The single gene and polymorphism approach may alter the results of the associations in particular pathways where more than one protein is involved. Thus, a cumulative evaluation study for all genes and SNPs is under progress by our research group. In our study, biochemical measurements such as the athletes' vitamin D levels were not measured, and it was not checked whether the athletes took vitamin D before the study. In future studies, more comprehensive studies can be conducted by taking these factors into consideration. Nevertheless, such approaches are planned as further studies. Furthermore, the number of the participants was relatively lower, which could influence the results, but this criterion was restricted to the number of elite athletes in the population.

5. Conclusions

The unclarity of the *VDR* Fok1 rs2228570 polymorphism on a molecular level, as well as the limited number of studies on athletic performance in the literature, stand out as limiting factors in the interpretation of the outcomes of the present study. Within this framework, it is thought that the present study will contribute to the developments in the field of sports sciences along with the limited number of other similar studies.

In conclusion, the genetic profile in the selected gene was similar in elite endurance, sprint athletes, and in controls, suggesting that rs2228570 polymorphism does not determine competitive performance in the analyzed athlete cohort. Additionally, it is foreseen that conducting similar studies in the future with athlete groups in different sports branches will allow for the effects of the *VDR* gene on athletic performance to be identified more clearly.

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Data Availability Statement: The data presented in this study are available on request from the corresponding authors.

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Systematic Review

Physical Performance and Sports Genetics: A Systematic Review of Candidate Gene Polymorphisms Involved in Team Sports

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Abstract

Background/Objectives: This systematic review aimed to gather the most recent evidence regarding the link between genetic polymorphisms and physical performance in team sports, with a focus on the practical utility of this information for athlete selection, training personalization, and injury prevention. **Methods:** Sixteen studies published between 2018 and 2025 were analyzed and selected from six international databases, in accordance with the PRISMA guideline. Only English-language studies were included, which evaluated active athletes in team sports and investigated associations between genetic variations, such as Actinin Alpha 3 (*ACTN3 R577X*), Angiotensin I Converting Enzyme (*ACE I/D*), Peroxisome Proliferator-Activated Receptor Alpha (*PPARA*), Interleukin 6 (*IL6*), and Nitric Oxide Synthase 3 (*NOS3*), and physical performance parameters. The methodological quality of the studies was assessed using the Q-Genie tool, with all studies scoring over 45 across all 11 items, indicating high quality. **Results:** The *ACTN3* and *ACE* genes stood out due to their consistent association with traits such as strength, speed, endurance, and recovery capacity. Other genes, such as *PPARA*, Fatty Acid Amide Hydrolase (*FAAH*), Angiotensinogen (*AGT*), and *NOS3*, complemented this genetic profile by being involved in the regulation of energy metabolism and injury predisposition. An increasing number of studies have begun to adopt cumulative genotype scores, suggesting a shift from a monogenic approach to complex predictive models. **Conclusions:** The integration of genetic profiling into the evaluation and management of athletes in team sports is becoming increasingly relevant. Although current evidence supports the applicability of these markers, robust future research conducted under standardized conditions is necessary to validate their use in sports practice and to ensure sound ethical standards.

Keywords: candidate gene; genetic polymorphism; team sports; athletic performance; injury risk; genotype score; personalized training; sport selection



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1. Introduction

The ongoing process of optimizing performance in team sports has led to an increasingly prominent trend toward understanding and utilizing knowledge about the biological mechanisms that support physical abilities. Even though traditional factors such as training, nutrition, and psychological aspects remain the main pillars for achieving notable

athletic results, current advances in genomics have highlighted the existence of a relevant genetic component involved in the manifestation of interindividual differences in motor performance [1]. Thus, it can be said that physical performance in any sports discipline, including team sports, is influenced by a complex combination of genetic and environmental factors. Over the past 20 years, sports genetics has focused significantly on identifying genetic polymorphisms. These can provide physiological advantages in sports activities, with genetic markers being involved in mechanisms such as energy metabolism, muscle contractility, cardiovascular adaptation, and post-exercise recovery [2].

As previously mentioned, over the past two decades, research has focused on identifying candidate genes involved in the regulation of key physiological processes such as muscle strength, oxygen utilization, inflammatory response, and neuroplasticity [3]. Genes such as *ACTN3*, *ACE*, Peroxisome Proliferator-Activated Receptor Gamma Coactivator 1-Alpha (*PPARGC1A*), and *NOS3* are among the most studied regarding their role in sports performance. Thus, sprinting ability, muscle strength, and aerobic endurance, understood as highly relevant factors for physical and athletic performance in team sports, have been correlated with polymorphisms in the *ACTN3* and *ACE* genes [4]. In this context, the *ACTN3* gene is typically associated with strength and speed, while the *ACE* gene, through the I allele, is believed to be involved in blood pressure regulation and endurance, being correlated with better metabolic efficiency and performance in endurance sports. The *R577X* polymorphism in *ACTN3* influences muscle fiber composition and has been linked to performance in elite athletes, particularly those engaged in power sports [5]. The same *R577X* polymorphism in the *ACTN3* gene determines the expression of the α -actinin-3 protein, which is present in type II (fast-twitch) muscle fibers. Athletes with the RR genotype tend to have a greater predisposition for power and speed sports, whereas those with the XX genotype may have an advantage in endurance activities [6]. Another major polymorphism studied is *ACE I/D*, where the I allele is frequently associated with superior performance in endurance sports, and the D allele is correlated with anaerobic and strength capacities [5]. In a team context, these genetic variations can influence player positioning and personalized training strategies. Furthermore, genes such as *PPARGC1A*, involved in mitochondrial biogenesis and energy metabolism, and *IL6*, linked to inflammatory response and recovery, offer an integrated perspective on how genetics can impact both performance and injury risk [7,8].

Although numerous studies in the scientific literature refer to the link between genetics and athletic performance, systematic research specifically analyzing team sports remains relatively scarce. Team sports such as football, rugby, handball, and hockey are characterized by a high level of functional demand and an increased influence of situational factors, where polygenic profiles may influence adaptive responses to training stimuli, stress conditions in decision-making, and injury risk [9]. Varillas-Delgado et al. (2022) argue that the determinism between genes and performance in team sports can significantly contribute to improving selection strategies, training personalization, and injury prevention [4]. Moreover, the integration of genetic screening tools into sports monitoring systems has generated debates concerning the ethical and practical implications of using Deoxyribonucleic Acid (DNA) to guide the development of athletic talent [4]. Another interesting and specific aspect in the context of high-effort, contact-based team sports in association with genetics refers to certain athletes' predisposition to injuries [10]. For instance, Ryan-Moore, Mavrommatis, and Waldron (2020) pointed out that certain types of candidate genes are linked to fracture risk and tissue resilience, suggesting that genetic predisposition may modulate biomechanical vulnerability under intense effort and elite-level performance conditions [10]. These genetic variations become particularly relevant in the context of team sports, where physiological demands are diverse and dynamic. They can be

used to better understand individual responses to training, tolerance to intermittent effort, and the capacity to perform repeated high-intensity actions. A number of recent studies suggest that integrating genetic profiles into the selection and development of athletes may contribute to optimizing performance at both the individual and team levels [11,12]. However, the research indicates that genetic markers, when integrated with discernment into the study of relevant athletic outcomes, may have complementary predictive value, without serving as decisive factors in determining performance [13,14].

In team sports, performance depends not only on athletes' individual speed or endurance abilities but also on cognitive, motivational, and neuromuscular coordination factors. Therefore, analyzing genetic factors in this context can contribute to training personalization, injury prevention, and the selection of athletes for specific positions on the field [7]. In particular, team sports provide an ideal framework for understanding gene-environment interactions, as physical and tactical demands vary significantly depending on the sport, position, and playing style. Thus, integrating genetic profiles into performance analysis can offer a holistic and evidence-based approach to optimizing athletic potential.

As interest in sports genetics has grown, a significant body of research has emerged concerning the role of genetic polymorphisms in athletic performance [13–15]. However, studies are often heterogeneous in terms of the populations analyzed, methods used, and sports investigated. In team sports, this diversity is further amplified by the complexity of physical activity and the influence of other factors such as tactics, coordination, and psychosocial interactions. In this context, the need becomes increasingly evident for analyses focused on a comprehensive understanding of these specific relationships involving relevant genetic associations for team sports, where types of effort and physiological demands are varied and interdependent [4,7,10].

Thus, the present study aims to conduct a systematic review of polymorphisms in candidate genes associated with physical performance in team sports, highlighting functional associations, predictive aspects, and future directions in genetic analysis applied to the field of elite sports.

2. Materials and Methods

2.1. Experimental Approach to the Problem

This systematic review was designed to synthesize evidence on the associations between candidate gene polymorphisms and physical performance in team sports. The process was conducted in accordance with the PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [16,17] and followed the established recommendations for conducting systematic reviews in sports science [18], aiming for a rigorous, transparent, and reproducible analysis of the existing literature. The main objective was to critically evaluate studies that investigated correlations between genetic variations—particularly in the *ACTN3*, *ACE*, *PPARGC1A*, and *NOS3* genes—and performance parameters in the context of team sports. The underlying hypothesis was that certain polymorphisms may influence performance through physiological mechanisms such as strength, endurance, metabolic adaptation, or recovery.

The methodological process included formulating the research question (which genetic polymorphisms of candidate genes are associated with physical performance in team sports, and what is their functional relevance in a sports context?), establishing selection criteria, conducting a systematic search in scientific databases, assessing the quality of studies, and extracting relevant data. Through this approach, this study provides an integrative view of genetic influence in team sports and identifies useful directions for future research.

2.2. Information Sources

The literature search process was conducted between December 2024 and May 2025, following the PRISMA methodological framework for systematic reviews, and included the majority of studies published between 1 January 2018 and 29 May 2025. The last access to the databases was performed on 30 May 2025. Eligible articles were identified in the following international databases: Web of Science, Scopus, MEDLINE/PubMed, SPORTDiscuss, ProQuest Central, and Google Scholar, with only English-language studies being included. Additionally, to identify further studies, the reference lists of relevant articles were manually checked.

2.3. Search Strategy

Based on the PICO framework (Patient, Problem, or Population—Intervention or Exposure—Comparison, Control, or Comparator—Outcome[s]) [19], a search strategy was developed to ensure the identification of studies and a systematic coverage of the relevant literature (Table 1).

Table 1. PICO model for study design.

P (Population):	I (Intervention):	C (Comparison):	O (Outcomes):
Athletes from team sports, both elite and amateur, are active in disciplines such as football, handball, rugby, hockey, basketball, etc.	Presence of genetic polymorphisms in candidate genes involved in physiological mechanisms essential to performance (e.g., <i>ACTN3 R577X</i> , <i>ACE I/D</i> , <i>PPARGC1A</i> , <i>IL6</i> , <i>NOS3</i> , and Brain-Derived Neurotrophic Factor (<i>BDNF</i>)).	Alternative genotypes (e.g., <i>ACTN3</i> XX vs. RR), absence of polymorphisms, athletes without a specific genetic profile, and athletes from individual or different types of sports (endurance vs. strength).	Physical performance parameters: speed, explosive strength, aerobic endurance, intermittent effort capacity, recovery time, physiological adaptation to training, and predisposition to muscular and osteoarticular injuries.

Study selection and evaluation were conducted independently by two researchers. In the interest of transparency, the authors were not blinded to journal names, authors, or study results. The keywords used in our search included combinations of the following thematic indicators: (“genetic polymorphism” or “gene variant” or “genetic markers” or “*ACTN3*” or “*ACE*” or “*PPARGC1A*” or “*NOS3*”) and (“team sports” or “football” or “rugby” or “handball” or “hockey” or “basketball” or “volleyball”) and (“performance” or “endurance” or “strength” or “power” or “aerobic capacity” or “injury risk” or “sports performance prediction”).

Across all consulted databases (Web of Science, Scopus, MEDLINE/PubMed, SPORTDiscuss, ProQuest Central, and Google Scholar), the following filters were applied: English language, original studies published in scientific journals, active athletes in team sports, and publication period between 2018 and 2025. Searches were conducted within the title, abstract, and keywords fields, where this option was available in the respective databases. For Google Scholar and ProQuest Central, the queries were applied to the full text. As previously mentioned, to maximize the relevance of the results, the reference lists of the identified articles were manually screened to identify additional eligible sources.

The search strategy was adapted for each database using the following queries:

- PubMed/MEDLINE: (“genetic polymorphism” [Title/Abstract] or “gene variant” [Title/Abstract] or “genetic markers” [Title/Abstract] or “*ACTN3*” [Title/Abstract] or “*ACE*” [Title/Abstract] or “*PPARGC1A*” [Title/Abstract] or “*NOS3*” [Title/Abstract]) and (“team sports” [Title/Abstract] or “football” [Title/Abstract] or “rugby” [Ti-

tle/Abstract] or “handball” [Title/Abstract] or “hockey” [Title/Abstract] or “basketball” [Title/Abstract] or “volleyball” [Title/Abstract]) and (“performance” [Title/Abstract] or “endurance” [Title/Abstract] or “strength” [Title/Abstract] or “power” [Title/Abstract] or “aerobic capacity” [Title/Abstract] or “injury risk” [Title/Abstract] or “sports performance prediction” [Title/Abstract]).

- Scopus: TITLE-ABS-KEY (“genetic polymorphism” or “gene variant” or “genetic markers” or “ACTN3” or “ACE” or “PPARGC1A” or “NOS3”) and TITLE-ABS-KEY (“team sports” or “football” or “rugby” or “handball” or “hockey” or “basketball” or “volleyball”) and TITLE-ABS-KEY (“performance” or “endurance” or “strength” OR “power” or “aerobic capacity” or “injury risk” or “sports performance prediction”).
- Web of Science: TS = (“genetic polymorphism” or “gene variant” OR “genetic markers” or “ACTN3” or “ACE” or “PPARGC1A” or “NOS3”) and TS = (“team sports” or “football” or “rugby” or “handball” or “hockey” or “basketball” or “volleyball”) AND TS = (“performance” or “endurance” or “strength” or “power” or “aerobic capacity” or “injury risk” or “sports performance prediction”).
- SPORTDiscus: AB (“genetic polymorphism” or “gene variant” or “genetic markers” or “ACTN3” or “ACE” or “PPARGC1A” or “NOS3”) and AB (“team sports” or “football” or “rugby” or “handball” or “hockey” or “basketball” or “volleyball”) and AB (“performance” or “endurance” or “strength” or “power” or “aerobic capacity” or “injury risk” or “sports performance prediction”).
- ProQuest Central and Google Scholar: the query was applied to the full text, as advanced filtering options were limited, using the same combination of terms.

The search returned a total of 355 articles (343 from automated searches and 12 from the reference lists of already identified articles). The distribution across databases was as follows: PubMed/MEDLINE—61 articles, Scopus—62 articles, Web of Science—45 articles, SPORTDiscus—28 articles, ProQuest Central—71 articles, and Google Scholar—76 articles. After the removal of 40 duplicates, 315 articles remained for title and abstract screening. In addition, 12 relevant publications were identified and included from the reference lists of eligible articles.

2.4. Eligibility Criteria

The selection of articles was based on their relevance to the proposed topic, and in order to ensure the quality and relevance of those included in this systematic review, clear inclusion and exclusion criteria were defined.

2.4.1. Inclusion Criteria

Scientific articles were included if they met the following conditions:

- Original studies, published in English only;
- Studies investigating associations between genetic polymorphisms and physical performance in team sports disciplines such as football, handball, rugby, hockey, volleyball, and basketball;
- Studies containing detailed data on specific candidate genes (e.g., *ACTN3*, *ACE*, and *AGT*);
- Studies involving participants from athletic samples such as juniors, professional athletes, or elite-level competitors actively involved in organized competitions;
- Studies reporting data on at least one physiological performance parameter (e.g., strength, speed, endurance, recovery time, aerobic/anaerobic capacity, and injury risk).
- Full-text availability of the articles, either through open access or institutional access (e.g., via university subscriptions).

2.4.2. Exclusion Criteria

To clearly delimit the variables analyzed, the following types of studies were excluded from the final selection:

- Studies focused exclusively on individual sports or those addressing general topics in physical education without a clear link to performance in team sports;
- Non-scientific articles, such as personal opinions, editorials, letters to the editor, or short communications that do not provide rigorous and verifiable empirical data;
- Incomplete studies or those without full-text access, as well as studies that mentioned the genetic markers analyzed but provided data that was too limited or insufficient for comparative evaluation;
- Articles published in languages other than English.

2.5. Study Selection and Data Extraction Process

The study selection process was structured into two main phases, in accordance with the PRISMA guidelines and best practices in systematic research. All scientific papers identified through the search were reviewed and selected using a two-step structured approach to ensure the accuracy and relevance of the studies included in this scientific endeavor. In the first phase, the titles and abstracts of all articles identified through the database search were screened to eliminate irrelevant papers, duplicates, or studies that did not meet the basic criteria. In the second phase, potentially eligible articles were reviewed in full to clearly determine whether they met the previously established eligibility criteria, both from a methodological standpoint and in terms of scientific relevance to this study's objective.

After reviewing all databases (Web of Science, Scopus, MEDLINE/PubMed, SPORT-Discuss, ProQuest Central, and Google Scholar), a total of 355 articles (343 + 12) were screened. In the first step, 40 duplicate articles were identified and removed. After this step, the authors assessed whether each of the remaining 315 articles met all inclusion criteria, which led to the exclusion of 256 articles. Full-text evaluation was then performed, leading to the exclusion of 32 studies due to reasons such as lack of reported genetic data ($n = 17$), populations not engaged in team sports ($n = 1$), and incomplete data or inadequate methodology ($n = 14$). Of the 27 studies that remained, 11 were subsequently excluded from the synthesis because they presented redundant data, non-comparable methodology, or insufficient information for result extraction. In the end, 16 studies were included in the systematic review analysis [20–35] (Figure 1).

Study selection was carried out independently by two reviewers, who worked in parallel and documented the selection process in a shared database. Any discrepancies between the two reviewers were discussed and resolved by consensus. Blinding of reviewers to authors, journal of publication, or reported results was not applied due to the nature of the field and the public accessibility of the information.

Data extraction from the included studies was performed using a standardized form designed to ensure consistency and comparability of the collected information. This form included the following categories: bibliographic information (author[s], year of publication, and country where the study was conducted), athletic level of participants (amateur vs. elite athletes), genes and polymorphisms analyzed, genotyping methods, physiological performance parameters, main findings, and the direction of the association between genotypes and performance.

The collected data were compiled and are presented in Table 2. The data were used to highlight patterns of association between genetic markers and physical performance in team sports. This stage facilitated comparative analysis across studies and the identification of methodological or conceptual variations relevant to interpreting the results.

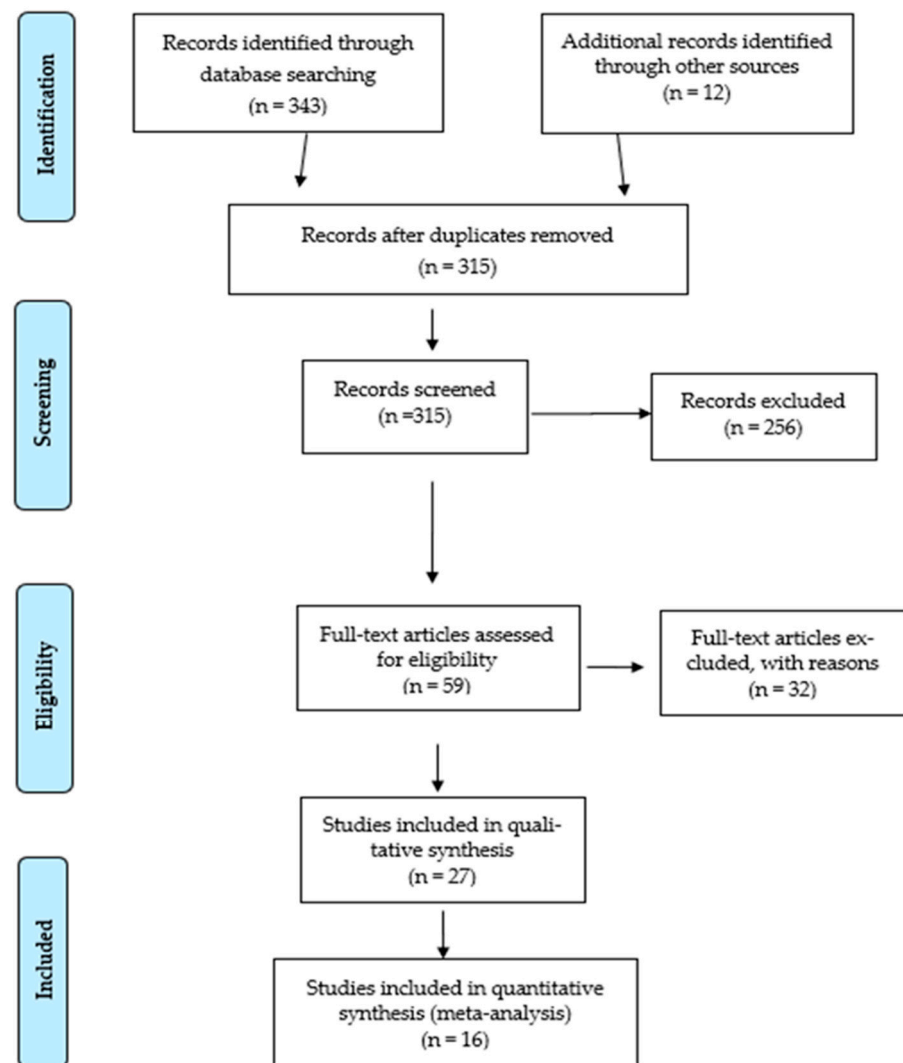


Figure 1. PRISMA flow diagram of study selection.

Table 2. Main characteristics of the studies included in this systematic review.

Author(s) and Year	Country	Sport/Population	Genes Analyzed	Evaluated Parameters	Key Findings
Orysiak et al., 2018 [20]	Poland	Polish athletes (various sports)	<i>ACE</i> , <i>ACTN3</i>	Muscle composition, strength	Combined influence of <i>ACE</i> and <i>ACTN3</i> polymorphisms on muscle profile
Pasqualetti et al., 2022 [21]	Italy	Elite-level rugby players	<i>ACE</i> , <i>ACTN3</i> , Monocarboxylate Transporter 1 (<i>MCT1</i>)	Sports performance	Preliminary associations between polymorphisms and performance level
McAuley et al., 2023 [22]	-	Football players	Systematic review—multiple genes	Injury predisposition	Genetic evidence of increased injury risk in football
Lima et al., 2023 [23]	Brazil	Basketball players, Brazilian League I	<i>ACTN3</i> R577X	Field position	Association between <i>ACTN3</i> genotype and playing position (center vs. wing)

Table 2. Cont.

Author(s) and Year	Country	Sport/Population	Genes Analyzed	Evaluated Parameters	Key Findings
Silva et al., 2023 [24]	Portugal	Elite athletes (sport unspecified)	<i>FAAH rs324420</i>	General performance, metabolic potential	Possible role of <i>FAAH</i> in optimizing elite performance
Altynova et al., 2024 [25]	Kazakhstan	Athletes from multiple disciplines	Multiple genetic markers (genetic passport)	General performance	An individual genetic profile may guide personalized training
Doğan et al., 2024 [26]	Turkey	Ice hockey players	<i>ACE</i> , <i>ACTN3</i> , <i>PPARA</i> , and Hypoxia-Inducible Factor 1-Alpha (<i>HIF1A</i>)	General physical performance	Different genotypes correlated with distinct physical outcomes
Maestro et al., 2022 [27]	Spain	High-level football players	<i>ACTN3</i> , <i>ACE</i> , Collagen Type V Alpha 1 Chain (<i>COL5A1</i>), Insulin-Like Growth Factor 2 (<i>IGF2</i>), <i>IL6</i> , Tumor Necrosis Factor (<i>TNF</i>), <i>NOS3</i> , and Vascular Endothelial Growth Factor A (<i>VEGFA</i>)	Types of muscle injuries, injury history	<i>ACTN3 XX</i> , <i>COL5A1 TT</i> , and <i>IL6 GG</i> genotypes are associated with increased muscle injury risk
Massidda et al., 2024 [28]	Italy	High-level football players	Total Genotype Score (<i>TGS</i>)	Muscle injuries	<i>TGS</i> correlated with the frequency of muscle injuries in football players
Vavak et al., 2025 [29]	Slovakia	Volleyball and basketball players	<i>ACE</i> , <i>ACTN3</i> , <i>PPARA</i> , <i>HIF1A</i> , and Adenosine Monophosphate Deaminase 1 (<i>AMPD1</i>)	Vertical jump	Genetic correlations with jump parameter variations
Silvino et al., 2025 [30]	Brazil	Junior handball players	<i>ACTN3</i> , Bradykinin Receptor B2 (<i>BDKRB2</i>), and <i>AGT</i>	Physical performance	Significant associations between <i>ACTN3</i> and <i>BDKRB2</i> with physical performance
La Montagna et al., 2019 [31]	Italy	Professional football players	<i>ACTN3</i> , <i>COL5A1</i> , <i>MCT1</i> , <i>VEGF</i> , and Homeostatic Iron Regulator (<i>HFE</i>)	Performance and injuries	<i>ACTN3</i> and <i>VEGF</i> are associated with performance; <i>COL5A1</i> and <i>HFE</i> are associated with injury predisposition
El Ouali et al., 2025 [32]	Morocco	Elite cyclists and hockey players	Cluster of Differentiation 36 (<i>CD36</i>) rs1761667	Susceptibility to non-contact injuries	<i>CD36</i> is associated with an increased risk of tissue injuries
Silvino et al., 2025 [33]	Brazil	Handball players	<i>ACE (I/D)</i>	Physical performance	Association between <i>ACE I/D</i> polymorphism and physical performance
Antrobus et al., 2023 [34]	UK	Elite rugby players	Catechol-O-Methyltransferase (<i>COMT</i>) rs4680	Elite athlete status, concussion risk	<i>COMT rs4680</i> is associated with elite status and predisposition to concussions
Rodas et al., 2019 [35]	Spain	Football, futsal, handball, basketball, hockey players	Multiple SNPs	Tendinopathy risk prediction	Genomic profile predictive of tendinopathy in team sports

2.6. Assessment of Methodological Quality

To evaluate the methodological quality of the studies included in this systematic review, the Q-Genie tool (Quality of Genetic Association Studies) was used, which was specifically developed for studies investigating associations between genetic variables and phenotypic traits [36]. This tool provides a solid framework for assessing genotype–phenotype association studies by evaluating 11 key domains related to study design, execution, and reporting (D1–D11). Specifically, D1 refers to the clarity of the research question; D2—appropriateness of the study design; D3—characteristics of the studied population; D4—participant selection method; D5—exposure assessment (genotyping); D6—outcome assessment (physical performance); D7—control of confounding factors; D8—statistical analysis; D9—interpretation of results; D10—relevance of conclusions; and D11—completeness of data reporting (Table 3).

Table 3. Methodological quality assessment of included studies.

No	Study	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	Total Score	Quality Rating
1	Orysiak et al., 2018 [20]	7	4	6	6	7	4	3	4	5	5	3	54	High
2	Lima et al., 2023 [23]	7	3	7	3	6	5	6	7	7	3	3	57	High
3	Vavak et al., 2025 [29]	3	6	3	5	3	4	7	4	6	6	3	50	High
4	Altynova et al., 2024 [25]	6	3	4	3	3	7	7	7	5	4	6	55	High
5	Pasqualetti et al., 2022 [21]	3	7	3	7	6	4	6	6	6	4	6	58	High
6	Doğan et al., 2024 [26]	6	7	6	4	6	4	4	4	5	6	5	57	High
7	Silvino et al., 2025 [30]	5	6	6	5	3	7	6	4	4	7	6	59	High
8	Silva et al., 2023 [24]	7	7	7	6	6	3	7	6	3	5	5	62	High
9	Maestro et al., 2022 [27]	6	5	6	7	7	3	7	6	4	5	7	63	High
10	McAuley et al., 2023 [22]	7	4	4	5	3	7	5	7	3	5	6	56	High
11	Massidda et al., 2024 [28]	5	7	4	5	4	4	7	4	3	7	4	54	High
12	La Montagna et al., 2019 [31]	7	6	6	7	6	5	6	7	6	6	6	68	High
13	Rodas et al., 2019 [35]	6	6	6	6	5	6	5	6	6	5	5	62	High
14	Antrobus et al., 2023 [34]	6	5	5	5	6	5	6	6	5	5	5	59	High
15	El Ouali et al., 2025 [32]	5	6	5	5	4	5	5	6	5	6	4	56	High
16	Silvino et al., 2025 [33]	6	6	6	6	6	6	6	6	5	6	6	65	High

Each evaluation criterion was scored on a scale from 1 (poor) to 7 (excellent), resulting in a total score ranging from 11 to 77. According to the Q-Genie guidelines, a score ≤ 35 indicates low study quality, a score between 36 and 75 indicates moderate quality, and a score > 45 indicates high quality [36].

All studies included in this systematic review obtained total scores above 45 points, placing them in the high-quality category according to the Q-Genie tool [36]. These results indicate that the studies were generally well-designed, with adequate descriptions of the study populations, robust genotyping methods, and relevant statistical analyses. The control of confounding variables and clear reporting of results were strengths in most of the studies. This evaluation supports the robustness of the conclusions formulated in the review and provides a high level of confidence in the validity of the genetic associations presented.

2.7. Registration and Protocol

This systematic review was not registered in PROSPERO or any other platform. A protocol was not prepared.

3. Results

Following the systematic selection process, a total of 16 studies that met the established eligibility criteria were included. These studies were analyzed in terms of the relationship between polymorphisms in specific candidate genes and relevant physical performance

parameters in the context of team sports. The results were synthesized based on the characteristics of the populations investigated, the genes analyzed, the types of team sports targeted, and the identified patterns of genetic association.

3.1. Included Studies and General Characteristics

The 16 included studies were published between 2018 and 2025 and originated from countries such as Spain, Poland, Brazil, Italy, and others. Most of these studies focused on athletes practicing team sports such as football, handball, basketball, rugby, hockey, and volleyball, and included both professional athletes and elite-level juniors.

The studies primarily investigated the *ACTN3* and *ACE* genes, but also examined other relevant markers such as *PPARA*, *IL6*, *BDKRB2*, *FAAH*, *AGT*, *HIF1A*, and *NOS3*, which are involved in the regulation of energy metabolism, muscle contractility, inflammatory response, or injury risk. The detailed characteristics of these studies are presented in Table 2 (Section 2.5).

Sample sizes varied considerably, ranging from pilot studies to research involving hundreds of active athletes competing in national or international leagues. Most studies employed PCR-based genotyping methods and assessed objective physical performance parameters such as speed, explosive strength, aerobic endurance, intermittent effort capacity, and the rate of muscular injuries.

3.2. Candidate Genes and Association with Physical Performance

The most frequently investigated genes in the included studies were *ACTN3* and *ACE*, both of which were repeatedly associated with key physical performance parameters such as explosive strength, speed, and endurance. Other genes of interest included *PPARA*, *HIF1A*, *AGT*, *BDKRB2*, *FAAH*, and *IL6*, which are involved in metabolic adaptation, inflammation, recovery, and injury susceptibility. In addition to the previously discussed markers, several other candidate genes have been identified as relevant to athletic performance and predisposition to injuries. These include *VEGF*, *COL5A1*, *MCT1*, *HFE*, *COMT*, *CD36*, and *NOS3*, each contributing to a more nuanced understanding of how genetic profiles may influence physical capacity and injury risk in the context of sports.

3.2.1. *ACTN3* Gene

The R577X polymorphism in the *ACTN3* gene was consistently associated with performance in power and speed-based sports. The RR genotype was more frequently found in athletes occupying positions that require explosive effort (e.g., defenders and forwards in football), while the XX genotype was correlated in some studies with enhanced endurance capacity. Studies conducted in basketball, volleyball, and handball supported these associations.

3.2.2. *ACE* Gene

The I/D (insertion/deletion) polymorphism in the *ACE* gene was linked to different physiological profiles: the I allele was associated with endurance sports performance, while the D allele was related to anaerobic, sprint-type, or explosive activities. Studies in football and rugby identified these associations based on player position.

3.2.3. Other Candidate Genes

Other studies analyzed genetic markers such as the following:

- *PPARA* and *HIF1A*—involved in mitochondrial adaptation and lipid metabolism, relevant for mixed-type sports;
- *BDKRB2* and *IL6*—linked to vasodilation, inflammation, and post-exercise recovery;

- *FAAH*—associated with the regulation of the endocannabinoid system and physiological stress;
- *AGT*—involved in blood pressure regulation, important for sustained effort;
- *NOS3 (eNOS)*—associated with endothelial function and blood flow regulation, with potential implications for aerobic performance and injury susceptibility;
- *VEGF*—plays a key role in angiogenesis, relevant to both aerobic capacity and tissue integrity;
- *COL5A1*—linked to collagen structure and predisposition to musculoskeletal injuries;
- *MCT1*—involved in lactate transport, impacting tolerance to high-intensity effort;
- *HFE*—regulates iron homeostasis, potentially affecting recovery and endurance;
- *COMT*—participates in neurocognitive processes and has been associated with concussion susceptibility;
- *CD36*—investigated for its role in susceptibility to non-contact tissue injuries;
- Polygenic approaches, such as the Total Genetic Score (TGS) or panels of multiple SNPs, have been employed to integrate the cumulative contribution of multiple genetic markers to athletic performance and injury risk prediction.

Table 4 summarizes the candidate genes investigated, the phenotypes evaluated, and the direction of observed associations.

Table 4. Candidate genes associated with performance in team sports.

Gene	Polymorphism	Associated Physiological Parameter	Team Sports Investigated	Type of Association	Included Studies
<i>ACTN3</i>	R577X (rs1815739)	Strength, speed, and sprint	Football, handball, basketball, and volleyball	Positive association (RR with power sports; XX with endurance sports)	Orysiak et al., 2018 [20]; Lima et al., 2023 [23]; Silvino et al., 2025 [30]; La Montagna et al., 2019 [31]
<i>ACE</i>	I/D (rs1799752)	Endurance, anaerobic effort	Football, rugby, hockey	I allele → endurance; D allele → strength	Orysiak et al., 2018 [20]; Pasqualetti et al., 2022 [21]; Doğan et al., 2024 [26]; Silvino et al., 2025 [33]
<i>PPARA</i>	rs4253778	Lipid metabolism, adaptation to mixed effort	Basketball, volleyball	Functional association with mixed-type effort	Vavak et al., 2025 [29]; Doğan et al., 2024 [26]
<i>HIF1A</i>	rs11549465	Metabolic efficiency under hypoxia	Volleyball, hockey	Positive association in intermittent sports	Vavak et al., 2025 [29]; Doğan et al., 2024 [26]
<i>AGT</i>	M235T (rs699)	Blood pressure regulation, physiological stress	Handball	Association with cardiovascular adaptation	Silvino et al., 2025 [30]
<i>BDKRB2</i>	−9/+9 (rs5810761)	Vasodilation, recovery	Handball	Association with post-effort recovery time	Silvino et al., 2025 [30]
<i>IL6</i>	rs1800795 (G174C)	Inflammation, recovery	Football	Association with inflammatory response and injuries	Maestro et al., 2022 [27]; McAuley et al., 2023 [22]
<i>FAAH</i>	rs324420	Stress tolerance, neuromodulatory regulation	Elite sports (unspecified)	Theoretical association with general physiological response	Silva et al., 2023 [33]

Table 4. Cont.

Gene	Polymorphism	Associated Physiological Parameter	Team Sports Investigated	Type of Association	Included Studies
NOS3 (eNOS)	Glu298Asp (rs1799983)	Endothelial function, blood flow, and muscle injuries	Football	Association with aerobic performance and injury susceptibility	Maestro et al., 2022 [27]
COL5A1	rs12722	Collagen integrity, injury risk	Football	Association with muscle injuries	La Montagna et al., 2019 [31]
MCT1	rs1049434	Lactate transport, exercise tolerance	Football	Association with tolerance to high-intensity exercise	La Montagna et al., 2019 [31]
HFE	C282Y and others	Iron homeostasis	Football	Possible impact on recovery and performance	La Montagna et al., 2019 [31]
COMT	Val158Met (rs4680)	Neurotransmission, risk of head trauma (concussions)	Rugby	Association with elite status and concussions	Antrobus et al., 2023 [34]
CD36	rs1761667	Lipid metabolism, injury risk	Field hockey	Association with non-contact injuries	El Ouali et al., 2025 [32]
VEGF	−634 C > G (rs2010963)	Angiogenesis, performance, and injuries	Football	Association with performance and injuries	La Montagna et al., 2019 [31]
TGS (poly-genic)	—	Composite genetic score	Football	Correlated with injuries	Massidda et al., 2024 [28]
Multi-SNPs (panel)	—	Tendinopathy prediction	Football, futsal, basketball, handball, and hockey	Predictive genomic profile	Rodas et al., 2019 [35]

Table 4 presents a relevant synthesis of the most frequently investigated candidate genes in team sports in the context of physical performance. Each of these genes is analyzed in direct relation to its specific biological functions and the associated polymorphisms. Through this approach, the identified correlations between these genetic variations and relevant motor, metabolic, or neurophysiological parameters are outlined in relation to athletic performance activity. In this context, the presented data may help identify recurring trends in the exploration of performance genetics, contributing to a clearer conceptual framework regarding the connection between the genome and the expression of physical abilities within the specific demands of team sports.

3.3. Candidate Genes and Their Distribution Across Team Sports

The studies included in this systematic review cover a variety of team sports such as football, handball, basketball, volleyball, rugby, and hockey. These sports are characterized by complex physiological and tactical demands, making them relevant for investigating genetic associations with physical performance. The most frequently studied sports discipline was football, appearing in more than half of the selected studies. It was followed by other sports, all of which involve high-intensity intermittent actions, decision-making factors, and mixed energy profiles. The studies showed a tendency to correlate specific genotypes with playing positions, intermittent effort capacity, and injury rates.

Additionally, a thematic trend can be observed in the selection of genes analyzed according to the type of sport. For example, in speed- and power-based sports (handball, rugby), the focus was on the *ACTN3 R577X* polymorphism; in sports with a sustained aerobic profile (football, hockey), the association of the I allele from *ACE* with physical performance was frequently investigated; and in contact sports or those with a higher risk of muscular injuries (rugby, football), genes such as *IL6*, *AGT*, and *FAAH* were often targeted (Table 5).

Table 5. Distribution of candidate genes by team sport discipline/investigated studies.

Team Sport Discipline	No. of Studies	Analyzed Population	Genes Studied
Football	6	Junior and professional athletes	<i>ACTN3</i> , <i>ACE</i> , <i>IL6</i> , <i>AGT</i> , <i>NOS3</i> , <i>COL5A1</i> , <i>MCT1</i> , and Multi-SNP panel
Handball	3	Junior and performance athletes	<i>ACTN3</i> , <i>BDKRB2</i> , <i>AGT</i> , <i>ACE</i> , and Multi-SNP panel
Basketball	3	First league players (Brazil), performance athletes	<i>ACTN3</i> , <i>PPARA</i> , and Multi-SNP panel
Volleyball	2	Performance athletes, mixed volleyball	<i>ACTN3</i> , <i>PPARA</i> , and <i>HIF1A</i>
Rugby	2	Elite athletes (Italy, UK)	<i>ACE</i> , <i>ACTN3</i> , <i>MCT1</i> , and <i>COMT</i>
Hockey (ice and field)	3	National athletes (Turkey, Morocco), elite athletes	<i>ACE</i> , <i>HIF1A</i> , <i>PPARA</i> , <i>CD36</i> , and Multi-SNP panel
Futsal	1	Elite athletes	Multi-SNP panel

This thematic distribution reflects researchers' growing interest in the individualization of training load and injury prevention based on athletes' genetic profiles. Correlating genotypes with the specific demands of each sport and the tactical role of players opens promising perspectives for the practical use of genetic testing within high-performance teams.

The data presented in Table 5 offer an integrated representation of the reviewed literature concerning the distribution of candidate genes according to the team sports investigated. This reflects a thematic adaptation trend in genetic research to the physiological and tactical particularities of each sports discipline. Team sports involve complex and varied metabolic demands, and the selection of genetic markers analyzed appears to have been guided by these specific characteristics. This differentiated approach supports the potential of applied genetics in elite sports for optimizing selection, personalizing training, and preventing injuries. The results highlight the relevance of an integrated analysis in which the genetic profile is correlated with the specific physical demands and role-related requirements of each sport.

3.4. Genetic Predisposition to Injuries

A recurrent topic in the reviewed scientific literature is the association between genetic profile and the predisposition to muscle or musculoskeletal injuries in team sports. This research direction primarily targets sports characterized by high-intensity intermittent effort, in which athletes are frequently exposed to trauma, physical contact, and repetitive biomechanical stress (Table 6).

Table 6. Genes and polymorphisms associated with injury risk.

Gene	Polymorphism	Associated Risk	Source Study(ies)
<i>IL6</i>	rs1800795	Increased inflammation, delayed recovery	Maestro et al., 2022 [27]; McAuley et al., 2023 [22]
<i>AGT</i>	rs699 (M235T)	Vascular susceptibility, mechanical stress	Silvino et al., 2025 [30]
<i>BDKRB2</i>	rs5810761 (−9/+9)	Risk of micro muscle injuries	Silvino et al., 2025 [30]
<i>FAAH</i>	rs324420	Low pain tolerance, physiological stress	Silva et al., 2023 [24]
<i>NOS3 (eNOS)</i>	rs1799983 (Glu298Asp)	Predisposition to muscle injuries via endothelial dysfunction	Maestro et al., 2022 [27]
<i>COL5A1</i>	rs12722	Collagen integrity, increased risk of musculoskeletal injuries	La Montagna et al., 2019 [31]
<i>VEGF</i>	rs2010963 (−634C > G)	Injury susceptibility, influence on angiogenesis	Maestro et al., 2022 [27]; La Montagna et al., 2019 [31]
<i>HFE</i>	C282Y and other variants	Possible impact on recovery and injury susceptibility	La Montagna et al., 2019 [31]
<i>COMT</i>	rs4680 (Val158Met)	Increased risk of concussions (head trauma)	Antrobus et al., 2023 [34]
Multi-SNP panels	A combination of SNPs from multiple candidate genes	Predictive genomic profile for tendinopathy and injuries	Rodas et al., 2019 [35]
Composite Genotype (TGS)	A combination of polymorphisms from multiple genes	Cumulative score associated with the risk of muscle injuries	Massidda et al., 2024 [28]; Maestro et al., 2022 [27]

Several studies have investigated the link between polymorphisms in the *IL6*, *AGT*, *BDKRB2*, and *FAAH* genes and injury risk or recovery time. For example, *IL6* (rs1800795) is involved in regulating the inflammatory response and may influence the speed of tissue regeneration after exertion, while *AGT* (rs699) and *BDKRB2* (rs5810761) are associated with blood pressure control, vascular function, and susceptibility to micro muscle injuries. The rs324420 polymorphism in *FAAH* has been analyzed in the context of physiological stress regulation and pain perception, with potential implications for tolerance to post-training discomfort and injury.

At the same time, other genetic markers relevant to connective tissue integrity and endothelial function have been reported. For instance, *COL5A1* (rs12722) has been associated with collagen resistance and an increased risk of musculoskeletal injuries, while *NOS3* (rs1799983, Glu298Asp) influences endothelial function and blood flow, being correlated with injury susceptibility and aerobic performance. In addition, the *VEGF* (rs2010963, −634C > G) variant has been linked to angiogenesis and injury vulnerability, whereas the *COMT* (rs4680, Val158Met) polymorphism has been reported in relation to an increased risk of concussions in rugby athletes.

Additionally, two of the included studies [27,28] employed a polygenic approach, calculating a composite genetic score (TGS—Total Genotype Score) to estimate the risk of muscle injuries in elite football players. These approaches suggest a promising direction for the application of genetics in sports practice, with the aim of preventing injuries through personalized interventions.

The available results indicate a moderately consistent association between genetic profile and injury vulnerability, but also highlight the need for larger sample sizes and the integration of other risk factors (training load, playing position, age, and medical history).

3.5. General Synthesis of Genetic Associations

The analysis of studies included in this systematic review offers a comprehensive view of how genetic variations may influence physical performance in team sports, while also suggesting that there is no linear or singular relationship between a specific gene and a particular type of performance. Instead, a multifactorial and polygenic model emerges, in which polymorphisms act cumulatively, in interaction with environmental factors, training strategies, and the competitive context. The convergence of multiple studies on recurring genes indicates that certain biological pathways are central to explaining variability in physiological responses—namely, energy metabolism, muscle contractility, cardiovascular adaptation, tissue recovery, and inflammatory response. These factors are essential in team sports disciplines, where performance involves rapid alternations between high-intensity efforts and partial recovery periods, coordination, and decision-making capacity under stress. An emerging methodological trend can also be observed: a shift from single-gene studies to multigenic models that consider multiple relevant polymorphisms. This holistic approach, expressed through cumulative genotype scores, increases predictive accuracy and enables the integration of genetic information into functional models that better reflect real-world sports conditions.

The distribution of sports disciplines investigated and the variety of performance parameters analyzed highlight considerable contextual diversity across studies, which hinders direct comparison of results but still provides a valuable resource for identifying common patterns. This heterogeneity reflects the nature of team sports, where player roles, intensity of demands, and training types can vary significantly within the same sports discipline.

Overall, current evidence supports the idea that an athlete's genetic profile can provide relevant, but not exclusive, information for understanding performance. Leveraging this profile requires not only the identification of markers with associative value, but also their contextualization based on playing roles, training objectives, and the athlete's individual history. Therefore, the practical applicability of these genetic data requires an integrated, interdisciplinary, and ethically grounded approach. Clearly, the available studies provide a strong foundation for developing decision-support tools in sports contexts. However, challenges remain in clinically validating these associations, standardizing methodologies, and building large-scale databases segmented by sport type and performance level.

In conclusion, the general synthesis of current findings supports a transition from descriptive to applied and functional genetics, in which the analysis of polymorphisms becomes part of a broader ecosystem for sports optimization. These summarized findings provide a necessary framework for critically interpreting results in light of the current research landscape in sports genetics.

4. Discussion

This systematic review aimed to synthesize the existing evidence regarding associations between specific genetic polymorphisms and physical performance in team sports, focusing both on the convergence of findings across studies and the practical relevance of these discoveries in sports practice. The analysis was based on 16 studies that examined the role of genetic variations in the context of team sports, an area less explored compared to individual sports.

The findings of our study indicate that, in team sports, there is a growing interest in identifying genetic associations that can support physical performance and injury prevention. Moreover, the results confirm that the *ACTN3 R577X* and *ACE I/D* polymorphisms remain among the most relevant genetic predictors of physical performance, even in the face of the complex and multidimensional demands characteristic of team-based disciplines.

These findings provide a solid foundation for understanding how genetic variations may influence physiological responses to training, intermittent effort capacity, injury risk, and even psychological adaptation to the specific demands of team sports.

4.1. Interpretation of Results in the Context of Team Sports

The vast majority of the studies analyzed in this systematic review reflect a convergent scientific interest in key candidate genes with proven physiological relevance in team sports. Among these, *ACTN3* and *ACE* stand out as the most frequently investigated, due to their contribution to interindividual variability in strength, speed, endurance, and recovery capacity—essential attributes in disciplines characterized by intermittent physical demands, specific to team sports [20,21,23,25,26,29,30]. In particular, the *ACTN3* R577X polymorphism has been consistently associated with differences in physical capacities among athletes: the RR genotype (functional) has been correlated with superior performance in power and speed-based activities, while the XX genotype (non-functional) is associated with greater metabolic efficiency and better tolerance to sustained effort, especially in positions that require prolonged aerobic activity [5]. According to these studies, athletes with RR or RX genotypes achieved superior results in tests such as sprinting, vertical jumps, and explosive strength exercises, a trend confirmed by data from sports like handball, basketball, rugby, and football [20,30]. This functional relationship is further supported by other studies [37–39]. For example, Garatachea et al. (2014) highlighted a clear association between *ACTN3* R577X and lower-limb explosive power in basketball players [37]. Similarly, Heffernan et al. (2016) demonstrated a differentiated distribution of this polymorphism depending on playing position in rugby athletes, suggesting a functional integration of the genetic profile into tactical demands [38]. In the same vein, Yang et al. (2023) confirmed the relevance of *ACTN3* in distinguishing performance levels among young football players in China, emphasizing its potential for early talent identification [39]. Moreover, recent research by Konopka et al. (2023) supports these observations in mixed-performance contexts, demonstrating the validity of *ACTN3* as a biomarker in sports such as basketball and football [40], while the meta-analysis by Ma et al. (2013) reported a higher prevalence of RR/RX genotypes in elite athletes from power sports, reinforcing the robustness of these associations [41]. On the other hand, despite the dominant perspective emphasizing the advantage of functional genotypes, some studies [5–7,42] have suggested that the XX genotype may provide metabolic benefits and superior adaptability to long-duration effort, offering strategic utility in positions such as midfielders or central defenders, where sustained intermittent effort and quick decision-making are essential. This approach opens new directions for customizing player roles and training based on the athlete's genetic profile.

Regarding the *ACE* I/D polymorphism, the results of our review support the idea that the I allele is correlated with intermittent endurance sports, while the D allele is associated with high-intensity anaerobic activities [20,26,29]. This division is also supported by other studies [43–45]. For instance, McAuley et al. (2020), in a meta-analysis focused on football, confirmed this functional relationship [43], while de Almeida et al. (2022) highlighted the increased predictive value of the *ACTN3*–*ACE* combination for the prevention of non-contact muscle injuries [44]. Furthermore, Gonzalez-Garcia & Varillas Delgado (2024) demonstrated that genetic variation influences performance throughout a competitive season, in correlation with accumulated fatigue and individual neuromuscular capacity [45].

At the mechanistic level, the D allele has been associated with higher levels of angiotensin-converting enzyme (ACE) activity, which may lead to increased muscle mass and elevated blood pressure, offering an advantage in contact sports such as rugby and hockey [21,26]. On the other hand, the I allele is linked to lower enzymatic activity but

greater cardiovascular efficiency and a better metabolic response to prolonged efforts, making it more favorable in sports or positions with an aerobic profile [3,46].

This dual relationship was supported by a comprehensive meta-analysis by Ma et al. (2013), which found increased frequencies of the D allele among strength athletes and the I allele in endurance sports [41]. Additionally, Myerson et al. (1999) showed that elite endurance athletes exhibited a higher prevalence of II and ID genotypes, suggesting more efficient cardiovascular adaptation [47].

The relevance of the *ACE I/D* polymorphism to team sports is emphasized by the mixed nature of these disciplines, where physiological demands involve both anaerobic components (such as explosive power, sprinting, or jumping) and aerobic components (intermittent effort, rapid recovery capacity). In this context, the distribution of *ACE* alleles may influence the optimal physiological response depending on the role played on the field: the D allele favors muscle hypertrophy and short-term strength, while the I allele is associated with increased cardiovascular efficiency and tolerance to prolonged effort. This genetic versatility offers strategic potential in personalizing training and athlete selection, based on playing position and the tactical demands of the game [48].

Expanding the analysis beyond the *ACTN3* and *ACE* genes, several studies included in this review have investigated additional genetic markers with complementary potential that are involved in key physiological processes essential for performance in team sports, such as energy metabolism, adaptation to hypoxia, inflammatory response, endothelial function, and pain perception. Genes such as *PPARA*, *HIF1A*, *IL6*, *NOS3*, *AGT*, *BDKRB2*, and *FAAH* have been associated with traits like aerobic capacity, metabolic efficiency, fatigue resistance, and injury susceptibility [25,26,29,30]. A notable example is the *PPARA rs4253778* polymorphism, involved in fatty acid oxidation, which has been linked to a favorable endurance profile, particularly among athletes in mixed-type sports such as basketball or hockey [49–51]. Other studies confirmed these associations, highlighting the prevalence of the GG genotype in endurance athletes and the association of CC genotypes with greater strength and muscle mass, suggesting a potential bidirectional effect of this gene [52,53].

Regarding cardiovascular response and adaptation to high-intensity effort, the *HIF1A* and *NOS3* genes have been associated with oxygen transport efficiency and endothelial function, influencing performance in intermittent effort contexts [54–56]. For instance, Eynon et al. (2010) reported that the *HIF1A Pro582Ser* polymorphism is linked to enhanced performance in endurance sports, while the *G894T* polymorphism in *NOS3* has been associated with a more effective vasodilatory response and improved recovery capacity [50].

Moreover, recent approaches emphasize multigenic analysis, integrating the cumulative effects of multiple genetic variations. Hall et al. (2021) demonstrated that a set of polymorphisms associated with VO_2max adaptation contributes to performance differentiation in both rugby and marathon running [57]. In a complementary direction, Balberova et al. (2021) proposed a functional gene network involved in contractility, metabolism, and muscle adaptation, providing a theoretical framework for linking genetic profiles with the physiological demands of team sports [58]. Additionally, Gonzalez-Garcia & Varillas-Delgado (2024) highlighted that the genetic profile influences the progression of neuromuscular performance throughout the season in football players, emphasizing the dynamic interaction between genetic predisposition and training stimuli [45].

In our study, several works explored cumulative genotype scores (Total Genotype Score—TGS) as an integrative method for assessing injury risk and adaptation capacity to physical effort in team sports. For instance, Maestro et al. (2022) and Massidda et al. (2024) proposed models based on the integration of multiple genetic variants into predictive scores for muscle injuries, suggesting a clear shift from monogenic approaches toward

more complex polygenic models, better reflecting the multifactorial nature of athletic performance [27,28].

This trend is supported by synthesis studies such as Ahmetov & Fedotovskaya (2015), who state that sports performance is determined by the interaction of dozens or even hundreds of genes, each with a modest but cumulative effect [7]. In the same direction, Pranckeviciene et al. (2021) showed that TGS (Total Genotype Score) derived from *ACTN3*, *ACE*, and *IGF1* polymorphisms can distinguish elite athletes from amateurs based on physical fitness level and injury susceptibility [59]. Similarly, Sarzynski et al. (2016) demonstrated that multi-gene scores can more effectively predict maximal effort performance and individual response to training, especially in sports with mixed physiological profiles [60]. Moreover, Varillas-Delgado et al. (2022) highlighted the utility of cumulative scores in the context of athlete selection and preparation in team sports, where demands are variable and adaptive [4]. This integrative approach suggests that individual genotypes should not be analyzed in isolation, but rather as part of a multigenic predictive network, which can be leveraged for personalized training and injury prevention.

In addition to those already discussed, associations have also been reported for other candidate genes, such as *VEGF* and *COL5A1*, which are involved in angiogenesis and collagen integrity. These findings support the hypotheses that vascular adaptation and connective tissue structure may contribute both to aerobic performance and to the risk of musculoskeletal injuries [27,31]. Similar observations have previously been described in the synthesis literature on the sports genome [7]. Other variations, such as those in *MCT1* and *HFE*, have been associated with tolerance to high-intensity exercise and recovery capacity, complementing existing evidence on the role of lactate metabolism and iron homeostasis in sports performance [31]. Semenova et al. (2023) also highlighted the relevance of these metabolic pathways in sports with intermittent demands [1].

In contact sports, the *COMT rs4680* polymorphism has been correlated with susceptibility to head trauma and elite athlete status [34], while *CD36 rs1761667* has been associated with the risk of non-contact injuries [32]. These findings expand the classical picture dominated by *ACTN3* and *ACE* and align with the perspective of Eynon et al. (2010), who emphasized the importance of neurocognitive and inflammatory markers in intermittent sports [50]. At the same time, the use of polygenic approaches, such as the Total Genotype Score (TGS) and Multi-SNP panels, indicates a shift from assessing individual markers to integrated genetic models, which offer greater applicability for predicting both performance and injury risk [28,35]. This direction is further supported by other studies proposing a transition towards a polygenic framework in sports genetics [4,7].

This systematic review confirms that team sports provide an optimal framework for investigating the contribution of genetic profiles to athletic performance, due to their physiological, cognitive, and tactical complexity. Current evidence supports reproducible associations between polymorphisms such as *ACTN3 R577X* and *ACE I/D* and relevant performance traits (strength, speed, endurance, and recovery), with functional differences depending on playing position and the specific characteristics of each sport. Furthermore, the integrative analysis of the included studies suggests that polygenic and personalized approaches offer real potential for improving strategies related to athlete selection, injury prevention, and training.

Despite some methodological and population-based variability, the consistency of associations across studies reinforces the validity of using genetic profiles as a complementary tool in sports science. However, the application of this information in practice must be accompanied by rigorous scientific validation and adherence to ethical standards, in order to prevent abusive or deterministic use of genetic data. Overall, the findings of this

review support the responsible integration of genetics into performance optimization in team sports, as part of a multidimensional and evidence-based approach.

4.2. Consistencies and Discrepancies with the Scientific Literature

The results of this systematic review align with the prevailing directions in the international literature on sports genetics, confirming the significant role of certain polymorphisms in predisposing individuals to athletic performance. In particular, there is thematic continuity between the included studies and previous theoretical syntheses, which identify *ACTN3* and *ACE* as core markers in the assessment of athletic profiles [2,5,7,51]. Recent works, such as those by Varillas-Delgado et al. (2022) and Roth (2021), expand on this perspective, highlighting the applicability of genetic information not only for initial athlete selection but also for decisions related to field positioning and training planning [4,12].

Moreover, there is a clear convergence between the international literature and the present review regarding the trend toward multigenic and integrative approaches. Studies by Sarzynski et al. (2016) and Heffernan et al. (2016) support the use of cumulative scores (TGS) for a more realistic prediction of performance and injury risk [38,60]. These directions reflect a paradigm shift from the isolated analysis of a single gene to the development of more robust predictive models.

On the other hand, some discrepancies reported in the literature relate to the variability in study design and characteristics of the populations investigated. For example, in the meta-analysis conducted by McAuley et al. (2020) on *ACTN3* and *ACE* polymorphisms in football, differences were noted based on sex, age, competitive level, and ethnicity—all of which significantly influenced the results [43]. Such contextual factors may contribute to inconsistencies in the statistical significance of genetic associations.

Another critical issue is the lack of standardization in defining athletic performance. The reviewed studies include highly variable parameters—from objective laboratory indicators (e.g., VO_2max , isometric strength) to competitive scores or self-assessments—which makes direct comparison between studies difficult. Moreover, many investigations focus exclusively on male athletes, excluding potential sex- or age-dependent effects [56,59].

In conclusion, although there is general agreement regarding the relevance of genetics in team sports, the current literature also highlights methodological limitations that affect the reproducibility of results. These findings emphasize the need for longitudinal, multi-center studies that integrate genetics, training context, and physiological response within a functional, scientifically validated predictive framework.

4.3. Implications for Sports Practice

The results of this study, complemented by the comparison with international specialized literature, highlight an important practical potential for integrating the genetic profile in the optimization of sports performance, injury prevention, and the personalization of training interventions in team sports. Specifically, genetic information can contribute to positional selection of athletes, according to their predisposition to strength, speed, or endurance; to the individualization of training, in accordance with the profile of metabolic, neuromuscular, or cardiovascular adaptation; to the planning of recovery periods and the anticipation of muscular risks, especially in the case of athletes prone to injuries; to the optimization of the selection process in training centers, allowing the completion of physical and psychological assessments with an objective and non-invasive profile; and to the monitoring of young athletes' development, in correlation with biological maturation and individual responses to training stimuli. However, the practical implementation of these findings must be approached with caution and ethical discernment, considering the lack of full consensus on the interpretation of genetic scores at the individual level

and the high variability between populations and sports disciplines, as well as the risk of stigmatization or incorrect selection of athletes in the absence of an integrative assessment (genetic + physiological + psychological).

Therefore, the role of the genetic profile must be understood as a complementary one, not a decisive one, in the equation of sports performance. It only becomes relevant when correlated with the training context, style of play, competition load, and the psychosocial environment of the athlete.

4.4. Limitations

Although this systematic review provides a comprehensive overview of relevant genetic associations in team sports, there are several methodological and contextual limitations that must be acknowledged in order to correctly understand the scope and applicability of the conclusions.

A first limitation of this study is given by the heterogeneity of the included research. The investigated populations vary significantly in terms of the type of sport practiced (football, handball, basketball, rugby, hockey, etc.), level of performance (amateur vs. professional athletes, juniors vs. seniors), and geographical or ethnic background. These differences may influence both the expression of the analyzed genes and the practical relevance of the investigated polymorphisms. Another limitation is that most of the studies are cross-sectional and do not allow for the establishment of causal relationships. The lack of longitudinal studies that track genetic adaptations over time or in response to training limits the predictive power of the results. Also, a few studies applied randomized designs or used well-defined control groups. Moreover, the variation in the way physical performance is measured represents another important limitation of this study. The parameters used (speed, strength, endurance, and injuries) are not uniform, and the lack of standardized evaluation tools creates significant difficulties in making direct comparisons between studies. Additionally, a few of the studies analyzed addressed the multifactorial dimension of performance, namely the integration of genetic factors with epigenetic, nutritional, psychological, or environmental ones. This fragmented approach may lead to overestimating the influence of a single gene while ignoring the complex interactions among multiple biological levels. Language and accessibility barriers also represent a limitation of this study, as only studies published in English and indexed in certain scientific databases were included in the analysis. In this regard, there is a possibility that some relevant research may have been omitted.

These limitations do not invalidate the results of this study. They merely suggest that these results should be interpreted with methodological caution and placed within the context of a research field that is still developing.

5. Conclusions

This systematic review synthesized the evidence presented in the 16 analyzed studies regarding the relationship between certain genetic polymorphisms and physical performance in team sports, highlighting the relevance of markers such as *ACTN3 R577X* and *ACE I/D*. These two polymorphisms have proven to be the most consistent genetic predictors of essential motor qualities—strength, speed, endurance, and recovery capacity in complex sporting contexts characterized by intermittent demands and diverse tactical roles. At the same time, the inclusion of complementary genes such as *PPARA*, *IL6*, *NOS3*, *AGT*, *FAAH*, and *BDKRB2* in the analysis allowed for a broader understanding of the applicative potential of genetic profiling, particularly in relation to adaptation to effort, injury susceptibility, and inflammatory/metabolic response.

Another area of interest is the shift toward polygenic models and cumulative scores (TGS), which offer a more realistic and integrative approach to athletic performance. These reflect a necessary transition from monogenic interpretations to a systemic understanding that can support the planning of personalized interventions in sports training, athlete selection, and injury prevention.

Nevertheless, methodological discrepancies, variations in the populations analyzed, non-uniform definitions of performance, and the lack of longitudinal validation limit the direct applicability of these data in sports practice. It is essential that future research be conducted within rigorous multicenter protocols, with diversified samples, standardized assessments, and careful ethical integration of genetic information.

Therefore, the integration of genetics into sports science should not be seen as a substitute for traditional evaluations, but rather as a complementary tool, capable of refining the understanding of individual potential and contributing to the optimal personalization of athletic development in high-level team sports.

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Systematic Review

Embedding Digital Technologies (AI and ICT) into Physical Education: A Systematic Review of Innovations, Pedagogical Impact, and Challenges

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Abstract

This systematic review investigates the integration of artificial intelligence (AI) and information and communication technologies (ICT) in physical education across all educational levels. Physical education is uniquely centered on motor skill development, physical activity engagement, and health promotion—outcomes that require tailored technological approaches. Through the analysis of recent empirical studies, the main areas where digital technologies contribute to pedagogical innovation are highlighted—such as personalized learning, real-time feedback, student motivation, and educational inclusion. The findings show that AI-assisted tools facilitate differentiated instruction and self-regulated learning by adapting to students’ individual performance levels. Technologies such as wearables and augmented reality (AR)/virtual reality (VR) systems increase engagement and support the participation of students with special educational needs. Furthermore, AI contributes to more efficient and objective assessment of motor performance, coordination, and movement quality. However, significant structural and ethical challenges persist, such as unequal access to digital infrastructure, lack of teacher training, and concerns related to personal data protection. Teachers’ perceptions reflect both openness to the educational potential of AI and caution regarding its practical implementation. The review concludes that AI and ICT can substantially transform physical education, provided that coherent policies, clear ethical frameworks, and investments in teachers’ professional development are in place.

Keywords: artificial intelligence; information and communication technologies; physical education; personalized learning; educational inclusion



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1. Introduction

The consideration of digital technologies in education has experienced accelerated development over the past 20 years, and physical education has been no exception to this trend. However, physical education presents unique pedagogical outcomes—where the main objective remains the stimulation of motor activity, coordination, and physical health, as also underlined by Aston (2018) [1] in the OECD study on children’s physical health and well-being. In this sense, digitalization policies promoted by the European

Union and UNESCO aim to include technology in the educational process in a balanced and sustainable manner [2,3]. Tools based on artificial intelligence (AI) and information and communication technologies (ICT)—such as wearable motion sensors (e.g., IMU sensors, smartwatches), AI-based video analysis software (e.g., OpenPose, Dartfish), and interactive feedback systems—have been increasingly used to transform and optimize traditional, domain-specific teaching and learning methods. Mobile applications (e.g., Strava, MyFitnessPal, Fitbod) that monitor physical activity offer real-time feedback and engagement; these technologies have opened new perspectives for improving educational processes in physical education [4–6].

Within this thematic context, the literature identifies a key factor influencing this modern trend: teacher competencies. Prat Ambrós et al. [7], Tearle and Golder (2008) [8], and Bianchi et al. (2008) [9] note a strong openness among educators to adopting various types of ICT, while also emphasizing gaps in domain-specific digital training and the availability of resources. Additionally, Cojocar et al. (2022) [10] show that e-learning, virtual reality, and related applications at two Romanian universities are creating flexible new learning spaces in physical education. Meanwhile, Díaz Barahona et al. (2020) [11] identify a connection between teachers' digital knowledge and their willingness to use ICT, noting that these aspects are influenced by significant inequalities related to equitable access to opportunities based on gender, age, and infrastructure [9,12].

The central findings of these studies emphasize the relevant impact of integrating information and communication technologies (ICT) in education. When ICT is used appropriately, it encourages students' active and conscious participation in teaching activities, supports knowledge consolidation and the development of digital skills, and thus creates a more stimulating formal learning environment that aligns with current socio-educational contexts. At the same time, these studies reveal persistent challenges, including inadequate teacher training, unequal access to digital resources, and difficulty in systematically incorporating new technological tools into pedagogical practice. These issues represent real barriers to educational modernization, aspects also confirmed by other studies [13,14].

Moreover, the wide variety of application strategies—such as gamification, hybrid methods, and distance learning—points to a significant reconfiguration of the traditional paradigm in physical education. These pedagogical directions clearly indicate a shift toward flexibility, individualization, and alignment with the nature of current digital environments. Current studies [15,16] reinforce the idea that technology in education must be based on coherent strategies based on teacher training and infrastructure development. Furthermore, all these studies suggest that ICT promotes an interesting transition from conventional physical education to a digitally enriched version—provided that all stakeholders are properly trained and resources are equitably distributed.

Few systematic reviews have addressed this topic in depth [17,18], especially distinguishing AI from ICT across the 2014–2025 period. This lack of synthesis hinders a comprehensive understanding of how these technologies can transform teaching, learning, and motor assessment in diverse educational contexts—from primary to higher education. Recent international literature includes many applied studies [19–21], but these differ significantly in methodology, target population, and objectives.

Considering these aspects, for the physical education lessons, a necessary analysis should focus on illustrating recurring patterns, developing trends, as well as common and specific challenges related to the implementation of information and communication technologies (ICT) and artificial intelligence (AI), respectively. This gap is especially relevant in the post-pandemic context, where schools have undergone an accelerated digitalization process, and physical education risks falling behind without informed and sustained inter-

ventions. A conceptual and empirical framework is needed to guide policy and pedagogical decisions regarding the equitable, safe, and effective use of technology in motor activities.

Most existing research consists of either case studies or contextual analyses, and the findings are often difficult to compare due to methodological diversity. In addition, many recent studies [22,23] focus on the general technological benefits in education without sufficiently detailing the bodily, motor, and relational specificities of physical education—elements that are essential when analyzing the integration of technology in this domain.

Thus, a synthesis of the aforementioned research suggests that integrating AI and ICT in physical education offers distinct advantages, such as enabling personalized learning approaches [4], providing real-time biomechanical feedback for rapid movement correction [6], and significantly improving student engagement through gamified and immersive experiences (e.g., VR/AR) [10,13]. These technologies have the potential to improve motor coordination, self-efficacy, and inclusive participation [7,9]. However, this perspective is not without potential drawbacks. These include an overreliance on technology, which may diminish traditional teacher–student interactions [8], risks of data privacy breaches [11], and exacerbating existing digital divides due to unequal access to resources and infrastructure [9,12]. Therefore, a critical and balanced approach is needed to maximize the benefits while mitigating these risks [5,14].

This paper addresses the existing gaps through a rigorous systematic analysis that classifies AI and ICT applications according to the targeted pedagogical domains. It critically evaluates both the transformative potential of these technologies and the structural and cultural barriers that limit their implementation. Thus, the study aims not only to provide a descriptive mapping but also to offer a critical reflection on the conditions that enable technology-assisted physical education while respecting the principles of equity, inclusion, and educational quality.

This systematic review seeks to highlight the main technological innovations used in physical education in recent years, to analyze their impact on teaching–learning processes, assessment, and inclusion, and to identify the challenges that hinder the effective application of these tools in formal educational settings—specifically in schools and universities. Another key objective is to illustrate both the educational benefits and the practical and ethical limitations that may disrupt or obstruct the use of technology in physical education lessons.

Through this analysis, the study aims to provide a comprehensive overview of the field’s evolution, outlining the main research and development directions necessary to foster an intelligent physical education that is responsive to students’ diverse needs and capable of maximizing the benefits of new technologies. Based on this analysis, future lines of research and development will be proposed to maximize the potential of intelligent technologies in physical education, ensuring their sustainable, equitable, and student-centered implementation.

The research hypothesis is that the effective integration of AI and ICT tools into physical education can significantly enhance the quality of the educational process by increasing student motivation, personalizing the learning experience, and promoting inclusion. However, the success of this integration depends on overcoming a range of technical, pedagogical, and ethical limitations.

2. Materials and Methods

2.1. Experimental Approach to the Problem

This systematic review was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [24–26] and followed the recommendations established for conducting systematic reviews in the field of sport

sciences [27]. Its aim was to identify, select, and analyze relevant studies investigating the integration of tools based on artificial intelligence (AI) and information and communication technologies (ICT) in physical education (PE) and physical activity (PA), with a focus on innovations, pedagogical impact, and associated challenges. PRISMA was applied primarily as a reporting guideline to ensure a transparent and consistent presentation of results, adapted to the specific context of sport science, where a strict systematic approach is not always possible. This practice is consistent with approaches documented in related studies.

2.2. Information Sources

The literature search was conducted between November 2024 and April 2025, guided by PRISMA methodology, and targeted studies published primarily in the last five years to ensure the relevance and currency of the findings. Eligible articles were identified in the following international databases: Web of Science, Scopus, MEDLINE/PubMed, and DOAJ—for literature in English. For literature in Romanian, direct access was used on the websites of relevant scientific journals in the field of sport science and physical education. This bilingual search strategy (English + Romanian) ensured broader coverage and contextual relevance.

2.3. Search Strategy

The PICO framework (Patient, Problem, or Population–Intervention or Exposure–Comparison, Control, or Comparator–Outcomes) [28,29] was used to structure the search strategy and ensure systematic coverage of the relevant literature (Table 1).

Table 1. Search strategy framework based on the PICO model adapted to sport sciences: P = children/adolescents in PE; I = AI/ICT; C = traditional PE or other technologies; O = motor, motivational, cognitive, and psychosocial outcomes.

P (Population):	I (Intervention):	C (Comparison):	O (Outcome):
Children and adolescents involved in physical education activities or formal physical activity programs in educational contexts (schools and universities), regardless of their performance level or socio-economic status.	The use of technologies based on artificial intelligence (AI) and information and communication technologies (ICT), including mobile applications, digital educational platforms, biomechanical feedback systems, augmented and virtual reality, and wearable devices.	Traditional physical education programs without the use of AI and ICT tools or, in some cases, comparison between different types of digital technologies (e.g., AR vs. mobile applications).	Improving the educational process, measured by increasing motivation, personalizing learning activities, developing digital skills, supporting vulnerable students, and improving the efficiency of the teaching and assessment process.

In the interest of transparency, the authors were not blinded to the names of the journals or the authors of the manuscripts. The keywords used in our approach included combinations such as “Physical education AND artificial intelligence”, “AI tools AND student engagement in physical education”, “ICT in PE/PA AND learning outcomes”, “PE/PA AND digital inclusion OR gamification”.

For sources in Romanian, equivalent terms were used, adapting the phrases to the specific linguistic reality.

2.4. Eligibility Criteria

The selection of articles was based on their importance in relation to the proposed topic, with a focus on the impact of AI and ICT in PE/PA, especially on the physical, cognitive, and psychosocial aspects of young participants (cognitive = self-regulation, decision-making; psychosocial = motivation, collaboration, reduced anxiety, inclusion).

2.4.1. Inclusion Criteria

Studies that met the following conditions were included in the analysis:

1. Scientific studies that targeted children and adolescents;
2. Research that referred to physical education activities or technology-assisted physical activity;
3. Articles published between 2014 and 2025, focused on physical education in the context of the use of AI/ICT;
4. Experimental or quasi-experimental, qualitative or quantitative studies, including relevant systematic reviews;
5. Scientific articles published only in English and Romanian, in scientific journals with academic visibility (indexed in Scopus/Web of Science or nationally recognized in sport sciences).

We mention the fact that the included population spans children, adolescents, and university students engaged in physical education contexts.

2.4.2. Exclusion Criteria

The following were excluded from the analysis:

- Letters to the editor, short comments, or editorial updates without scientific basis;
- Unpublished papers or papers published in languages other than English or Romanian;
- Studies that did not explicitly address PE/PA and did not address aspects that referred to the use of any technology;
- Scientific communications presented only in the form of posters, conference abstracts, editorials or lectures;
- Articles dated before 2014.

2.5. Selection and Analysis Process

After analyzing all the databases (Web of Science, Scopus, MEDLINE/PubMed, and DOAJ), as well as the websites of relevant scientific journals in the field of sport science and physical education in Romanian, the content of 865 articles (850 + 15) was reviewed. In the first stage, 384 duplicate articles were identified. After removing the duplicates, the authors analyzed whether each of the remaining 398 articles met all the inclusion criteria, which led to the elimination of 357 articles. This was followed by a full-text evaluation, during which another 9 studies were excluded. Of the 32 remaining, 13 were included in the quantitative synthesis of the systematic review. Of the 13 studies, 3 focused on primary education, 5 on gymnasium/high school, and 5 on university students. Nine used ICT, four used AI explicitly. Ten were in English, three in Romanian (Figure 1).

The articles were evaluated in two stages: first by analyzing the title and abstract, and then through full-text reading. Two independent evaluations were conducted for each article, and all discrepancies were resolved through consensus among the authors.

The extracted data were coded according to the following criteria: (1) the type of technology used (AI, ICT, mobile applications, virtual reality, etc.); (2) the target group (age, educational level); (3) the educational dimensions addressed (teaching, assessment, motivation, inclusion); (4) reported challenges; and (5) conclusions regarding effectiveness or limitations.

Screening was conducted independently by two evaluators. Disagreements were resolved by consensus (agreement rate > 85%).

2.6. Assessment of Methodological Quality

To assess the methodological quality of the studies included in this systematic review, the Mixed Methods Appraisal Tool (MMAT), version 2018 [30,31], was used—an internationally recognized tool for the critical appraisal of studies employing diverse methodologies (qualitative, quantitative, and mixed methods). The choice of MMAT was justified by the

heterogeneous nature of the included studies, which employed a variety of approaches—from quasi-experimental interventions and descriptive studies to qualitative investigations and mixed-method designs. This choice was motivated by the heterogeneous nature of the included studies (quantitative, qualitative, and mixed), ensuring coherent evaluation.

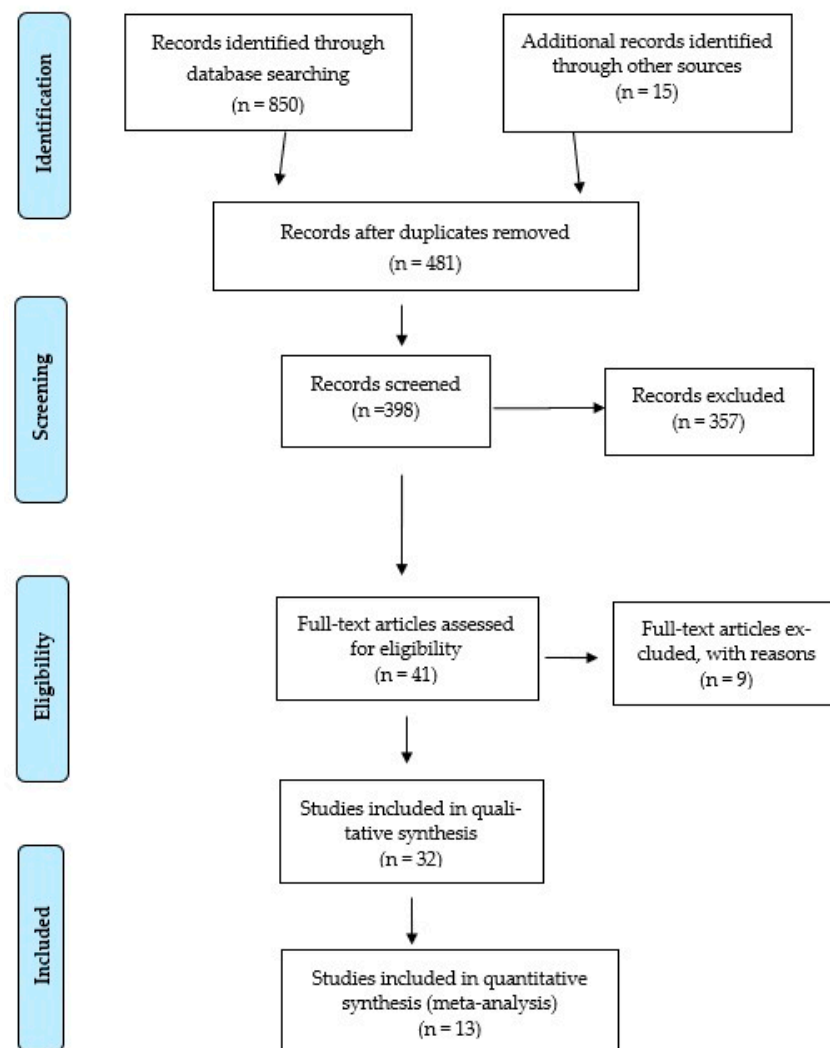


Figure 1. PRISMA flow diagram of study selection.

Of the 13 studies reviewed ($n = 13$), most ($n = 9$) were quantitative descriptive studies. Two studies used a mixed-method approach, and two were qualitative in nature.

- A total of 3 studies (23%) scored 80% (4/5 criteria), being considered good quality.
- Eight studies (62%) scored 60% (3/5 criteria), reflecting moderate quality.
- Two studies (15%) scored 40%, indicating low quality, mainly due to the lack of rigorous sampling methods and validation of instruments (Table 2).

The main methodological shortcomings identified include lack of comparison groups, lack of adjustment for confounders, data collection instruments without documented validation, and lack of clarity in describing data analysis.

2.7. Registration and Protocol

This systematic review was not registered in PROSPERO or any other platform. A protocol was not prepared.

Table 2. Methodological quality assessment using MMAT (2018) for included studies.

No.	Author And Year	MMAT Method Type	No. of “Yes/Clearly Yes” Criteria (out of 5)	Score (%)	Quality Interpretation
1	Culajara (2023) [32]	Mixed methods (pre-post + focus group)	3	60%	Moderate
2	Nieto et al. (2022) [33]	Quantitative descriptive (self/peer evaluation)	2	40%	Low–moderate
3	Wallace, Scanlon & Calderón (2023) [34]	Quantitative descriptive (perception survey)	3	60%	Moderate
4	Montiel Ruiz et al. (2023) [35]	Qualitative (case study: focus group/interview)	4	80%	Good
5	Ahmed & Sarkar (2022) [36]	Presumed descriptive (ICT intervention)	2	40%	Low–moderate
6	Koh et al. (2022) [37]	Quantitative descriptive (perception survey)	3	60%	Moderate
7	Cao et al. (2022) [38]	Quantitative descriptive (AI system)	3	60%	Moderate
8	Mukan et al. (2021) [39]	Quantitative descriptive (static balance test)	3	60%	Moderate
9	Deng et al. (2024) [40]	Quantitative descriptive (governance survey)	3	60%	Moderate
10	Trabelsi et al. (2022) [41]	Quantitative descriptive (national teacher survey)	4	80%	Good
11	Jun et al. (2024) [42]	Quantitative descriptive (blockchain/ML)	3	60%	Moderate
12	Tagimaucia et al. (2024) [43]	Mixed methods (exploratory review from title)	4	80%	Good
13	Poulitsa et al. (2025) [44]	Quantitative descriptive (ICT emotional impact)	3	60%	Moderate

3. Results

This systematic review synthesized 13 relevant studies, providing a structured perspective on AI and ICT applications in physical education. The results are thematically organized, reflecting four major directions: (1) typologies of technology use, (2) pedagogical and motivational impact, (3) challenges and barriers in implementation, and (4) solutions identified in the specialized literature. Each direction is supported by summary tables, analytical interpretations, and correlations between studies.

3.1. Typologies of AI and ICT Applications in Physical Education

The analyzed studies identify four main categories of AI and ICT use in physical education: motor e-learning, self-monitoring, biomechanical feedback, and VR/AR-assisted teaching. These reflect a diversification of technological approaches depending on the pursued pedagogical objectives, the targeted educational level, and the type of technology applied. It is worth noting that although technologies such as virtual reality and augmented reality (VR/AR) are often classified as ICT, their advanced implementation for adaptive learning and personalized feedback is often influenced by artificial intelligence algorithms, which make the differences between the two categories increasingly difficult to notice, thus leading to the emergence of tools that work well together. For example, motor e-learning supports visual and asynchronous instruction, especially targeting secondary and higher education. Mobile applications for self-monitoring aim at students’ self-regulation, while wearable devices and biomechanical sensors are used for movement analysis and improving execution precision. VR/AR allows for interactive simulation of motor gestures, being predominantly applied in lower and upper secondary education (Table 3).

AI was defined as systems using machine learning, motion recognition, or automated feedback. ICT included broader digital tools such as Learning Management Systems (LMSs), VR/AR, mobile applications, and wearables. Results are presented in separate AI-specific and ICT-general subsections.

This technological diversity does not occur in isolation, but as part of a hybrid pedagogy in which digital tools can be complementarily integrated to support motor, cognitive, and social learning.

These directions highlight a diversity of educational purposes. Motor e-learning supports visual learning and asynchronous instruction, responding to the need for flexibility in teaching. Self-monitoring applications, such as those documented by Montiel-Ruiz et al. [35] and Ahmed & Sarkar [36], encourage self-regulation and the development of intrinsic motivation. Biomechanical feedback, based on sensors and wearable devices,

supports posture correction and the efficiency of motor training. Last but not least, the use of VR/AR technologies in teaching gestures introduces elements of increased interactivity and immersion, especially at the middle and high school levels.

Table 3. Types of AI and ICT applications in physical education.

Field of Use	Relevant Studies	Technology Used	Priority Direction	Target Educational Level
Motric e-learning	Culajara (2023) [32], Nieto et al. (2022) [33], Wallace et al. (2023) [34]	Interactive video platforms, LMSs	Supporting visual learning and distance learning	Gymnasium, high school, university
Self-monitoring	Montiel-Ruiz et al. (2023) [35], Ahmed & Sarkar (2022) [36], Koh et al. (2022) [37]	Mobile applications with logging and self-assessment functions	Developing self-regulation and personal motivation	Elementary, gymnasium, university
Biomechanical feedback	Cao et al. (2022) [38], Mukan et al. (2021) [39], Deng et al. (2024) [40]	Motion sensors, wearable devices	Posture and movement analysis and correction	High school, university
Teaching gestures with VR/AR	Trabelsi et al. (2022) [41], Jun et al. (2024) [42], Tagimaucia et al. (2024) [43]	Virtual and augmented reality	Motric simulations and increased interactivity	Gymnasium, high school

The results suggest that these applications are not mutually exclusive, but can coexist in a complementary pedagogical approach, contributing to the development of students' motor, cognitive and social skills.

3.2. The Pedagogical and Motivational Impact of AI and ICT

The use of AI and ICT generates notable educational benefits, highlighted in the literature through three main mechanisms: providing real-time feedback, personalizing tasks, and supporting the inclusion of vulnerable students. Instant feedback, obtained through sensors and algorithms, supports rapid correction of movements and improves students' self-efficacy. This approach contributes to an active and self-regulated learning process. Individualizing exercise programs allows for the adaptation of the degree of difficulty and motor content, depending on the progress of each student, demonstrating the potential of these technologies for student-centered education.

Furthermore, the application of technology to support students with disabilities or psychosocial difficulties shows the inclusive valences of ICT, facilitating the adaptation of exercises and reducing performance anxiety. These findings indicate a transformation of the educational relationship, from a frontal, uniform one, to a personalized and flexible one, supported by smart technologies. Table 4 summarizes these effects.

Table 4. Pedagogical and motivational impact of integrating AI and ICT in physical education.

Impact Indicator	Relevant Studies	Description	Observations
Real-time feedback	Mukan et al. (2021) [39], Wallace et al. (2023) [34], Deng et al. (2024) [40]	Sensors and AI provide instant feedback, supporting correction and self-efficacy	Contributes to increasing internal motivation
Individualizing the exercise program	Cao et al. (2022) [38], Jun et al. (2024) [42], Koh et al. (2022) [37]	AI personalizes difficulty level and motor content based on student progress and preferences	Promising applications but still limited in widespread use
Support for vulnerable learners	Poulitsa et al. (2025) [44], Montiel-Ruiz et al. (2023) [35], Tagimaucia et al. (2024) [43]	Using technologies to reduce anxiety, support inclusion, and adapt exercises	ICT can support the participation of students with disabilities or psychosocial difficulties

Real-time feedback, provided through sensors and AI algorithms, allows for the immediate correction of movements and reinforces the sense of personal efficacy. The personalization of exercises according to individual progress reflects the adaptive potential of these technologies, especially in the context of emerging platforms. Moreover, the support offered to vulnerable students—including those with disabilities or psychosocial difficulties—demonstrates the technologies' ability to promote inclusion and active participation.

These findings suggest that AI and ICT not only support the educational process but can structurally transform it by stimulating student autonomy and encouraging a pedagogical approach centered on individual needs.

3.3. Challenges and Barriers in Implementation

Despite the remarkable benefits, the academic literature highlights a series of systemic obstacles. The most frequently identified barriers include the following: (1) inequalities in access to digital infrastructure, known as the “digital divide”; (2) lack of adequate digital training among teaching staff; (3) ethical concerns regarding the collection and use of personal data; and (4) technical limitations in applying technologies in dynamic environments such as outdoor activities (see Table 5).

Table 5. Challenges and barriers in integrating AI and ICT in physical education.

Type of Challenge	Relevant Studies	Description	Target Educational Level
Digital divide (inequality of access)	Trabelsi et al. (2022) [41], Ahmed & Sarkar (2022) [36], Tagimaucia et al. (2024) [43]	Inequalities in access to digital infrastructure between urban and rural areas, as well as between developed and developing countries	Public schools in peripheral areas, countries with limited resources
Lack of digital training for teachers	Wallace et al. (2023) [34], Koh et al. (2022) [35], Poulitsa et al. (2025) [44]	Lack of digital skills among teachers limits the effective use of modern technologies	Physical education teachers in primary and secondary education
Ethical and data concerns	Deng et al. (2024) [40], Jun et al. (2024) [42], Montiel-Ruiz et al. (2023) [35]	The use of wearables and apps in education is often accompanied by a legislative vacuum regarding data privacy	Applications with biometric tracking, online learning environments
Technical limitations in outdoor environments	Mukan et al. (2021) [39], Culajara (2023) [32], Trabelsi et al. (2022) [41]	AI and ICT are difficult to apply in dynamic contexts (outdoor activities)	Outdoor lessons, lack of connectivity, or instability in measurements

These challenges are not isolated but interdependent: lack of infrastructure limits the application of technology, and lack of training hinders its effective use. At the same time, issues related to data privacy and protection become central in the context of wearable use and online environments, requiring a clear legal framework and ethical digital literacy.

Among the most common barriers is the inequality of access to digital infrastructure, a phenomenon that is more pronounced in rural areas and underfunded regions. Additionally, the lack of adequate teacher training limits their ability to effectively use new technologies. Other significant obstacles are related to the risks concerning the protection of personal data collected through applications and wearables, as well as technical difficulties encountered during outdoor activities (poor connectivity, interference).

These findings highlight the importance of an integrated approach to digital transformation in education, in which equity, safety, and professional competencies become essential conditions.

3.4. Intervention Directions for Overcoming Limitations

The literature also offers realistic solutions for overcoming these challenges. Among the most frequently suggested interventions are the development of open-source resources adapted to disadvantaged environments, continuous teacher training in advanced digital competencies (including the use of VR/AR), the promotion of autonomous technologies

for environments without constant internet access, and the development of an ethical and legal framework specifically for the use of AI in education (Table 6).

Table 6. Intervention directions to mitigate limitations.

Limits	Relevant Studies	Intervention Directions	Observations
Unequal access	Tagimaucia et al. (2024), [43] Ahmed & Sarkar (2022) [36]	Developing open-source educational materials and optimizing applications for environments with limited technological infrastructure	It assumes the involvement of the authorities
Insufficient training	Wallace et al. (2023) [34], Poulitsa et al. (2025) [44]	Continuous improvement programs in digital skills for teachers	Integrates the development of AR/VR skills and familiarization with mobile educational tools
Outdoor limitations	Mukan et al. (2021) [39], Cao et al. (2022) [38]	Using sensors that do not require a permanent internet connection and developing resilient equipment	Encouraging technological experimentation in PE
Personal data	Deng et al. (2024) [40], Jun et al. (2024) [42]	Creating an ethical framework for the use of technology, complemented by information and training actions for beneficiaries	It assumes a connection between the fields of information technology and legal regulations

The success of these interventions, however, depends on the simultaneous involvement of institutional actors (policymakers, school managers), technology developers, and practitioners.

The results of this systematic review highlight the significant potential of AI and ICT in transforming physical education towards a more flexible, personalized, and inclusive model. The benefits identified—from real-time feedback to support for vulnerable students—are significant, but they cannot be fully realized without addressing systemic challenges, such as insufficient professional training and lack of infrastructure.

This analysis confirms that AI and ICT can act as accelerators for the re-shaping of physical education, but requires an integrated vision, focused on equity, safety, and pedagogical quality. In this sense, the studies reviewed provide not only a mapping of the current state of technological integration in PE, but also a guiding framework for future educational policies and institutional initiative.

Table 7 summarizes the main characteristics of the included studies, such as sample size, outcome measures, type of effect observed, and its size. This presentation facilitates comparison of methodological approaches and conclusions formulated in the reviewed literature.

Table 7. Descriptive characteristics and main findings of included studies on AI and ICT integration in physical education.

No.	Author/Year	Sample Size	Outcome Measures	Main Findings/Effect Description	Effect Size
1	Culajara (2023) [32]	52 students + 5 in focus group	Pre-test/post-test scores	Video-based presentations (VBP) significantly improved learning performance	Not reported
2	Nieto et al. (2022) [33]	38 students (age 15)	Self-assessment, peer-assessment via Plickers	Authentic + transformative assessment positively received	Not reported
3	Wallace et al. (2023) [34]	N/A (qualitative study)	Teacher and student perceptions	Low digital competence hinders tech integration in PE	Not reported
4	Montiel-Ruiz et al. (2023) [35]	56 students + 10 teachers	Interviews and focus groups	Edmodo + gamification increased physical activity engagement	Not reported
5	Ahmed & Sarkar (2022) [36]	N/A	Observational and narrative analysis	ICT enhances teaching and learning processes in PE	Not reported
6	Koh et al. (2022) [37]	11 teachers + 72 students	Interviews and focus groups	Positive perceptions but low digital skills among teachers	Not reported
7	Cao et al. (2022) [38]	N/A	AI + multimedia performance tracking	Intelligent system showed promising results in PE monitoring	Experimental results positive, no exact figures
8	Mukan et al. (2021) [39]	N/A	Static balance testing via ICT	Innovative assessment method using multivariate analysis	Not reported
9	Deng et al. (2024) [40]	N/A	Theoretical + case-based analysis	Smart governance in PE using next-gen IT	Not reported

Table 7. Cont.

No.	Author/Year	Sample Size	Outcome Measures	Main Findings/Effect Description	Effect Size
10	Trabelsi et al. (2022) [41]	424 teachers	Quick Tech Survey questionnaire	Low ICT usage but generally positive attitudes	Not reported
11	Jun et al. (2024) [42]	N/A	ML algorithms + blockchain	Correlation between behavior and physical performance	F1 = 0.928; Calinski–Harabasz > 240
12	Tagimaucia et al. (2024) [43]	35 teachers	Questionnaire + interviews	Online PE challenged by connectivity and resource gaps	Not reported
13	Poulitsa et al. (2025) [44]	N/A (conference paper)	Emotional well-being assessment + ICT tools	ICT in PE improved emotional state of vulnerable students	Not reported

4. Discussion

The results of the present study provide a coherent perspective on teachers' perceptions of the integration of artificial intelligence (AI) in primary physical education classes. Overall, the data show a positive attitude towards the potential of these technologies to support personalized learning, streamline the assessment process, and increase student motivation and engagement. This receptivity is aligned with recent developments in the international literature on the digital transformation of physical education teaching. For instance, AI-assisted gamification and AR tools increase active involvement, especially in less motivated students.

Most findings reflect self-reported perceptions, not objective motor performance data. Evidence for objective improvements remains preliminary.

Furthermore, the convergence of teachers' perceptions and empirical evidence provides a strong argument for reconsidering curriculum design in physical education, in a manner compatible with digital environments and artificial intelligence.

The first direction identified in the empirical data is related to personalizing learning and adapting tasks to the pace and level of each student. Teachers interviewed in our study acknowledge that AI can allow them to dynamically adjust requirements according to individual student performance levels, thus providing a differentiated learning environment. Kaya (2025) [45] argues that artificial intelligence contributes to this process through algorithms that can analyze students' motor activity in real time and provide immediate corrective feedback, thus increasing learning efficiency. Similarly, Cui et al. (2025) [46] emphasize that AI can generate automated reports and differentiated training programs, depending on the observed progress of each individual. These results indicate significant potential for promoting student-centered physical education, in which AI functions not only as a support tool, but also as a mediator between teaching and learning.

This adaptive capacity is amplified by the integration of wearable technologies and IoT (Internet of Things), which allow for the measurement of physiological and biomechanical parameters during motor activities. In this sense, Montiel-Ruiz et al. (2023) [35] have demonstrated that the use of smart devices in physical education increases students' self-efficacy and allows teachers to intervene with quick and precise adjustments. At the same time, these devices contribute to the development of data-driven teaching, which optimizes not only student activity, but also instructional decisions in real time. These findings are corroborated by other scientific studies addressing similar topics [47,48].

The second major theme identified is the increase in student motivation and the improvement of their engagement in physical activities. Teachers observe that AI-assisted environments, especially those including augmented reality, mobile applications, or educational games, lead to more active student participation, particularly among those with low interest in traditional physical activities. This finding is supported by Modra et al. (2021) [17], who identified a direct correlation between the use of digital technologies and increased student motivation, especially through flipped learning methods and video-assisted assessment. Likewise, Wallace et al. (2024) [34] emphasize that artificial intelligence, combined with gamification elements, fosters a positive attitude among students toward

motor activities. This suggests that AI can function as an emotional and cognitive catalyst, reducing resistance to physical effort and transforming the educational experience into one perceived as meaningful and enjoyable. These mechanisms are interpreted through the lens of Self-Determination Theory and the Guidance Hypothesis.

In terms of learning autonomy, interviewed teachers highlight that intelligent technologies can support the development of students' self-assessment abilities through visual feedback and self-monitoring. This direction is confirmed by Dahri et al. (2024) [49] and Khasawneh et al. (2025) [50], who show that AI-assisted platforms enhance self-regulation and the development of personal responsibility in students toward their own learning process. Complementarily, Ahmed (2023) [51] and Tariq et al. (2025) [52] indicate that the integration of AI contributes to the development of integrated health, including physical, psychosocial, and cognitive aspects, within a student-centered curricular model. These findings are consistent with contemporary models of transformative learning, in which the student is not merely a beneficiary but also a co-author of their own development.

Another significant result of the study is the perceived relevance of AI in assessing student performance, with a focus on objectivity and efficiency. Teachers mention that intelligent technologies allow for the generation of real-time results, reducing the time required for the evaluation process and providing standardized indicators. This view aligns with the research of Song et al. (2024) [53], who argue that AI optimizes physical testing processes and the identification of intervention needs, and with that of Wang & Wang (2024) [54], who indicate an increase in the quality of formative assessment through the use of motor analysis algorithms. This strengthens the idea of an objective pedagogy, supported by digital evidence and the reduction in subjective errors in the assessment of motor performance.

At the same time, teachers point out a series of structural and pedagogical barriers to the integration of AI in physical education, the most important being the lack of professional training, insufficient technological infrastructure, and cultural reluctance. These obstacles are also highlighted by Shrestha (2025) [18], who shows that in many educational contexts, technology integration is limited by social inequalities and the lack of institutional support. Similarly, Jastrow et al. (2022) [55] warn about the risks related to data privacy and the need for a clear legal framework for the use of AI in schools. These aspects confirm that technological progress in education is not autonomous but fundamentally depends on contextual support, including legislative, training, and infrastructural factors. An important ethical dimension is also captured in this study: the protection of students' personal data and the transparency of algorithms used in educational platforms. This concern is legitimate, given that AI involves continuous data collection and processing, which implies an increased risk of intrusion and misuse of sensitive information. Hu et al. (2024) [56] argue that the development of a clear regulatory framework and the training of teachers in digital ethics are essential steps for the sustainable implementation of AI in education. This ethical component becomes even more relevant in physical education, where the data are often biometric and can affect students' self-image.

In addition to challenges, the results also highlight the potential of AI to contribute to educational equity, especially through the adaptability of content for students with special educational needs or from vulnerable backgrounds. In this regard, Habib et al. (2022) [57] explore how AI can support the active participation of students with mild disabilities through interactive digital games and visual feedback, and Zhang et al. (2022) [58] demonstrate that adaptive AI platforms reduce performance gaps between urban and rural students. This transformative potential of AI is not only technological but also deeply social, as it aims to reduce disparities and democratize access to quality physical education. Recent studies [43–46] reinforce the relevance of digital tools in PE across diverse contexts.

In summary, the results of our study are consistent with major trends highlighted in the specialized literature, outlining a consensus regarding the usefulness and potential of AI in transforming the educational process in the field of physical education. However, for this transformation to be real, sustainable, and equitable, it is essential that educational decision-makers support teachers through continuous training programs, investments in infrastructure, and the development of an ethical and legislative framework adapted to new technological realities.

4.1. Limitations of the Systematic Review

This systematic review presents a number of limitations that must be taken into account when interpreting and generalizing the results. Firstly, the selection of sources was limited to studies available in English and Romanian, which may lead to the exclusion of relevant contributions from other cultural and educational contexts. Moreover, a significant part of the included literature comes from exploratory or pilot studies with diverse methodologies, making it difficult to directly compare the results.

Another major limitation is the absence of a quantitative meta-analysis. Most of the analyzed sources are qualitative or conceptual in nature, which reduces the possibility of drawing strong statistical conclusions about the actual effectiveness of artificial intelligence in physical education. In addition, the reviewed studies largely reflect the opinions of teachers and students' subjective evaluations, without a broad empirical base to track long-term objective performance.

Regarding the primary source of the study—our own article—the qualitative data obtained through semi-structured interviews are valuable for understanding teachers' perceptions but cannot be extrapolated without caution to the entire educational system due to the sample size and its exploratory nature. Furthermore, the lack of triangulation with other categories of educational stakeholders (e.g., students, parents, decision-makers) limits the multi-level perspective of the analysis.

Last but not least, the rapid pace of technological development means that some of the applications and platforms analyzed may quickly become outdated or replaced, which affects the long-term stability of the conclusions. Therefore, the results of this review should be seen as a snapshot in time, with theoretical and methodological guidance value, but requiring continuous updating and extensive empirical validation.

This review also has other limitations: the lack of prospective protocol registration, which may affect the transparency and reproducibility of the analysis, and the exclusive selection of studies in English and Romanian, which may limit the applicability of the results to more diverse educational contexts. In future research, protocol registration and expansion of linguistic criteria could increase the methodological rigor and international relevance of the conclusions.

4.2. Future Research Directions

Going forward, research will need to focus on evaluating the real and lasting effects of integrating artificial intelligence into physical education, moving beyond perceptions and stated intentions. Longitudinal and comparative empirical studies will be essential to determine the extent to which these technologies influence students' motor development, motivation, and engagement. It is also important that future research addresses multiple perspectives—those of students, parents, and educational decision-makers—to form a more complete picture of the acceptance and usefulness of these tools. Lastly, the development of integrated pedagogical models that combine motor skills with digital literacy and learning autonomy will represent a fundamental challenge for future educational research.

5. Conclusions

This review highlights that AI and ICT also directly support motor skill development, e.g., through biomechanical feedback for correcting gestures, VR for safe practice of motor tasks, and self-monitoring apps for fitness. These benefits coexist with challenges (infrastructure gaps, teacher training, and data ethics).

The integration of digital technologies and artificial intelligence in physical education represents a promising approach with the potential to transform teaching practice, motor learning, and student motivation.

The results of this systematic review highlight that artificial intelligence (AI)-based technologies and ICT tools can represent significant vectors of transformation in contemporary physical education, at all levels of education. Emerging applications, from real-time biomechanical feedback to augmented reality and self-monitoring solutions, shape a student-centered digital pedagogy that favors the personalization of learning, the development of self-efficacy and the inclusion of students with diverse needs. The studies analyzed support the potential of these technologies to facilitate the transition from standardized, frontal teaching to a flexible, adaptable, and interactive instructional model.

Teachers' perceptions indicate a positive receptivity towards AI, motivated by the pedagogical and functional advantages of these tools. Personalizing exercises, quick access to standardized feedback, and the ability to adapt to different learning rhythms are recurring elements in teachers' testimonies. At the same time, AI is perceived as a facilitator of inclusion, allowing the adaptation of activities for students with disabilities or integration difficulties. Nevertheless, for such a transformation to take root in a meaningful and equitable way, it requires committed support from educational policymakers. This includes sustained investment in teacher training, infrastructure upgrades, and the creation of a clear ethical and legal framework aligned with emerging technological realities. These challenges can act as inhibiting factors for progress, especially in educational systems with limited resources. In this context, a systemic vision of the digital transformation in physical education is essential, which articulates technological innovation with the real needs of educational actors. There is a need for educational policies focused on digital equity, continuous training programs adapted to the bodily and relational specificity of the discipline, as well as coherent investments in educational infrastructure. Only through an integrated and ethical approach can digital technologies authentically contribute to the democratization of physical education and the development of a culture of active, interactive, and inclusive learning.

Teachers → need targeted digital training. Students → equitable access to inclusive technologies. Schools → infrastructure investments. Policymakers → ethical/legal frameworks for AI in PE.

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Article

Improving Body Mass Index in Students with Excess Weight through a Physical Activity Programme

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Abstract: The obesity epidemic among young people can be tackled through regular physical activity. For this purpose, we developed and implemented a physical activity programme (PAP) that we carried out in students' free time during the school year 2018–2019. The target group consisted of 79 students with excess weight, aged between 12 and 15 years, selected from an initial sample of 495 students from 5 pre-university education units located in an urban area. That group followed a differentiated PAP for 26 weeks. The impact of the programme highlighted the following points: the average physical activity/week for the entire sample of subjects was 3.67 physical activities, with an allocated time/week ranging from 1 h 30 min to 3 h; in terms of effort intensity, 7.70% of the activities were performed at low intensity, 75.07% at medium intensity and 17.23% at submaximal intensity. At the end of the programme, out of 79 subjects who were overweight/obese at the initial testing, 37 improved their body composition at the final testing, with a healthy BMI. It was also found that there is a negative correlation coefficient ($r = -0.23$) between the time spent performing physical activities and the BMI of the subjects.



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Keywords: physical activity; programme; children and adolescents; excess weight; urban environment

1. Introduction

Physical activity habits have changed over the years, and today, increasing numbers of young people are tending to become less active from a motor perspective, a fact that is reflected in their lifestyles. The reality that current research reveals is that the evolution of physical activity has stagnated in recent decades among all categories of citizens, and the percentage of those who practiced but have stopped has increased alarmingly [1]. A study on current trends in physical inactivity in adolescents was published at the end of 2019 [2]. This study pointed out that in 2016, overall, 81% of the respondents (adolescents aged 11–17 years) were not physically active enough (77.60% of boys and 84.70% of girls), and that by territorial socioeconomic level, the prevalence of physical inactivity in 2016 was 84.90% in underdeveloped countries and 79.40% in economically developed countries.

The reality of the situation, particularly in adolescence, applies to virtually any other citizen, regardless of age or country of origin. About all of the above, by a relatively simple differentiation, it can be said that some are more physically active, and others are less likely to participate or to devote time consistently and significantly to this kind of biological effort (physical, mental, emotional). Explanations along this line of selective human behaviour are quite complex as the behaviours are multifactorially determined and, to simplify things, most researchers, rightly perhaps, choose one or another of the possible and relevant variables that determine physical activity or inactivity as the topic of study. Therefore, there are studies that generally address the following variables: age [3–11],

gender identity [1,10,12–22], socioeconomic and education level [23–31], personality characteristics/motivation [12,15,32], social environment/family and friends [12,26,31,33], as well as environmental setting [4,34–36], all of which can influence the level of physical activity as a means of maintaining and/or improving health. Some of the variables listed above are not changeable (such as age, gender), but the others can be altered to a certain extent (level of education, subjects' motivations, social and proximal environment in which each individual lives).

Closely related to health, as a direct cause–effect relationship, is the concept of lifestyle [37,38], presented as a subjective term, encompassing different aspects. One of these is physical activity, which if performed with an appropriate frequency, intensity and duration, is an integrated factor in the so-called healthy lifestyle, which decisively contributes to the maintenance of health and quality of life [39]. In the same vein, any physical exercise performed sporadically does not become part of a stable lifestyle, and its beneficial influences cannot make their presence known.

Paradoxically perhaps, in this area of interest are taken as subjects of studies, to a large extent, only young people, namely “normal” people, and those who practice should be in the forefront of research attention; under these circumstances, it would be justified to be young people/adolescents who for one reason or another have deviated from the state of normality. Our study is also part of this category, which aims to support, in a proactive manner, adolescents with excess weight (of nonendocrine nature), considering that they are the first to either self-exclude or are excluded by others from the enjoyment of physical activities and as a result are not the beneficiaries of this kind of habit, becoming, in the not too distant future, those who will suffer from serious health conditions such as: cardiovascular diseases, diabetes, immune deficit liver diseases.

Specialized studies approach the category of overweight subjects, in most cases, through the prism of the subjects' physical activity/inactivity and only through questionnaires. These are more of an observational nature, being “passive” studies that only point out the problem in question. For example, there are international studies showing an inverse relationship between physical activity and body fat [40–42] and the degree to which physical inactivity contributes/predisposes to increased levels of overweight among the infantile population compared with those who declare themselves physically active [43]. Along the same lines, other studies using objective methods to assess physical activity levels have shown negative associations between physical activity and the development of excess weight, obesity and central/abdominal adipose tissue among children and adolescents [44–46]. Similarly, in a cross-sectional study conducted with adolescent schoolchildren [47], an inverse relationship was found between physical activity and body weight. The results indicated that those who suffered from overweight and obesity spent less time engaged in physical activity than adolescents with a normal body weight. In the same observational manner, a Norwegian study [48] revealed that a substantial decrease in the level of physical activity among adolescents led to a significant increase in body mass index over the same period. Based on this argument, the authors of the study emphasize the importance of maintaining physical activity levels in order to reduce negative trends in body mass index growth. In Romania, research in this area has been largely of a constative nature and, moreover, without any connection with physical activity, presenting only statistical data either from interested institutions or researchers in fields related to physical education and school sport. For example, in an urban study conducted in 2008 on a group of 7904 children and adolescents in grades I–XII from 20 schools and high schools, prevalences were shown of overweight of 12.84% and obesity of 8.29%. Adolescents in this study had lower-than-average prevalences of, respectively, 7.66% for overweight and 3.81% for obesity [49]. In Timiș County (located in western Romania), according to another study [50] conducted between 2010 and 2011 on a total of 3731 subjects aged 7 to 19 years, the overall prevalence of overweight was 18.20% (boys, 20.70% and girls, 16.30%), and that of obesity was 7.20% (boys, 9% and girls, 5.80%). Overweight was more common in the urban areas, a percentage of 18.20%, compared with 17.90% in the rural area. Another

observational study carried out over a period of 10 years (2006–2015) on 25,060 subjects aged between 6 and 19 years coming from 8 counties in Romania [51] showed that 28.30% of them had excess weight (obesity and overweight). The same study also finds that the prevalence of excess weight in children and adolescents in urban areas (29.5% = 18.30% overweight and 11.20% obesity; $n = 20,137$ subjects) is higher than that of children and adolescents in rural areas (22.90% = 14% overweight + 9.90% obesity; $n = 4923$ subjects). The examples are endless, but the important point is that in Romania, there is still little emphasis on the health-generating value of physical exercise practiced in one form or another continuously throughout life.

All this research, as well as other studies not mentioned here, is indeed a wake-up call for responsible entities (institutional and nongovernmental alike), who must take appropriate measures to prevent this globalized phenomenon, currently called the obesity epidemic. For this goal, however, proactive actions/practices are needed, not only to identify but, importantly, also to mobilize young people with excess weight in the constant practice of physical activities, especially in their free time, following a proper methodology. This is also the major goal of our study, which aimed to design and implement a physical activity programme (PAP) exclusively for adolescents aged 12 to 15 years with excess weight (overweight or obesity). Our working hypothesis was that the body mass index in adolescents with excess weight would correlate with the total amount of physical activity that the subjects performed in their free time in completing an average-duration physical activity program.

Following the implementation of this programme, some results were obtained that we consider encouraging. They offer real/objective perspectives on improving the body mass index for the study subjects according to their proactive attitudes toward these kinds of activities. The data highlighted for each subject how much time they dedicated to physical activities (sequentially averaged/day/week/month and overall for the 6 months) and what type of activities they enjoyed, as well as with what effort intensity they chose to perform their preferred activities. These data were finally correlated with the body mass index to demonstrate the existence or nonexistence of relationships there between.

2. Materials and Methods

2.1. Methodology of the Physical Activity Programme

The physical activity programme (PAP) was created at our initiative as an operational model that could be disseminated among students with excess weight according to BMI and benefited, for the implementation of its contents, from the guidance of several specialists and volunteers in the field of sports science and physical education from the Transilvania University of Brasov Faculty of Physical Education and Mountain Sports. In order to be able to cover the entire range of activities related to our study, starting with the initial and final anthropometric measurements, the presentation and implementation of the PAP programme, as well as the monitoring/evidence and centralization of activities, we turned to the help of 5 physical education teachers from the subjects' schools of origin, as well as to a university professor (teacher), and last but not least, to 5 students from our institution, from the study program Kinetic Therapy and Special Motricity.

In addition, we followed the recommendations of the World Health Organization (WHO) regarding the characteristics of our target group (young people with excess weight), namely at least 60 min/day of moderate to vigorous physical activity. When designing the PAP, it was also taken into account the idea that physical activity should be mostly aerobic but include other types of activities that contribute to the strengthening of the musculoskeletal system [52].

To select the subjects for our research, we performed anthropometric measurements on a larger group of students (Section 2.3) from among whom we extracted those with excess weight. Specifically, we measured height with a thaliometer and weight with an electronic scale, respecting the recommended methodologies in both measurement procedures, including regarding the summary clothing of subjects and lack of footwear.

We next used these measurements to calculate the body mass index (BMI) of each subject (according to the formula: $BMI = \text{weight}/\text{height}^2$), thus obtaining the sample of subjects targeted in our approach.

In developing the methodological guidelines of the PAP, we started from the assumption/recommendation that, in general, children and adolescents (6–17 years) with excess weight and/or who are usually physically inactive may not be able to practice 60 min of moderate (according to WHO) let alone increased physical activity. In this context and for our subjects, we felt that they should start in the PAP with moderate intensity physical activity and gradually increase the frequency and time allocated to physical activity to reach the target of 60 min of physical activity/day after a reasonable period of time. Therefore, it was suggested that for the activities carried out with higher intensity, the students should progressively incorporate them into their individual activity plans until they can perform high-intensity activities 2–3 times/week.

In the model PAP, which was designed for 26 weeks and distributed to students to guide their choices, 5 weekly sessions of physical activity were proposed, with an intensity generally between 60 and 70% of the maximum heart rate/subject. During these sessions, we suggested for the weekend physical activities carried out in nature (hiking, cycling, sports orientation, etc.), all with a marked aerobic energy substrate and usually recommended for subjects with excess weight.

Additionally through the designed programme, we wanted to ensure that physical activity/exercise was not abandoned during the study, thus combating the sedentary lifestyle so common today at these ages. At the same time, the programme was developed in such a way as to allow the participants to modify its contents according to their personal preferences.

The physical activity volume, in terms of frequency, the intensity of physical effort and the duration and type of physical activity chosen, was monitored through the physical activity journals that we designed and distributed to the students. Periodically, from these journals, the different quantitative indicators needed for the processing of the executive/practical components of the study were extracted. The students recorded their frequency of physical activities, duration and activity type after each execution in tables in their journals.

In the case of identifying the zones of physical effort (low, aerobic 1, moderate, aerobic 2 and submaximal, aerobic–anaerobic), recorded in the same format of the journal, the subjects were asked to self-determine their heart rate (either by measuring the heart rate by palpating it at the level of the radial artery or by downloading the Heart Rate Monitor-Pulse App from any type of smartphone from the Play Store menu) at 6–8 min after starting an activity, as well as at 15, 20 and/or 30 min (depending on the type of activity), finally averaging the 2 or 3 values obtained. As indicative values for framing the effort intensity zones for ages 12–15 years, we chose the intervals: 130–150 rpm (low); 155–170 rpm (moderate); >175 (submaximal).

Due to the variety, attractiveness and fun that the physical activities of PAP can generate, we encouraged family and friends, even if they were not overweight, to participate together with the subjects to support, encourage and motivate them in their efforts to complete their activities.

Regarding the locations for practicing physical activities that make up the PAP (these being extracurricular activities), the following were suggested to students/their parents: spaces in one's own school, neighbourhood or home, a park or any other accessible public space that offers physical safety and has a purpose that allows the practice of these types of activities.

All this information, as well as the benefits of completing the PAP, were presented at the beginning of the school year (September 2018, after the target group was created), within the pre-university education units involved in the study: physical education teachers, students and their parents, from which the acceptance agreement was obtained. As a result, the study was conducted in accordance with the Declaration of Helsinki and approved by

the Institutional Examination Board of the Faculty of Physical Education and Mountain Sports of the Transilvania University of Brasov (No. 243 from 26 September 2018), and informal consent was obtained from all subjects (the parents of the 79 students) involved in the study.

As a final clarification regarding the methodological aspects of the application of the PAP, we would like to mention that all the proposed activities were chosen in such a way as to have a non-competitive character, thus encouraging the development of confidence in one's own strengths, without favouring the manifestation of inferiority complexes and with the contents adapted to individual motor/physical capabilities.

2.2. Presentation of the Contents and Structure of the Physical Activity Programme (PAP) for Schoolchildren with Excess Weight

The PAP was designed on 4 modules of physical activities: aerobic endurance; strength and muscular endurance; flexibility and weekend activities. Please note that these modules were not randomly selected. Their development was based on the recommendations of several studies carried out internationally that indicate that these types of activities are the most effective for adolescents. It is considered that from a physiological point of view, children and adolescents (6–17 years) adapt easily to physical activities practiced to develop muscle strength and endurance [53,54], aerobic endurance [55,56] and flexibility/mobility [57,58]. However, because the musculoskeletal system is still immature at this age, children and adolescents should not engage in excessive amounts of high-intensity physical activity.

Within each programme out of the 4 proposed, for each physical activity, we estimated the total caloric consumption generated by its execution. These values were obtained experimentally by measuring the MET (the metabolic equivalent of a task/activity) in an obese 13-year-old girl weighing 70 kg and an overweight 15-year-old boy weighing 67 kg. Please note that MET is the unit of measurement for oxygen consumption, and for calculating the total calories consumed/physical activity, the oxygen consumption and the body weight were used, in addition to other parameters such as age, stature and total time dedicated to physical activity. The calculator used to obtain these data is available online at <https://healthyeater.com/calories-burned> (accessed on 3 October 2018). Regarding the weekend activities module, in order to estimate the caloric burns occurring in the body, we took into account constants such as: body weight, distance covered (in kilometres), type of terrain (presence of uphill and/or downhill sequences) and level difference. The calculator used is available online at: <https://caloriesburnedhq.com/calories-burned-hiking/> (accessed on 5 October 2018).

Table 1 present the main indicators of each module.

These modules of the PAP represent diversified offers for physical effort. Due to this fact, they are not of interest in terms of their contents (which are obviously different) but more for the relevant indicators they develop, such as: the number of activities carried out/subject, their average duration/week and the intensity zones in which they fall.

As a way of presenting the PAP document to the students, physical education teachers and the students' parents, each module included: preamble, objectives, application requirements/recommendations and methodological conditions (as appropriate) and examples of activities in different intensity steps with the equivalent in caloric burn.

From a longitudinal perspective, the model PAP, designed over an effective duration of 6 months (26 weeks effectively), was divided into 4 sections with different steps/purposes of action as follows: weeks 1 to 4 (the settling-in period); weeks 5 to 8 (the development period); weeks 9 to 12 (the optimization period); weeks 13 to 26 (the completion period).

Each physical activity session (regardless of the module chosen) consisted of 3 parts that were recommended to students, namely:

1. A body preparation phase (warm-up) lasting 5–10 min, consisting of 4–5 min of brisk walking/running/cycling, etc., followed by dynamic joint mobility exercises, 5–6 min.

2. A main part, lasting 20–30 min, in which exercises on a suitable energy substrate/activity are combined to develop fitness (depending on the module chosen).
3. A body recovery phase after exercise (winding down), lasting 5–10 min, which is important for lowering the heart and breathing rates and is achieved by performing a active physical mobility exercises (stretching), static and/or dynamic, to avoid muscle pain.

Table 1. PAP program features.

PAP—Aerobic Endurance Module			
Session Frequency	Intensity	Dosing	Type of Activity
5–7 times/week	Moderate-high 130–150 heartbeats/min. 155–170 heartbeats/min.	15–60 min/session (With an upward dynamic in volume)	Running, skating, cycling, swimming, cross-country skiing or any other cyclical physical activity
PAP—Strength and Muscular Endurance module			
Session frequency	Intensity	Dosing	Type of activity
at least 3 times/week	Moderate 130–150 heartbeats/min.	8–10 repetitions; 8 to 10 exercises/set of exercises	A wide range of exercises for harmonious physical development, toning and muscle trophicity.
PAP—Flexibility module			
Session frequency	Intensity/Amplitude	Dosing	Type of activity
at least ≥3 times/week	There must be no pain	Dynamic exercises—Position must be held for 4–5 s, 3–5 repetitions Static exercises—Position must be held for 10–20 s.	Pilates stretching (Active and combined)
PAP—Weekend activities module			
Session frequency	Intensity	Dosing	Type of activity
1 time/week	Moderate 130–150 heartbeats/min.	Depending on the chosen route (2 to 4.2 km)	Hiking, Theme parks

2.3. Research Subjects, Inclusion/Exclusion Criteria

The experiment was conducted from September 2018 to June 2019. The target group for the study consisted of 79 subjects with excess weight (38 girls and 41 boys) from General Schools No. 11, No. 13, No. 15, No. 19 and No. 30 of the Municipality of Brasov, aged between 12 and 15 years. In the 5 educational units, we had access through the collaboration protocol concluded between our academic institution and the Braşov County School Inspectorate (partnership agreement no. 298/18 October 2017). The selection of subjects was targeted on multilayered sampling to cover a varied population in terms of age and gender. From an initial group of 494 pupils, the eligible population was selected: 79 subjects with excess weight (52 overweight subjects, group SP, and 27 obese subjects, group O). We divided the final study sample into 4 subgroups for analysis and comparison: obese girls; obese boys; overweight girls; overweight boys).

- Inclusion criteria: pupils from secondary school (grades V–VIII); obesity: BMI ≥ 95th percentile (+2SD) for gender and age; overweight: 85th percentile ≤ BMI < 95th percentile (+2SD) for gender and age; possibility of monitoring and evaluating the results by completing the proposed physical activity programme.
- Exclusion criteria: impossibility to monitor subjects; refusal of parents and/or students to participate in the study.

2.4. Statistical Methods Used in Research

The processing and interpretation of the collected data was carried out using the Statistical Package for the Social Sciences Program (SPSS version 25.0; IBM Corp., Armonk, NY, USA).

3. Results

3.1. Identification of Subjects with Excess Weight at the Initial Measurement

Tables 2 and 3 present the distributions of the students' height and weight at the initial measurement, respectively.

Table 2. Distribution of height in the target group—initial testing.

Statural Classification		Frequency	Percentage	Percentage of Measured Subjects	Cumulative Percentage
Height (cm)	Hyperstatural	1	1.30	1.30	1.30
	Normostatural	74	93.70	93.70	94.90
	Hypostatural	4	5.10	5.10	100
	Total	79	100	100	

Table 3. Distribution of weight in the target group—initial testing.

Body Weight Classification		Frequency	Percentage	Percentage of Measured Subjects	Cumulative Percentage
Weight (kg)	Extra Heavy Weight	23	29.10	29.10	29.10
	Healthy weight	56	70.90	70.90	100
	Very low weight	0	0.00	0.00	
	Total	79	100	100	

Table 3 indicates that most of the subjects had a healthy body weight and only about one-third had a very high body weight. However, calculating the body mass index showed that all subjects had excess weight (Table 4).

Table 4. Distribution of initial body mass indices by gender.

			BMI (kg/m ²)		Total
			Overweight	Obesity	
Gender	Girls	Frequency	25	13	38
		Percentage (%)	65.80%	34.20%	100%
	Boys	Frequency	27	14	41
		Percentage (%)	65.90%	34.10%	100%
Total	Frequency	52	27	79	
	Percentage (%)	65.80%	34.20%	100%	

The subjects' distribution by grade is as follows: 15 students (18.99%) were in the 5th grade, 16 students (20.25%) in the 6th grade, 23 students (29.11%) in the 7th grade and 25 students (31.65%) in the 8th grade. In terms of age, the oldest students were the 8th-grade students, with an average age of 15 years; followed by the 7th-grade students, with an average age of 14 years; 6th grade, average age 13 years; and 5th grade, average age, 12 years.

At the end of the physical activities programme (April 2019), we collected a significant amount of data in the following areas: volume of activity performed/subject, expressed as the number of activities performed; time allocated to physical activities (expressed in minutes and hours); the intensity of the physical activities; and the subjects' actual choices of the activities provided in the PAP. Below, we present the findings according to the four student subgroups: overweight boys and girls and obese boys and girls.

3.2. Average Volume/Frequency of Physical Activities Performed According to the Body Mass Index and Gender of Subjects, Post-Impact PAP

Over the 26 weeks, overall, the subjects in our study (the 79 subjects—38 girls and 41 boys) performed an average of 95.36 physical activities/subject, the fewest being 64 and the most, 124 (Table 5), for an average for the entire sample of subjects of 3.67 physical activities/week. This result was obtained by dividing the average physical activity/subject (95.36) by the duration of the PAP (26 weeks).

Table 5. Total physical activity by body mass index and gender.

BMI	Gender	N	Frequency Average	Standard Deviation	Average Standard Error	95% Conf. Range Min.	95% Conf. Range Max.	Minimum	Maximum
O	Girls	13	96.38	21.02	5.83	83.68	109.09	73	123
	Boys	14	85.07	13.30	3.55	77.39	92.75	69	123
	Total	27	90.72	18.04	3.47	83.38	97.66	69	123
SP	Girls	25	100.60	13.92	2.78	94.85	106.35	75	124
	Boys	27	95.37	18.87	3.63	87.91	102.83	64	124
	Total	52	97.98	16.72	2.32	93.23	102.54	64	124

O = obesity; SP = overweight.

It can also be observed that based on the body mass index, over the entire duration of the programme, obese girls performed more activities on average than obese boys, a fact found also in the case of overweight girls in relation to overweight boys (Table 5).

Both overweight boys and girls performed more physical activities than the obese girls and boys by an average difference of 7.36 activities. Over the 6 months of the programme, the 79 students performed a total of 7534 activities, an overall average of 3.67 activities/week/subject. Figure 1 presents their activities by month. It can be observed that most physical activities were carried out in April, while the fewest were carried out in November.

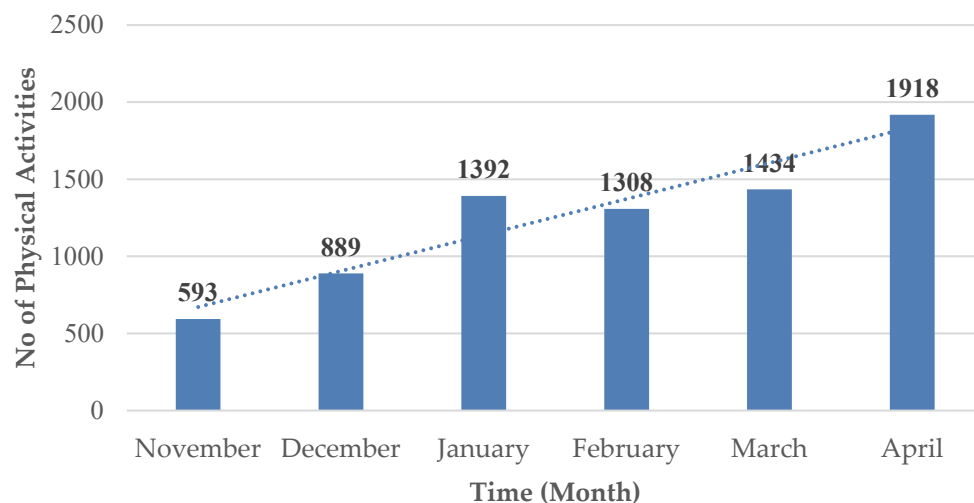


Figure 1. Distribution of the total number of physical activities /month.

3.3. Averages/Subgroups of the Time Allocated to the PAP Sessions

The total amount of time dedicated to the PAP was calculated for the entire period of the programme (1 November 2018–30 April 2019), according to the body mass index and gender of the subjects concerned. On an overall level (79 subjects), the time dedicated to the physical activity programme shows an increasing trend from month to month: from a total of 916 h 8 min in November 2018 to a total of 1101 h 10 min in April 2019. In obese subjects, girls spent more time on physical activity (983 h 24 min) than boys (883 h 57 min). In the case of overweight subjects, girls (1990 h 29 min) and boys (1976 h 23 min), allocated approximately the same total amount of time to the program. Table 6 presents average

times spent on the physical activities according to weight group (obese or overweight) and time interval (between 1 h 30 min–2 h 29 min and ≥ 3 h), as well as their number/activity time interval/week (Table 6 and Figure 2).

Table 6. Distribution of total weekly time spent on physical activity by weight group and time interval.

BMI (kg/m ²) Quantitative Indicators		Average Time Volume/Week Dedicated to the Physical Activity Programme by Subject/Group					Total	
		≥ 1 h	≥ 1 h 29 min	1 h 30 min–2 h 29 min	2 h 30 min and 2 h 59 min	≥ 3 h		
Groups	Overweight	Frequency (N)	0	0	10	21	21	52
		Percentage (%)	0.00%	0.00%	19.20%	40.40%	40.40%	100%
	Obese	Frequency (N)	0	0	17	3	7	27
		Percentage (%)	0.00%	0.00%	63.00%	11.10%	25.90%	100%
Total		Frequency (N)	0	0	27	24	28	79
		Percentage (%)	0.00%	0.00%	34.20%	30.40%	35.40%	100%

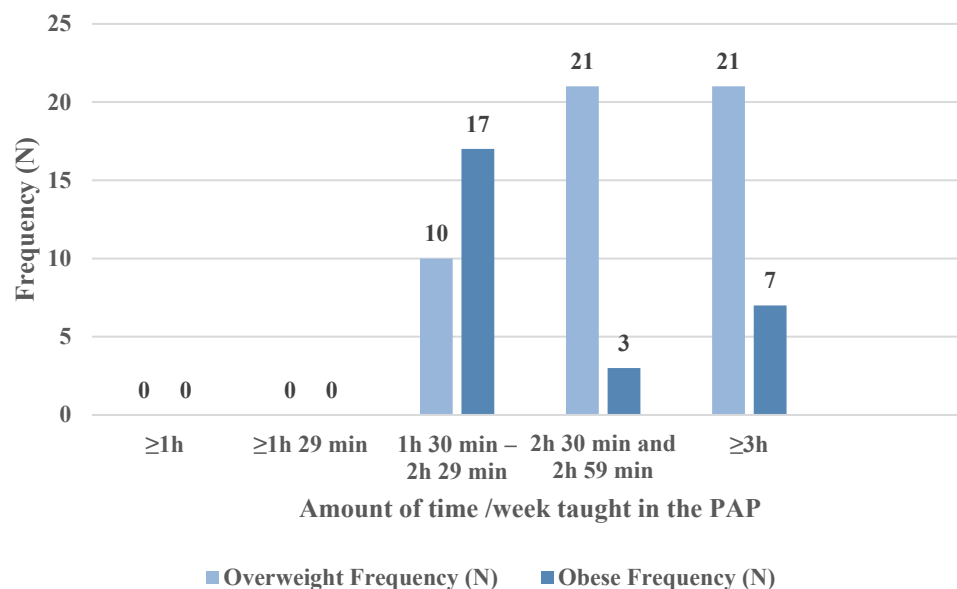


Figure 2. Distribution of total weekly time spent on physical activity.

3.4. Averages/Subgroup Effort Intensity of the Physical Activities

To determine the average of the physical activities/subject according to the intensity of the physical effort, we cumulated the frequency of the physical activities performed (percentages) by each subject, and subsequently, divided the obtained result by the total number of subjects corresponding to each of the 4 subgroups.

The collected data highlight the fact that during the 26 weeks of activity, in the group of obese girls (13 girls), out of the total of 1253 physical activities performed, 98 were performed with a low intensity of physical effort, 964 were performed with an average intensity and 191 were at submaximal intensity. The percentages physical activities/effort zones for obese girls are shown in Figure 3a.

In overweight girls, out of the total of 25 subjects, we found that out of the total of 2515 physical activities carried out, 158 were performed with a low intensity of physical effort, 1917 with an average intensity and 440 at submaximal intensity. In Figure 3b, these data are presented as percentages.

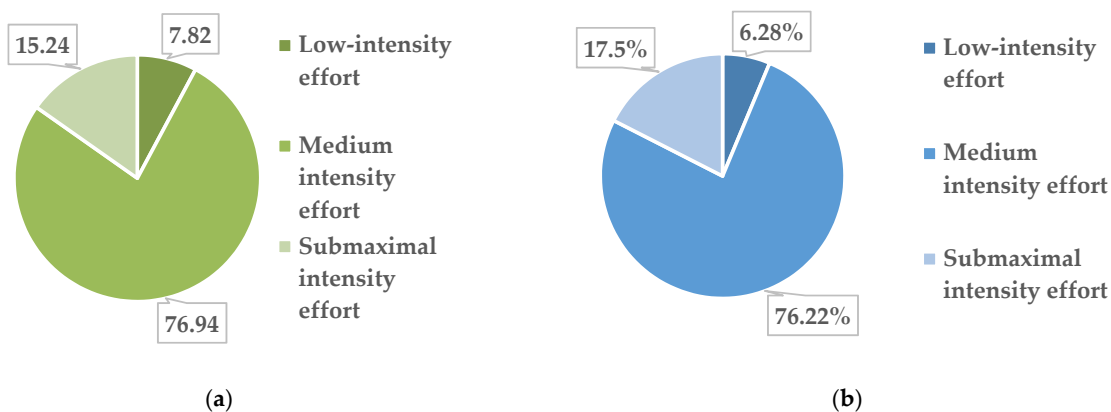


Figure 3. Distribution of physical activity by intensity of the physical effort in obese girls (a) and overweight girls (b).

In the subgroup of obese boys (14 subjects), out of the total of 1191 physical activities, 129 were performed with a low intensity of physical effort, 886 with an average intensity and 176 with a submaximal intensity. The corresponding percentages are presented in Figure 4a.

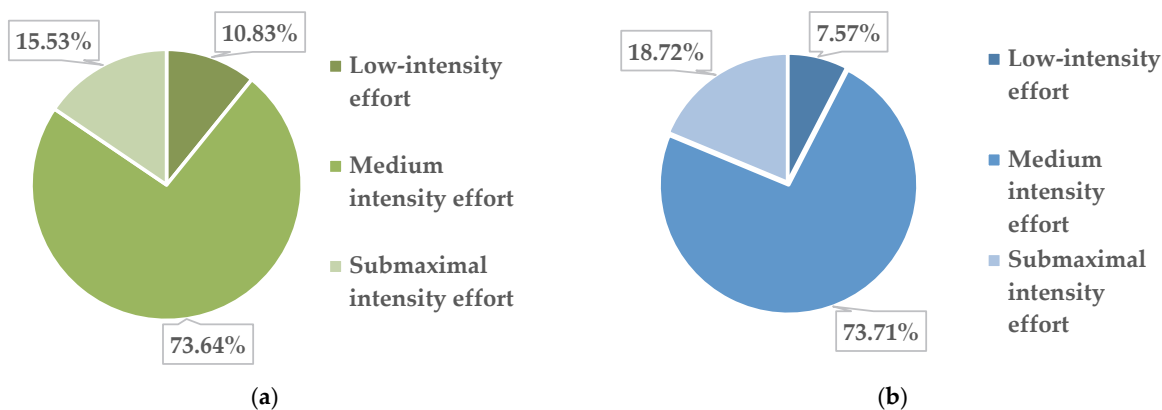


Figure 4. Distribution of physical activity by intensity of the physical effort in obese boys (a) and overweight boys (b).

In overweight boys, out of the total of 27 subjects, out of the total of 2575 physical activities, 195 were performed with a low intensity of physical effort, 1898 physical activities with an average intensity and 482 at submaximal intensity. The corresponding percentages can be found in Figure 4b.

Table 7 presents the 52 overweight and 27 obese (at initial measurement) study subjects' numbers of physical activities (AF), their percentages (%) and the intensity zones of the activities (A, B, C).

Table 7. Total number of performed physical activities by gender, weight group, and intensity of the physical effort.

BMI (kg/m ²)	Gender	No. of Subjects	Freq. N/AF	Total		
				A	B	C
overweight	Girls	25	No. AF	158	1917	440
			%	6.28%	76.22%	17.50%
	Boys	27	No. AF	195	1898	482
			%	7.57%	73.71%	18.72%

Table 7. Cont.

BMI (kg/m ²)	Gender	No. of Subjects	Freq. N/AF	Total		
				A	B	C
obesity	Total	52	No. AF	353	3815	922
			%	6.94%	74.95%	18.11%
	Girls	13	No. AF	98	964	191
			%	7.82%	76.94%	15.24%
	Boys	14	No. AF	129	877	185
			%	10.83%	73.64%	15.53%
Total	27	No. AF	227	1841	376	
		%	9.29%	75.33%	15.38%	
Total		79	No. AF	580	5656	1298
			%	7.70%	75.07%	17.23%

A = low intensity, B = medium intensity, C = submaximal intensity, AF = physical activity.

3.5. Types of Activities Chosen by the Study Subjects

Figures 5a,b and 6a,b present the percentages of participants in each activity module for the obese and overweight girls and boys, respectively, for all 79 subjects.

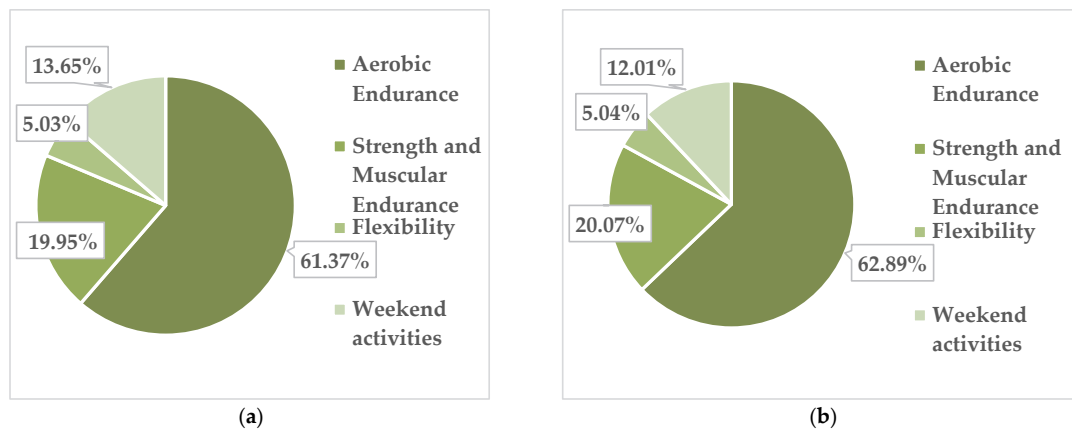


Figure 5. Frequency of preferred activities/module in the physical activity programme in obese girls (a), obese boys (b).

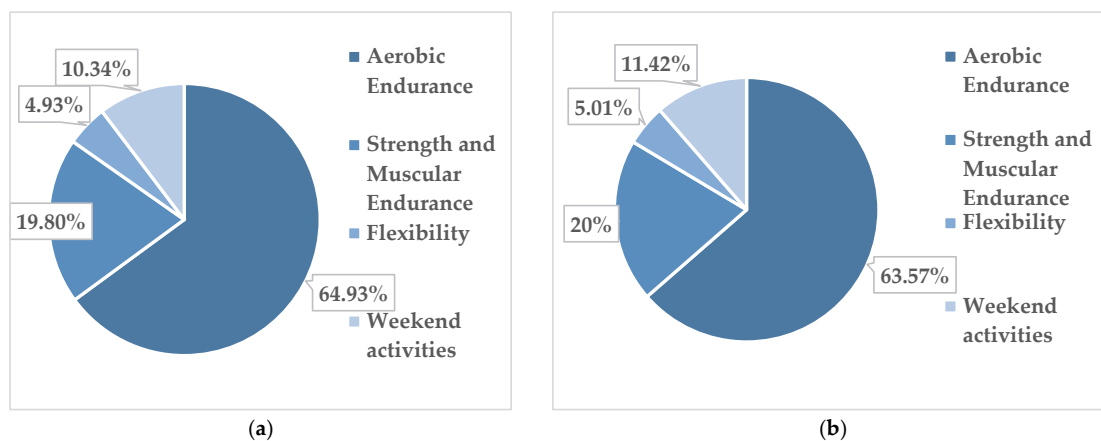


Figure 6. Frequency of preferred activities/module in the physical activity programme in overweight girls (a), overweight boys (b).

The data reflect the fact that all students, regardless of their subgroup, liked the physical activity modules in the following order: 1. aerobic endurance; 2. strength and muscular endurance; 3. flexibility; 4. weekend activities.

3.6. Interpretation of Final Results

At the end of the 6-month programme, we again measured the students' height and weight and again calculated body mass index for the subjects in the four subgroups in order to ascertain if there are, especially in the latter parameter (BMI), significant changes resulting from the effect of the continued practice of physical exercise.

- In the final testing, the majority of the subjects measured, namely 75 subjects, had a normal stature index (Table 8).
- In the final measurement of weight, the students showed an average body weight of 66.57 kg, and the results deviate from the average by 12.13 kg. The majority of the subjects measured (77 subjects) had a normal body weight, and only 2 subjects still had a high body weight relative to age (Table 9).

Table 8. Distribution of height in the target group—final testing.

Statural Classification		Frequency	Percentage	Percentage of Measured Subjects	Cumulative Percentage
Height (cm)	Hyperstatural	1	1.30	1.30	1.30
	Normostatural	75	94.90	94.90	96.20
	Hypostatural	3	3.80	3.80	100
	Total	79	100	100	

Table 9. Distribution of weight in the target group—final testing.

Body Weight Classification		Frequency	Percentage	Percentage of Measured Subjects	Cumulative Percentage
Weight (kg)	Extra Heavy Weight	2	2.50	2.50	2.50
	Normal weight	77	97.50	97.50	100
	Very low weight	0	0.00	0.00	
	Total	79	100	100	

There were no significant differences between boys and girls in either height or weight at both the initial and final testings. The majority of the subjects out of the total of 79 (38 girls and 41 boys) were of normal height and of weight within normal limits.

- The analysis of the body mass index at final testing reveals the BMI at the time of final testing by gender. Basically, in order to centralize the results, we defined the categories of subjects according to the new body mass indices obtained after participating in the PAP. Out of the total of 38 girls identified at the initial testing as having excess weight (25 overweight girls and 13 obese girls; see Table 4), at the final testing (Table 10) after completing the PAP, 23 girls acquired a healthy BMI, 9 girls were classified as overweight and 6 girls were obese. In boys, out of the total of 41, initially 27 overweight and 14 obese (Table 4) in the final testing (after completing the PAP), 14 boys reached a healthy BMI, 17 boys were classified as overweight and 10 boys as obese.

Regarding BMI, determined at the initial and final testings, it can be noted that at the initial test, 52 overweight subjects were recorded, and at the final test only 26 students remained classified as overweight. At the same time, of the 27 subjects identified with obesity at initial testing, only 16 subjects still showed obesity on final testing (Figure 7).

With regard to body mass index by gender, as determined in the initial and final testings (Figure 8), it can be observed that:

Table 10. Distribution of body mass indices at the final testing.

BMI Classification		Frequency	Percentage	Percentage of Evaluated Subjects	Cumulative Percentage
BMI (kg/m ²)	healthy	37	46.80	46.80	46.80
	overweight	26	32.90	32.90	79.70
	obesity	16	20.30	20.30	100
	Total	79	100	100	

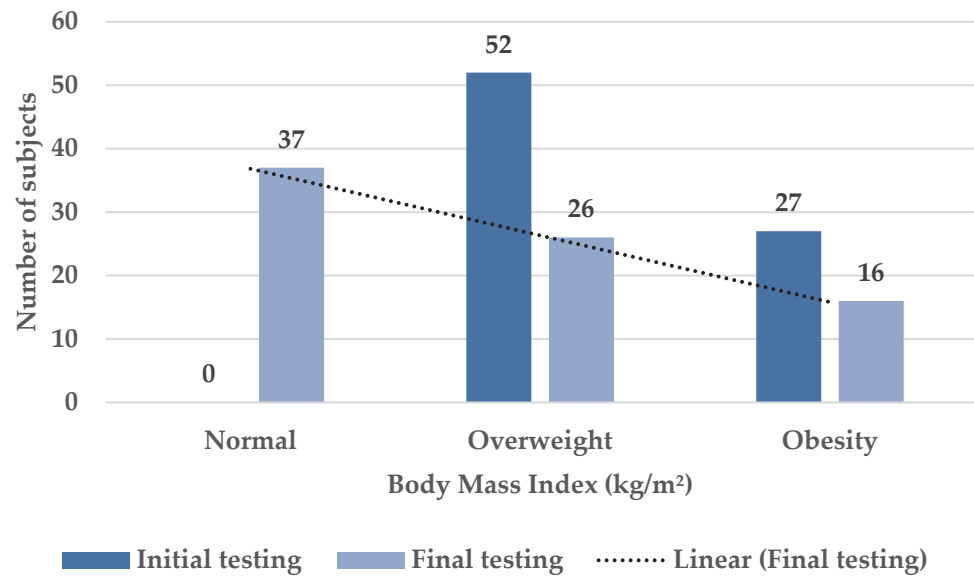


Figure 7. Body mass index distribution in initial and final testing for the target sample.

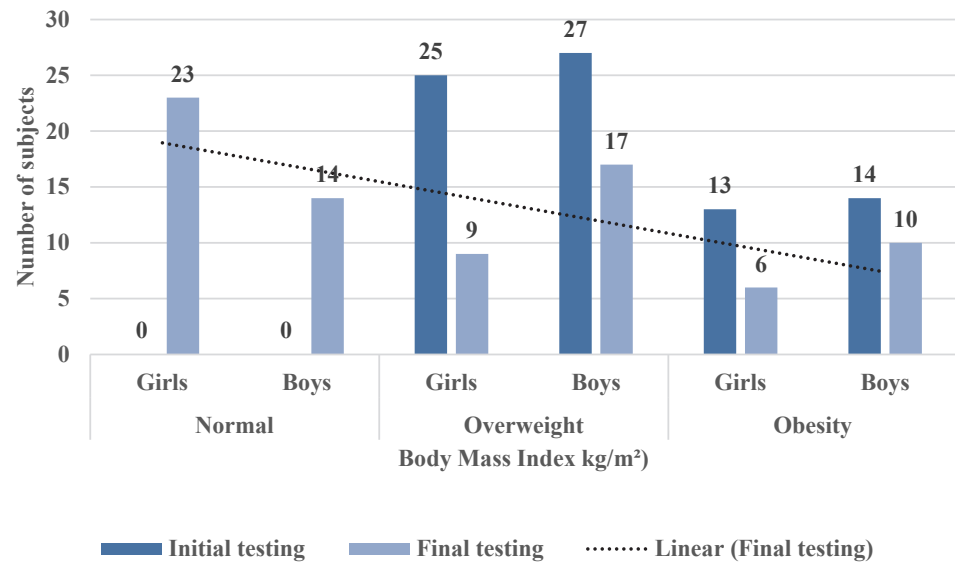


Figure 8. Distribution of initial and final body mass indices for the target sample by gender.

- In the initial testing, 25 girls were identified as overweight, while in the final testing, only 9 girls were still overweight;
- In the case of overweight boys, in the initial testing, 27 boys were overweight, and in the final testing, 17 boys with overweight were identified;
- In the case of obese girls, 13 girls were recorded with obesity at the initial testing, and 6 girls were obese at the final testing;

- For obese boys, 14 were identified in the initial testing, while in the final testing, only 10 boys had obesity;
- Out of the total number of subjects (79), at the final testing, 37 subjects with a healthy body mass index were reported (23 girls and 14 boys).
- In concluding this study, we wanted to determine whether there was a relationship between body mass index (acquired at the time of final testing) and the total amount of time allocated by the subjects with excess weight to the physical activity programme (PAP). Thus, the materiality threshold ($p = 0.04$) obtained in the bivariate analysis between the BMI determined at the final testing on the one hand and the total amount of time devoted to PAP on the other hand shows that there is a statistically significant correlation. As we can see, this correlation is reversed ($r = -0.23$), which allows us to state that in the entire sample (79 subjects with overweight and obesity), a higher body mass index was associated with less time dedicated to the physical activity program (PAP) (Table 11 and Figure 9).

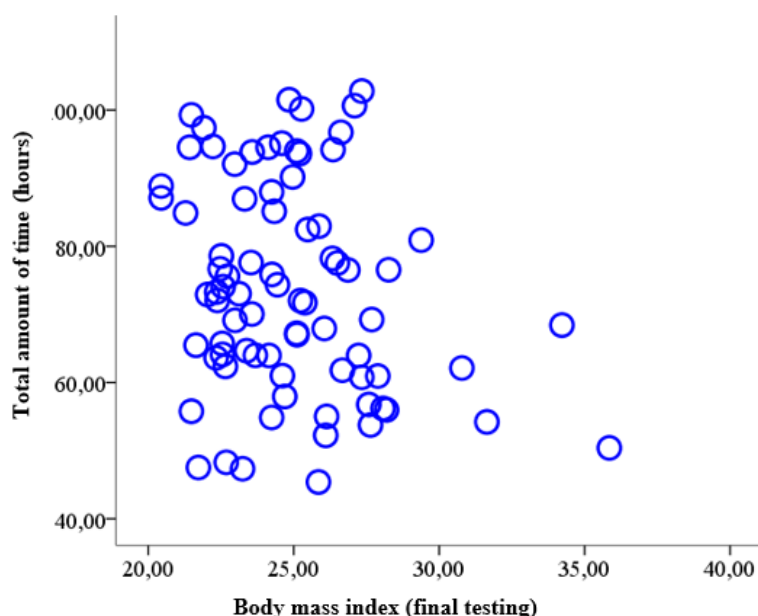


Figure 9. Scatter diagram for the relationship between the body mass index determined at the final testing and the total amount of time devoted to physical activity (hours).

Table 11. Results of the Pearson correlation analysis between the body mass index determined at final testing and the total amount of time devoted to the physical activity programme (PAP).

		BMI-TF	VT. PAP
BMI-TF	Correlation coefficient	1	-0.23
	Materiality threshold (p)		0.04
	N	79	79
VT. PAP	Correlation coefficient	-0.23	1
	Materiality threshold (p)	0.04	
	df	79	79

The correlation is significant at a threshold of 0.05; BMI-TF = body mass index determined at final testing; VT. PAP = total amount of time dedicated to the physical activity programme.

Furthermore, the statistical analysis using the chi-squared test shows that there is a significant difference in the sample selected to participate in the PAP based on body mass index in terms of the total amount of time spent weekly on physical activities ($\chi^2(9) = 19.33$, $p = 0.02$). Along the same lines, the analysis of the data with the help of Fisher’s exact test leads us to the conclusion that there is a significant difference (Fischer’s exact probability $p \leq 0.001$) in the total amount of time spent per week on physical activity between obese

subjects (27 subjects, 13 girls and 14 boys) and overweight subjects (52 subjects, 25 girls and 27 boys) (Table 12). In other words, our study shows that overweight subjects (girls and boys) devoted more time to physical activity than obese students.

Table 12. Statistical significance of the total amount of time devoted weekly to the physical activity programme based on excess weight category and gender.

	Value	Degrees of Freedom	<i>p</i>
Pearson Chi-Square	16.01	2	0.001
Fisher's Exact Test	15.53		0.001
Valid responses	79		

The data presented confirm, from a statistical and mathematical point of view, our working hypothesis, which we mentioned in the introductory part of the study.

4. Discussion

In Romania, the National Center for Evaluation and Promotion reported on the state of health (CNEPSS) for the 2016–2017 school year (study published in 2018), centralizing data regarding the prevalence of chronic diseases found in preschoolers and students, and highlighted the fact that in the second place is obesity of nonendocrine causes in both urban and rural areas [59]. For the urban environment, the following values are presented: 66.95% of children and young people are healthy weight, 21.75% are overweight and 11.3% are obese. Analysing the preliminary sample from our research, the data show us that of the total number of subjects measured ($n = 494$), a percentage of 84.01% are healthy weight and 15.99% are overweight, of whom 10.54% are overweight and 5.46% obese. As can be seen, our sample falls into lower values of excess weight compared with the national averages for Romania. We believe that this difference is due to the geographic area of the city where the measurements were made. Braşov is one of the biggest mountain tourist towns in Romania, with a multi-ethnic population, where there is a certain culture of practicing physical activities. This fact can be an argument for the mentioned differences. On the other hand, also for Romania, the World Obesity Federation estimated in 2016 that 4% of girls and 9.20% of boys aged 10–19 overweight /obese, thus resulting in a sum of 13.2%. Comparing this value with that of our sample (15.99%), which fits into a narrower age range (12–15 years), we can consider that the two means are quite close. Also, the same source [60] estimates that in the year 2030, in Romania, approximately 14.30% of the population aged 10–19 will be obese, and our initial value, related to the excess weight of the subjects, was 15.99%. At the end of the PAP, this percentage dropped significantly, to 8.50% (42 subjects with excess weight out of $n = 494$), with a difference of almost half of the initial percentage, 7.49%. In this context, we can say that the independent variable through which we intervened and which we monitored was given only by the continuous practice of physical activities (through PAP), and this fact determined an improvement in the body mass index at the level of the majority of the targeted subjects.

Regarding the number/frequency of physical activities recommended for children and adolescents, it is true that the World Health Organization [52] recommends practicing at least 60 min/day of moderate to high intensity physical activity (vigorous). We did not succeed in reaching this level of participation with our subjects, our average of physical activities/week having a frequency of 3.66 (global value). However, the same source believes that currently there is no clear evidence of an association between physical activities and managing a healthy weight, and more research is needed to determine the level of association between them. Our study, based on the collected data, is also oriented towards this shortcoming, and the statistical correlation that emerged as a result of our calculations ($r = -0.23$) shows that the students in our interventions with higher body mass indices spent less time dedicated to the physical activity program (PAP). In this context, also in the direction of those indicated previously, we found through the obtained data that there was a statistically significant difference ($p \leq 0.001$) in terms of the total time dedicated weekly

to the PAP between obese and overweight subjects. In other words, our study shows that overweight subjects (girls and boys), who in general allocated a higher proportion of time to PAP activities (80.80% in the intervals of 2 h 30 min and 2 h 59 min or ≥ 3 h), than the obese (37%), achieved a more significant improvement in body mass index in relation to the obese, a fact that can be considered as representing an association between physical activity and a healthy weight.

Regarding the contents of the four modules within the PAP (aerobic endurance; strength and muscular endurance; flexibility; weekend activities, mostly aerobic 1), the final results of our research show that they were correctly chosen, being effective for the intended purpose, and confirm the correctness of the recommendations offered by some specialized studies that consider that children and adolescents (6–17 years) can easily adapt to physical activities practiced in order to develop strength and muscular endurance [53,54], aerobic endurance [55,56] and flexibility/mobility [57,58].

Regarding the intensity zones of effort that we agreed on for the PAP, they are also supported by the recommendations of extensive specialist studies [61]. Thus, in these informative documents, for children and adolescents between 5 and 17 years of age, not only physical activities of moderate intensity but also physical activities of high intensity carried out at least 3 times a week including muscle strength exercises are recommended. We, through the PAP, offered to adolescents the opportunity to perform activities (regardless of their content) with the possibility of performing them in three intensity zones (low, moderate and submaximal). Monitoring this aspect during the 26 weeks, we found that overall, the intensity zone where the most activities were performed was the moderate one (75.07% of the total PAP activities), followed by the submaximal one (17.23%) and the one with low intensity (7.70%). Compared with the previously mentioned recommendations, our study does not fully comply with the provision for high-intensity physical activities, but taking into account the fact that the 79 subjects were all with excess weight at the beginning of the intervention and the source reference is given for those of healthy weight, we still consider that the indication in question was respected to a certain extent, and it follows that in the future, one should insist on performing physical activities that require a more sustained effort.

One last aspect we would like to point out is adolescents' physical activity according to gender. Summarized data [21] referring to 20 studies from different countries found that in children and adolescents, boys in all countries were more active than girls. Along the same lines, [12] it was found that girls practice less physical activity regardless of the age analysed (from 11 to 16 years). According to the authors, for a long time, the socialization process has caused sports inhibition among girls because sports have been labelled a "male activity".

Compared with the mentioned considerations, through the data of our research, we did not notice these differences in attitude between the 38 girls and 41 boys (79 subjects) included in the PAP. Our claims are based on the cumulative data obtained on the number of physical activities performed within the PAP, throughout the monitoring period (26 weeks). Thus, from the total of 7534 physical activities completed, the boys performed 3766 activities and the girls 3768. This equality in the data is given, we believe, by the way we constantly promoted and motivated the subjects (especially through the five physical education teachers who centralized the weekly records of the activities) to practice physical activities in view of our common goal, to improve the excess weight. We believe that the most important factor to consider when it comes to changing physical activity behavior is motivation, which is the inner force that determines the completion of a task for which a commitment has been agreed on.

Our study, admittedly conducted on a more specific sample, namely monitored adolescents with a certain level of excess weight, showed, we believe, that there are no major differences between the levels of participation of girls and boys in PAP activities and even in the types of agreed-on/accessed modules according to the centralized self-reports.

As a general educational aspect, we are also not sure whether it is a good idea, from a pedagogical perspective, to group students in physical education lessons as a constant organizational form of directed motor activity according to normal and overweight categories and compare the manifested attitudes. After all, all children and adolescents are ours (from a didactic perspective), and we are therefore bound to support them in their own training. Perhaps even based on this idea, we decided that the activities in our study should be carried out in the students' free time and differentiated according to their interests and enjoyment. We believe that when those responsible (we refer primarily to physical education teachers) adopt a positive pedagogy in their training approach (whether formal or non-formal), encourage the students, motivate them, show persuasive power through relevant arguments formulated according to the student's level of understanding, constantly highlight each student's progress, support the student in their most difficult moments, keep in touch with the students' families, adopt social learning techniques through movement, etc., the results and attitudes towards physical activities can be surprising. Thus, first in our minds, then in the minds of teachers, and from there through the education provided to all young people and their families, the ideas that discriminate between the two sexes with regard to the practice of physical exercise in any form will fade over time, and even more, the psychological boundary given by the criteria of body mass index will be eliminated, everything being redirected towards the real pleasure that movement can generate for all regardless of age, body weight and any other criteria of human segregation.

5. Research Limitations

The present study is only one section of a larger research project that also includes dietary aspects of students with excess weight, as well as measuring the levels of physical fitness in this target group before and after the impact of the physical activity programme. Due to lack of space, we have not been able to synthesize all the data we have available. The study is also focused on a selective sample in terms of inclusion criteria and limited in terms of number of participants, which is why the data presented need to be confirmed by other more comprehensive studies from a quantitative point of view and possibly extend to the rural school population.

Author Contributions: Conceptualization, M.D.S., L.B. and R.M.; methodology, M.D.S. and L.B.; validation, L.B. and R.M.; literature review: M.D.S., L.B. and R.M.; writing—original draft preparation, M.D.S. and L.B.; writing—review and editing, L.B. and R.M.; supervision, M.D.S., L.B. and R.M. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of the Faculty of Physical education and mountain sports at Transilvania University of Braşov no. 243 from 26 September 2018.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study, concurrent with the agreement of the ethics commissions of the Braşov County School Inspectorate and the Faculty of Physical Education and Mountain Sports, with no. 298 from 18 October 2017.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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Relationship between Body Mass Index and Muscle Strength, Potential Health Risk Factor at Puberty

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Abstract: According to some studies, muscle strength (F) is a predictor of health when this motor quality is associated with body mass index (BMI). Based on this statement, our study aims to find out if there is a significant relationship between the two variables, in the context in which the BMI was determined on 160 subjects, selected from students aged 12-15 and who were subsequently included in 4 subcategories: underweight, normal weight, overweight and obese. For the assessment of muscle strength, we used handgrip strength and standing long jump (broad jump) (respecting the EUROFIT methodology). The results show a moderate positive relationship between the level of muscle strength development and BMI ($\rho = .44, p \leq .01$; $\rho = .43, p \leq .01$). Our data shows that there is a significant, moderate-intensity connection between BMI and strength development, the subjects with excess weight (overweight and obese) having lower strength values compared to normal-weight subjects. Although some authors consider that only the relationship between BMI and strength does not provide conclusive data for predicting the health of adolescents, the results of our study still confirm the existence of an inverse relationship between BMI and muscle strength at overweight and obese subjects. Because the studies on this direction are not very numerous yet, we consider that other observational studies with a larger sample size, especially longitudinal and prospective studies, are necessary.

Keywords: *Puberty; overweight; body mass index; muscle strength; health condition.*

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1. Introduction

Studies that focused on body mass index, as a landmark for identifying overweight, have reported an increase in the prevalence of obesity in children worldwide, both in developed, highly industrialized and ongoing countries (Deren et al., 2018; Wang & Lobstein, 2006). In that context, the foresights for the future is not encouraging, with some estimates suggesting that 254 million children aged 5 to 19, will be obese until 2030 (Buoncristiano et al., 2021).

Being overweight (overweight and obesity) has become one of the most common nutritional diseases in the world, being considered the disease of the 21st century (Agustina et al., 2021). By 2017, it has grown to epidemic proportions, with more than 4 million people dying each year from overweight or obesity (World Health Organization, 2017). The same WHO (2020), is the one that militates more and more to encourage the systematic practice of moderate and high intensity physical activity and which, in combination with a healthy diet, can be a global strategy to prevent many diseases, non-transmissible. Myers et al. (2002), since 2001, have highlighted the importance that should be given to physical activity as an element that promotes longevity and quality of life, and contemporary studies have shown an inverse relationship between physical activity and mortality rate.

Excess weight is directly related to caloric intake and, therefore, is related to diet and physical activity, and its main characteristic is given by the increase in body weight. Regarding the practice of physical activities in order to reduce the volume of adipose tissue, it is often recommended aerobic physical exercises, which young people of school age perform mainly during physical education classes (Ross & Janssen, 2001). On the other hand, more and more scientific studies suggest that not only functional endurance capacity but also muscle strength, another major component of fitness, related with health status, is an important factor in the prevention of chronic diseases (Piercy et al., 2018; Williams et al., 2015). Also, in relation to strength, in its manifest form, namely muscular endurance, it has been shown to be an important determinant of insulin sensitivity, and its low levels are associated with suffering from the so-called „metabolic syndrome” (abdominal obesity, glucose intolerance, type 2 diabetes, hypertension, hyperlipidemia and insulin resistance) (Jurca et al., 2005; Metter et al., 2002).

In the same vein, several studies have shown that the decreasing of muscle mass and strength represents a favorable premise for the development of cardiovascular and metabolic disorders in people of all ages (Silventoinen et al., 2009; Ramírez-Vélez et al., 2014; Eckman et al., 2016). As for children and adolescents, in the study conducted by Ruiz et al. (2011),

they reported that there is a relationship between the level of development of muscle strength and fitness, especially in the overweight and obese ones. In the same way, Ortega et al. (2012) indicated that the development level of the muscle strength in the lower limbs was inversely proportional to the percentage of abdominal adipose tissue. Similarly, Steene-Johannessen et al. (2009) found that, irrespective of the percentage of adipose tissue and the development level of cardio-respiratory resistance, an increase in strength resistance depending on the body weight has been associated with lower levels of indicators of chronic inflammation, such as C-reactive protein, leptin and tumors necrosis factor alpha (TNF- α).

In order to assess the muscle strength, as an indicator of physical condition, which correlates with health status, numerous tests have been described taking into account the fact that its level of development depends on several factors such as biological differentiation, age, size and number of muscles involved, the number of fibers that are activated, intermuscular coordination, etc. (Kendall et al., 2005). The results of the AVENA studies (Food and Assessment of the Nutritional Status of Spanish Adolescents) (Ortega et al., 2005), HELENA (Healthy Lifestyle in Europe by Nutrition in Adolescents) (Ortega et al., 2008) and ALPHA (Assessing Levels of Physical Activity and Fitness) (Ruiz, 2011) demonstrates that the manual grasping force and standing long jump are the most used tests in epidemiological studies to assess the level of muscle strength development in children and adolescents, due to their high degree of reliability and validity.

In the same vein, but in a narrower direction of research, Rodríguez-Valero et al. (2015) consider that assessing the level of development of muscle strength at an early age, allows - as a complementary means - early detection of risk factors for disease, with reference to issues that may result in better future cardiovascular health.

Based on all the above findings, **the aim** of our study is to identify and analyze from a statistical perspective, the relationship between body mass index and muscle strength, depending on biological differentiation and age, on a sample of students from Brasov, trying to capture by the assigned percentage values, the possible predispositions towards the deterioration of the future state of health at the puberty, according to the criterion given by the correlation between the body mass index and the level of force that they manifest at some point.

2. Methodology

2.1. Research participants

The research was conducted between April and June 2014, at the General School No. 30, from Braşov. We mention that the participation in this study was voluntary, and the subjects have been guaranteed anonymity.

The study was conducted according to the guidelines of the Declaration of Helsinki. Also, the agreement was obtained from the school (no.891/15.10.2014) where the measurements were made and the participation agreements of the tutors of the children included in the study were obtained.

The sample chosen consisted of 160 subjects, 78 girls and 82 boys, aged between 12 and 15 years. Of the 160 subjects, 127 have a normal body mass index (65 girls and 62 boys), 20 are overweight (7 girls and 13 boys) and 13 are obese (6 girls and 7 boys). The body mass index was calculated in order to identify the prevalence of overweight (overweight and obesity), with a level of interpretation of the values obtained according to age and gender, in 4 (four) categories: underweight, normal weight, overweight and obesity. It should be mentioned that from the accessible sample the underweight subjects were eliminated because they are not our object of study.

2.2. Research methodology

To measure the development level of muscle strength we have applied the tests described in the EUROFIT battery, „Handgrip strength”, respectively „Standing long jump”. As for the quantification of the results, we notice that the performance was recorded using an evaluation scale, in percentiles, according to the gender and age of the subjects, according to the „Fit-calculadora” model (Intef, n.d.). The scores (percentiles) obtained by our subjects, following the mentioned tests, have been transformed, as follows: for the mediocre grade - score <20; for the weak grade - score 20 - 39; for the average grade - score 40 - 59; for the good grade - score 60 - 79; for the very good grade - score > 80.

We used the ANOVA analysis of variance in order to find out if there are significant differences between the dependent variable (strength) and the independent variables (gender, age and body mass index), and the Spearman coefficient to highlight the correlation between the variables. The level of statistical significance was set at $p < 0.05$ and $p < 0.01$, depending on the statistical applied sample (Popa, 2008).

3. Results

As to the evaluation of the static strength by applying the “Handgrip strength” test, it is found out that the obtained average is 24.79 kgF. The results deviate from the average, plus or minus, by 8.30 kgF. A modular value of 20 kgF was the most common result in the subjects from the targeted sample. The results obtained show an asymmetric distribution to the left (.86), extreme values being met to the right, while the positive flattening index (1.39) indicates a leptokurtic curve, with values concentrated around the average (Table 1 and Figure 1).

Table 1. Statistical representation of the *Handgrip strength* test

<i>Handgrip strength</i> test		
N	Valid measurements	160
	Missing measurements	0
Mean		24,79
Median		23,00
Mode		20,00
Standard deviation		8,30
Variance		68,97
Skewness		,86
Kurtosis		1,39
Minimum		10,00
Maximum		60,00

Source: Authors' own conception

A percentage of 43.10% (26.30% - very good and 16.90% - good) of the evaluated subjects has a level of development of the static strength above average, 25% of them have an average level, and 31.90% (20% - poor and 11.90 % - mediocre) one below average (Table 2 and Figure 2).

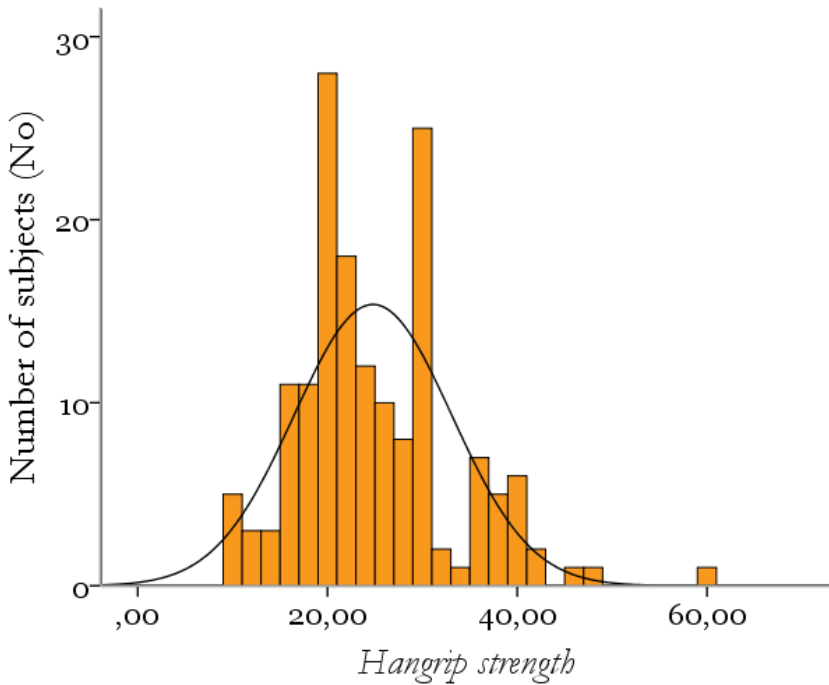


Figure 1. The distribution of frequency scores obtained in the *Handgrip strength* test
Source: Authors' own conception

Table 2. Distribution of the level of development of the static strength evaluated by the *Handgrip strength* test

	Frequency	Percent	Valid percent	Cumulative percent
Very good	42	26,30	26,30	26,30
Good	27	16,90	16,90	43,10
<i>Handgrip strength</i> Average	40	25,00	25,00	68,10
Weak	32	20,00	20,00	88,10
Mediocre	19	11,90	11,90	100
Total	160	100	100	

Source: Authors' own conception

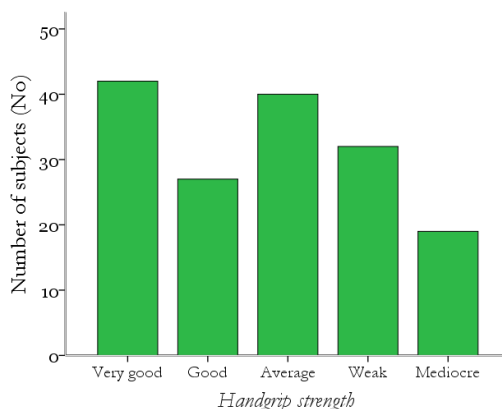


Figure 2. Distribution of the level of development of the static strength evaluated by the *Handgrip strength* test

Source: Authors' own conception

As for the body mass index, 40.90% (25.20% - very good and 15.70% - good) of the subjects with a normal body mass index have a level of development of the static strength above average, 30% (5% - weak and 25% - mediocre) of the overweight subjects and 30.80% (15.40% - weak and 15.40% - mediocre) of the obese subjects have a level below the average (Table 3 and Figure 3).

Table 3. Distribution of the development level of the static strength evaluated by the *Handgrip strength* test, according to the body mass index

		Evaluation scale					Overall result	
		Very good	Good	Average	Weak	Mediocre		
BMI (kg/ m ²)	Normal	No	32	20	34	29	12	127
		(%)	25,20	15,70	26,80	22,80	9,40	100
	Over-weight	No	6	5	3	1	5	20
		(%)	30,00	25,00	15,00	5,00	25,00	100
	Obesity	No	4	2	3	2	2	13
		(%)	30,80	15,40	23,10	15,40	15,40	100
Overall result		No	42	27	40	32	19	160
		(%)	26,30	16,90	25,00	20,00	11,90	100

Source: Authors' own conception

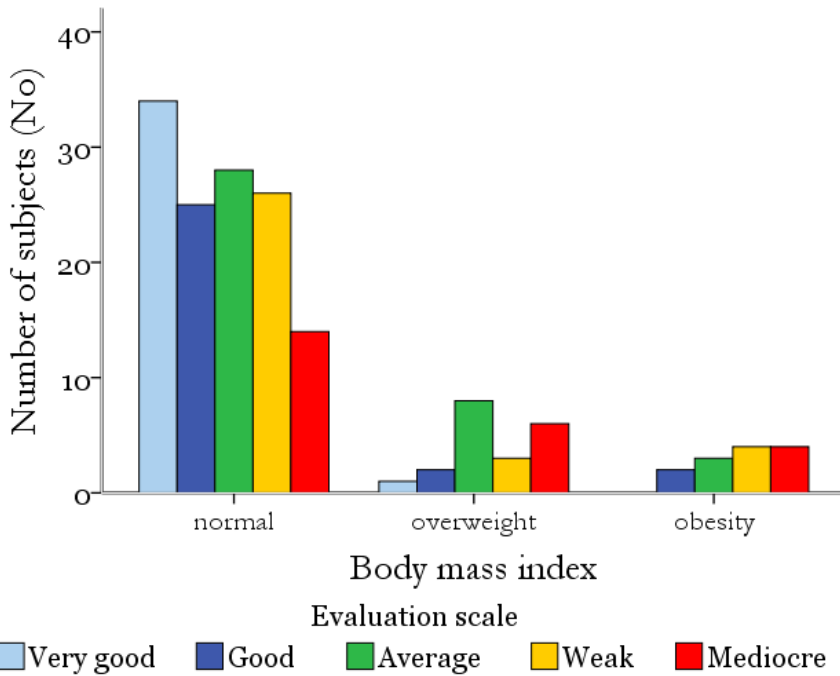


Figure 3. Distribution of the level of development of the static strength evaluated by the test *Handgrip strength* test, according to the body mass index

Source: Authors' own conception

As to the level of development of the static strength, depending on the body mass index and the gender of the subjects, the bifactorial analysis of variance (ANOVA) shows a significant overall effect ($F_{(3)} = 14.01, p \leq .01, \eta^2 = .21$) which comes entirely from the main effect of the body mass index factor ($F_{(2)} = 17.85, p \leq .01, \eta^2 = .19$) and of the gender factor ($F_{(1)} = 0.61, p = .43, \eta^2 = .01$). It can be seen that both, gender and the interaction between body mass index and gender, do not show a statistically significant effect on static force (Table 4).

Table 4. ANOVA variance analysis for the scores obtained in the *Handgrip strength* test, depending on the body mass index and gender

Source	Sum of squares	DF	Mean square	F	p	Partial Eta (η^2)	Observed power ^b
Model	2328.24 ^a	3	776.08	14.01	.00	.21	1.00
BMI	1977.41	2	988.70	17.85	.00	.19	1.00
Gender	34.14	1	34.14	.62	.43	.01	.12

BMI*	.00	000
gender						
Error	8640.54	156	55.39			

Dependent variable: *Handgrip strength* test; DF = degrees of freedom; BMI = body mass index;

a. $R^2 = 0.21$ (R^2 adjusted = 0.20); b. $p = 0.05$

Source: Authors' own conception

Depending on the body mass index and the age of the subjects, the results show a significant overall effect ($F_{(9)} = 16.33$, $p \leq .01$, $\eta^2 = .39$) which results entirely from the main effect of the body mass index factor ($F_{(2)} = 4.56$, $p = .01$, $\eta^2 = .06$) and of the age factor ($F_{(3)} = 15.01$, $p \leq .01$, $\eta^2 = .23$). However, the interaction between body mass index and age does not have a statistically significant effect on the static force (Table 5).

Table 5. ANOVA variance analysis for the scores obtained in the *Handgrip strength* test, depending on the body mass index and age

Source	Sum of squares	DF	Mean square	F	p	Partial Eta (η^2)	Observed power ^b
Model	4282.75 ^a	6	713.79	16.33	.00	.39	1.00
BMI	398.34	2	199.17	4.56	.01	.06	.77
Age	1968.50	3	656.16	15.01	.00	.23	1.00
BMI* age	6.02	1	6.02	.14	.71	.01	.07
Error	6686.03	153	43.70				

Dependent variable: *Handgrip strength* test; DF = degrees of freedom; BMI = body mass index;

a. $R^2 = 0.39$ (R^2 adjusted = 0.37); b. $p = 0.05$

Source: Authors' own conception

Bivariate correlation analysis, based on the Spearman correlation coefficient, shows that there is a significant, moderate-intensity link ($\rho = .44$) between the body mass index and the development level of the handgrip strength, due to the fact that $p \leq .01$ (Table 6).

Table 6. The result of the correlation analysis according to the Spearman coefficient, between the development level of the static strength and the body mass index

Spearman's rho		<i>Handgrip strength</i>	BMI (kg/m ²)
<i>Handgrip strength</i>	CC	1.00	.44**
	P	.	.00
	N	160	160
BMI (kg/m ²)	CC	.44**	1.00
	P	.00	.
	N	160	160

** The correlation is significant at a significance level ≤ 0.01 ; BMI = body mass index; CC = correlation coefficient

Source: Authors' own conception

As for the evaluation of the explosive power or of the horizontal detonation by applying the test *Standing long jump*, it is found out that the obtained average is 159.91 cm. The results deviate from the average, plus or minus, by 25.11 cm. A modular value of 150.00 cm was the most common result in the subjects in the sample. The obtained results illustrate an asymmetric distribution to the left (.65), extreme values being met to the right, while the positive flattening index (.92) indicates a leptokurtic curve, with values concentrated around the average. (Table 7 and Figure 4).

Table 7. Statistical representation of the *Standing long jump* test

The <i>Standing long jump</i> test		
N	Valid measurements	160
	Missing measurements	0
Mean		159,91
Median		155,00
Mode		150,00
Standard deviation		25,11
Variance		630,11
Skewness		,65
Kurtosis		,92
Minimum		100,00
Maximum		243,00

Source: Authors' own conception

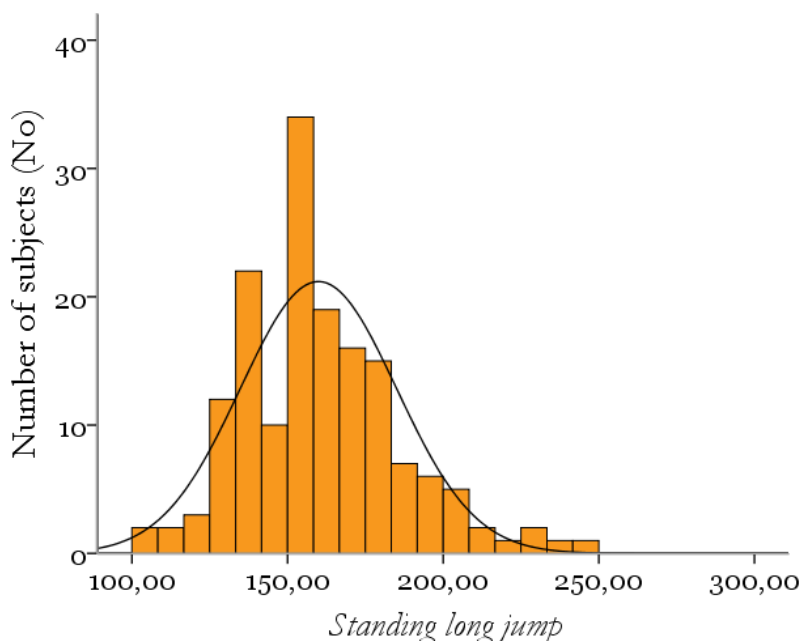


Figure 4. Distribution of the frequencies of the scores obtained in the *Standing long jump* test
 Source: Authors' own conception

A percentage of 24.40% of the evaluated subjects has an average level of development of the explosive power, 40% (21.90% - very good and 18.10% - good) of these have an above the average level, and 35.60% (20.60% - weak and 15.00 % - mediocre) show a level below the average (Table 8 and Figure 5).

Table 8. Distribution of the development level of the explosive power by the *Standing long jump* test

	Frequency	Percent	Valid percent	Cumulative percent
Very good	35	21,90	21,90	21,90
Good	29	18,10	18,10	40,00
Average	39	24,40	24,40	64,40
Weak	33	20,60	20,60	85,00
Mediocre	24	15,00	15,00	100
Total	160	100	100	

a. *S.L.J.* = *Standing long jump* test

Source: Authors' own conception

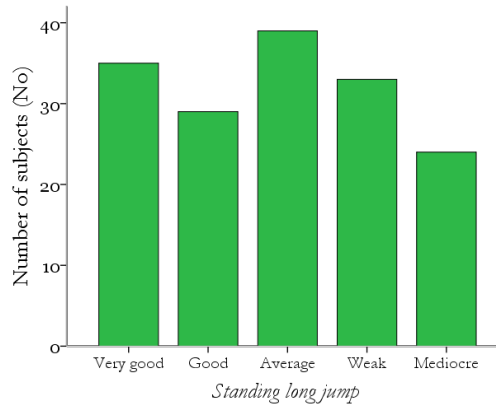


Figure 5. Distribution of the development level of the explosive power by the *Standing long jump* test

Source: Authors' own conception

As for the body mass index, 46.50% (26.80% - very good and 19.70% - good) of the subjects who have a normal body mass index, have a development level of the explosive power above average, 45% (15% - weak and 30% - mediocre) of the overweight subjects and 61.60% (30.80% - weak and 30.80% - mediocre) of the obese subjects present a level below average (Table 9 and Figure 6).

Table 9. Distribution of the development level of the static strength evaluated by the *Standing long jump* test, according to the body mass index

		Evaluation scale					Overall result	
		Very good	Good	Average	Weak	Mediocre		
BMI	Normal	No	34	25	28	26	14	127
		(%)	26,80	19,70	22,00	20,50	11,00	100
(kg/ m ²)	Over-weight	No	1	2	8	3	6	20
		(%)	5,00	10,00	40,00	15,00	30,00	100
	Obesity	No	0	2	3	4	4	13
		(%)	0,00	15,40	23,10%	30,80	30,80	100
Overall result		No	35	29	39	33	24	160
		(%)	21,90	18,10	24,40	20,60	15,00	100

Source: Authors' own conception

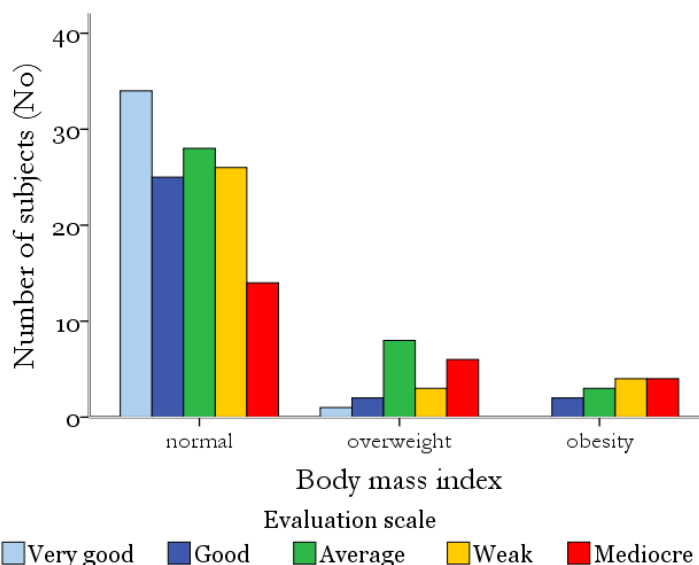


Figure 6. Distribution of the development level of the explosive power evaluated by the test *Standing long jump*, according to the body mass index
Source: Authors' own conception

As to the development level of the explosive power, depending on the body mass index and the gender of the subjects, the bifactorial variance analysis (ANOVA) shows a significant overall effect ($F_{(3)} = 16.98, p \leq .01, \eta^2 = .25$) which results entirely from the main effect of the body mass index factor ($F_{(2)} = 14.75, p \leq .01, \eta^2 = .16$) and of the gender factor ($F_{(1)} = 1.83, p = .18, \eta^2 = .01$). It can be noticed that both, the gender and the interaction between the body mass index and the gender, do not indicate a statistically significant effect on the development level of the explosive power (Table 10).

Table 10. ANOVA variance analysis for the scores obtained in the test *Standing long jump*, depending on the body mass index and the gender

Source	Sum of squares	DF	Average of square	F	p	Partial Eta (η^2)	Observed strength ^b
Model	24665.95 ^a	3	8221.98	16.98	.00	.25	1.00
BMI	14285.43	2	7142.72	14.75	.00	.16	.99
Gender	886.61	1	886.61	1.83	.18	.01	.27

BMI*	.00	000
gender						
Error	75520.82	156	484.11			

Dependent variable: the Standing long jump test; DF = degrees of freedom; BMI = body mass index

a. $R^2 = 0.25$ (R^2 adjusted = 0.23); b. $p = 0.05$

Source: Authors' own conception

Compared to the body mass index and the age of the subjects, the results show a significant overall effect ($F_{(6)} = 11.88, p \leq .01, \eta^2 = .32$) which results entirely from the main effect of the body mass index factor ($F_{(2)} = 7.83, p = .01, \eta^2 = .09$) and of the age factor ($F_{(3)} = 5.58, p = .01, \eta^2 = .10$). However, the interaction between the body mass index and the age does not illustrate a statistically significant effect ($p = .06$) on the development level of the explosive power (Table 11).

Table 11. ANOVA variance analysis for the scores obtained in the *Standing long jump* test, depending on the body mass index and age

Source	Sum of squares	DF	Average of square	F	p	Partial Eta (η^2)	Observed power ^b
Model	31842.96 ^a	6	5307.16	11.88	.00	.32	1.00
BMI	6999.85	2	3499.93	7.84	.01	.09	.95
Age	7483.45	3	2494.48	5.58	.01	.10	.94
BMI* age	1565.84	1	1565.84	3.51	.06	.02	.46
Error	68343.82	153	446.69				

Dependent variable: the Standing long jump test; DF = degrees of freedom; BMI = body mass index;

a. $R^2 = 0.22$ (R^2 adjusted = 0.19); b. $p = 0.05$

Source: Authors' own conception

The bivariate correlation analysis, based on the Spearman correlation coefficient, shows that there is a significant link, of moderate intensity ($\rho = .43$), between the body mass index and the development level of the explosive power, due to the fact that $p \leq .001$ (Table 12).

Table 12. The result of the correlation analysis according to the Spearman coefficient, between the development level of the explosive power and the body mass index

Spearman's rho		S.L.J.	BMI (kg/m ²)
	CC	1.00	.43**
S.L.J	p	.	.00
	N	160	160
BMI	CC	.43**	1.00
(kg/m ²)	P	.00	.
	N	160	160

*** The correlation is significant at a significance level ≤ 0.01 ; CC = correlation coefficient
 S.L.J. = Standing long jump test; BMI = body mass index*

Source: Authors' own conception

4. Limits and Discussions

The nature of this study does not allow us to determine the exact causality of the relationships established between the variables considered. Also, the investigative approach that we carried out was a selective one and it was done at a single educational unit in Brasov. We have focused our attention on directions related only to the possible correlations that can be established between the values of the body mass index and the level of manifestation of the force, and this the latter only for its forms of manual static force, respectively the explosive force of the lower limbs.

The international significance of the study is given by the diversity of findings on the presence in many other studies based on the same topic. Thus, in addition to the studies that showed a relationship - from the perspective of health - between body mass index and the level of manifestation of strength, and which we mentioned briefly in the introductory part of this study, there are some more reserved opinions about this issue. Thus, Silventoinen et al. (2009) found only an insignificant association between strength and cardiovascular disease in Swedish subjects, and Artero et al. (2012) consider that it is not possible to say exactly whether the level of muscle strength development is associated with long-term cardiovascular disease and independent of cardiorespiratory capacity. Likewise, Gonzalez Valero et al., 2018, p. 396) believe that cardiorespiratory endurance can be a good indicator of the general physical condition of young people, if it is assessed at the population level. On the other hand,

Ortega et al. (2005), in a cross-sectional study of more than 3 000 adolescents, found that cardiorespiratory endurance is closely associated with other components of physical condition, in both young people and adults, and subjects with a high level of cardiorespiratory endurance had, at the same time, a higher level of muscular strength (upper and lower limbs), speed and flexibility. In the context of those mentioned, the originality of our research paper consists in highlighting data with moderate significance in terms of the relationship between body mass index and muscle strength, being very few studies, strictly in this direction.

Accordingly with those presented, we believe that our research topic remains open to new investigations, which try to highlight which of the components of physical condition has a greater weight in optimizing and/or maintaining health or vice versa, these only addressed in a in an integral way, it is a factor to be taken into account for the decrease of the citizens' morbidity.

Last, but not least, in the context of these limitations, we consider that observational studies with a larger sample size, especially longitudinal and prospective studies, are needed to verify the results obtained in this paper.

5. Conclusions

The conclusions drawn from the research are the following:

- Body mass index and age have a statistically significant effect on static strength, but not if we take into account only their biological differentiation.

- There is a significant connection of moderate intensity between the body mass index and the level of development of the manual grip force, as well as between the body mass index and the level of development of the explosive force that manifests in the lower limbs, and in a large proportion, the excess weight subjects (overweight and obese) show lower values of strength, in both tests (*Handgrip strength* and *Standing long jump*), compared to normal weight subjects.

- From a statistical-mathematical point of view, the level of development of muscle strength, a component of physical condition, is dependent on the body mass index, which can be a predictor of health in overweight adolescents.

- The data obtained in our study can help us to establish comparisons with other school populations, as well as to estimate the proportion of students with changes in the level of development of muscle strength, depending on the excess weight measured at some point.

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Article

Physical Activity, Body Mass Index, and Bullying in Higher Education: A Comparative Analysis of Students with and Without Structured Sports Training

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Abstract

Background/Objectives: Organized physical activity is frequently considered a protective factor against bullying behaviors, yet evidence within the university context remains limited. This study investigates the relationships between physical activity levels, body mass index (BMI), and involvement in traditional and digital bullying, taking into account the differences between students with and without structured sports training. **Methods:** A total of 2767 first-year students from Transylvania University of Braşov participated. The sports group (n = 161; 65 females, 96 males) was compared to the non-sports group (n = 2606; 1472 females, 1134 males). Instruments included the Physical Activity Questionnaire for Adolescents (PAQ-A), validated scales for traditional and cyberbullying and victimization, and BMI calculation. Statistical analyses involved *t*-tests (two-tailed), 2 × 2 factorial ANOVA, and sex-stratified multiple linear regressions. **Results:** Students with sports training reported higher physical activity (PAQ-A 4.2–4.6), lower BMI, and lower bullying involvement (traditional ≈ 14–21% vs. ≈32%; cyber ≈ 8–17% vs. ≈25%). Group differences were large for physical activity (Hedges' *g* ≈ 1.5) and moderate for BMI and bullying (*g* ≈ 0.68–0.96; point-biserial *r*² ≈ 3–4%). ANOVA showed sports status main effects (partial η_p^2 ≈ 4–5% for bullying/BMI; ≈20% for PAQ-A). In regressions, sports status (*B* = −0.30 to −0.44) and physical activity (*B* = −0.22 to −0.32) predicted lower aggression/victimization, whereas BMI showed positive associations (*B* = 0.11 to 0.18) (all *p* < 0.001). Sex × sports interactions were significant for PAQ-A and for traditional and cyber-victimization. **Conclusions:** Structured physical activity contributes to reducing the risk of bullying involvement and supports better psychosocial adjustment among students. These findings underscore the educational and preventive potential of university sports programs.

Keywords: organized physical activity; bullying; cyberbullying; body mass index; university students; aggression; victimization; psychosocial adjustment



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1. Introduction

Bullying, defined as intentional, aggressive, and repetitive behavior occurring in a context of power imbalance [1,2], continues to represent a major psychosocial health issue among adolescents and young adults. According to the international *Health Behavior in School-aged Children* (HBSC) report, approximately 20% of European students aged 11 to 15 report bullying experiences, including digital forms of aggression [3].

Although these data primarily target pre-university populations, more recent literature highlights a concerning expansion of victimization behaviors within higher education settings, where academic pressures, identity insecurities, and unlimited access to digital platforms often converge [4,5].

In university contexts, bullying may take various forms, from subtle social exclusion to direct intimidation or systematic harassment, sometimes exacerbated by the absence of clear institutional prevention policies or by imbalanced relational dynamics [6,7]. Both peer-to-peer and student–faculty relationships may serve as sites of victimization, and both quantitative and qualitative studies indicate that the phenomenon remains underreported and insufficiently documented in higher education [4,6].

An increasing number of studies support the idea that systematic physical activity may serve as a protective factor against various forms of bullying, including those occurring in digital environments. A recent meta-review of 29 studies found that regular participation in individual or team sports reduces the risk of bullying and cyberbullying, particularly by enhancing self-esteem, social skills, and emotional self-regulation [8]. Another research shows that students who are consistently engaged in sports activities report lower levels of bullying and better psychosocial adjustment, along with more positive perceptions of the educational climate [9]. Organized sport is also recognized as a setting for cultivating prosocial values (such as cooperation, empathy, rule-following, and fair play) that positively influence group behavior [10]. However, some studies provide a critical perspective, warning about the dual potential of sport environments (particularly in team sports or those with strict competitive hierarchies), where subtle forms of exclusion, humiliation, or even “normalized bullying” may occur [11–13].

Another key determinant in understanding victimization is body weight status. Research indicates that adolescents and young adults with elevated body mass index (BMI) are more frequently exposed to both traditional and online bullying [14,15]. Weight stigma can lead to negative social labeling, marginalization, and humiliation, especially on social media platforms, where appearance-related pressures are intensified. Moreover, a negative perception of one’s own body image (even in the absence of clinical obesity) may heighten psychosocial vulnerability [16]. In this context, physical activity becomes relevant not only for physical health but also as a mechanism for identity reconstruction and social inclusion. The so-called “fat-but-fit paradox” describes individuals with high BMI but good physical fitness who show greater resilience to victimization [17]. This protective effect may operate through enhanced self-confidence and social integration developed through physical competence. Evidence suggests that physical strength, endurance, and motor skills contribute to a reduced incidence of bullying, particularly among boys [18].

This study proposes an integrative approach theoretically grounded in Bronfenbrenner’s ecological model of human development, which enables the analysis of multiple interacting factors—individual (e.g., body image and health behaviors), relational (peer interactions), and institutional (academic norms and educational policies)—that influence victimization experiences [19]. It also draws on social capital theory to highlight how sports participation supports the development of prosocial relationships, group cohesion, and empathy [20]. From a psychosocial perspective, negative body image and dissatisfaction with one’s appearance function as vulnerability factors in the face of social stress and exclusionary behaviors. Recent studies report significant associations between body dissatisfaction, quality of life, and psychological distress, reinforcing the role of physical activity not only as a health intervention but also as a protective mechanism against stigma and victimization in university settings [21].

In Romania, research on these issues among university students remains scarce. The specific context of Transylvania University of Braşov, where all faculties include physical

education in their curricula, yet only one offers intensive professional training in sports, creates an opportunity for a comparative analysis between students with and without sports backgrounds, focusing on bullying risk, weight status, and related psychosocial resources. This institutional context provides a unique natural experiment for examining the protective effects of structured physical activity within Romanian higher education.

Based on this institutional context and gaps in the current literature, the present study hypothesized the following:

- (1) Students with structured sports training would demonstrate significantly lower involvement in both traditional bullying and cyberbullying than students without such training;
- (2) Higher BMI would be positively associated with victimization and aggression;
- (3) Greater physical activity would function as a psychosocial protective factor against involvement in bullying and cyberbullying.

Within this complex framework, the present research seeks to contribute to the emerging literature on relational health and social inclusion in higher education. Through a comparative analysis of students with and without sports training, the study explores the relationships between physical activity, weight status, and bullying experiences (both traditional and digital) while offering an integrated perspective on the psychosocial protective mechanisms fostered by sport.

2. Materials and Methods

2.1. Study Design

This study employed a cross-sectional and comparative design, aimed at exploring the relationships between systematic engagement in sports activities, body status (measured through body mass index—BMI), and the phenomenon of bullying (including cyberbullying) among first-year students at Transylvania University of Braşov. The cross-sectional design allowed for the simultaneous analysis of these variables at a fixed point in time without any external interventions, thus providing a relevant picture of the correlations among them [22].

The study was structured as a comparison between two clearly defined groups: (1) students enrolled in an intensive professional training program in the field of sports and (2) students from other faculties with no specific physical education training. This approach allowed for the identification of potential differences in exposure to bullying, body status, and levels of physical activity, as well as the prosocial values developed through sport [23].

Data collection occurred during a strategic period—January 2024, near the end of the first academic semester—when students are already partially adapted to university life but still socially and emotionally vulnerable. The literature suggests that the first-semester transition is associated with increased sensitivity to social influences and a fragile sense of belonging, especially among students from underrepresented groups, which may impact their engagement and well-being [24].

2.2. Participants

The sample included first-year students from all 18 faculties of Transylvania University of Braşov. The primary group of interest consisted of students from the Faculty of Physical Education and Mountain Sports, enrolled in three undergraduate programs: Physical Education and Sport (EFS), Sports and Motor Performance (SPM), and Kinesiotherapy and Special Motricity (KMS). These programs involve intensive and diverse training in physical and sports-related activities. Students are prepared for careers such as physical education teachers, coaches, and kinesiotherapists, and the curriculum includes a broad range of applied disciplines: team sports, gymnastics, athletics, winter sports, combat sports, water sports, and others.

This classification yielded two groups based on exposure to structured physical activity: an athlete group (EFS/SPM/KMS) and a non-athlete group, drawn from the remaining 17 faculties, covering profiles such as engineering and technology (mechanical, materials, civil, product design and environment, furniture design and wood engineering, and technological engineering and industrial management), computer science and mathematics, law, economics and business administration, and social sciences (psychology and education sciences, and sociology and communication), humanities and arts (letters and music), medicine, food and tourism, and silviculture and forest engineering (see the full faculty list in the Supplementary Materials), with no advanced sport-related curricular components, who otherwise attended the mandatory physical education course.

Most students in the athlete group had a strong background in organized sport (sports clubs, specialized high schools, and official competitions), estimated at 8–10 years for those in EFS and SPM and 4–6 years for those in KMS. This previous experience is considered a significant predictor of motivational involvement and the development of prosocial values through sport [25]. On average, students in the athlete group participated in approximately 10 h of practical activities per week (EFS—11 h, SPM—12 h, and KMS—7 h). Of these, around 35% were also engaged in competitive sports, training an additional minimum of 8 h per week in sports clubs. The university has applied an institutional exemption policy allowing justified absences of up to 25% or 50%, depending on the competition level. Despite this, the overall attendance rate for this group was estimated at 87%. Applying this percentage to the 185 enrolled students, 161 sports students effectively participated in the study and were included in the final analysis.

In contrast, students from the other 17 faculties, although enrolled in the mandatory physical education course during the first semester, did not benefit from systematic sports training. Their physical activity was generally limited to one hour per week, and their academic programs did not include components dedicated to sport-based development. During the administration of questionnaires and anthropometric measurements, 2606 of the 3890 eligible non-athlete students (approximately 67%) were included in the analysis. This inclusion rate reflected actual class attendance during the evaluation period, as well as the exclusion of students who declared long-term organized and systematic sports participation (at least three training sessions per week for at least four years). This methodological decision aimed to prevent contamination of the comparison group [26].

Inclusion criteria were as follows: enrollment as a first-year student in 2023–2024; participation in physical education classes or sport training during January 2024; written informed consent; and completion of all questionnaires. Exclusion criteria were as follows: long-term organized sport among non-sports students; incomplete questionnaires; refusal or missing consent; and cases without valid height/weight for BMI. These criteria enhanced internal validity by reducing uncontrolled variance and increasing group homogeneity [27,28].

2.3. Procedure and Data Collection Instruments

Data were collected between 8 and 19 January 2024 during physical education classes. Two printed questionnaires—one on physical activity and one on bullying/cyberbullying experiences—were administered in group settings under the supervision of faculty members. The administration atmosphere was informal yet well structured, encouraging honest responses and accurate completion. Administering instruments in familiar environments, such as regular class sessions, is a validated method for improving response rates and data quality [27].

To maximize contextual specificity, participants were instructed to report only experiences involving social interactions with fellow university students (excluding family, work, and non-university peers) when answering bullying/cyberbullying items. This

limitation was clearly formulated and communicated verbally during administration to all participating groups.

Anthropometric measurements (BMI and height) were obtained under standardized procedural conditions and in parallel with questionnaire administration using a Tanita MC-780 MA bioimpedance analyzer (clinically validated for body composition, TANITA CORPORATION, Tokyo, Japan) and a portable stadiometer (ADE MZ10042, ADE Germany GmbH, Hamburg, Germany). Measurements were performed during each group's scheduled physical education class across the 18 faculties; therefore, time of day and pre-measurement nutritional status (food and fluid intake) were not standardized. To minimize variability, participants were informed in advance to wear light indoor clothing; shoes were removed prior to height measurement; and for weight, participants remained in light indoor clothing without heavy outerwear or accessories. Devices were calibrated before each session, and a fixed measurement sequence was applied by trained staff. Each participant was assigned a unique numeric code based on faculty and gender, which was used uniformly across all instruments (physical activity, bullying, and BMI). This coding system enabled the correlation of individual responses without compromising anonymity and supported comparative and predictive analysis. For methodological transparency, all applied instruments—the questionnaires, the BMI registration form, and the data coding guide—are fully provided in the Supplementary Materials attached to this article.

Three main instruments were used, adapted for the university population:

1. Physical Activity Questionnaire (adapted from PAQ-A)

The first instrument used in this study was the *Physical Activity Questionnaire for Adolescents (PAQ-A)*, which is widely employed to assess the general level of physical activity among adolescents [29]. The version applied in the current study retained the standard structure of the scale, including eight items used to compute the composite score and one additional control item aimed at identifying atypical weeks (e.g., illness and injury), which does not affect the final score. Items were structurally and semantically adapted to the Romanian university context to refer to curricular physical education, voluntary activities in university sport facilities (training, gym, and recreational sport), and on-campus physical movement during breaks or leisure.

The reference period was extended to cover 2 October 2023–19 January 2024, including holiday breaks, in order to capture physical behavior representative of the entire university semester. Responses used a 5-point Likert scale (1 = very low; 5 = very high); the composite PAQ-A score was calculated as the mean of the eight scored items, explicitly excluding the control item. In addition, a supplementary control question was introduced concerning the regular practice of organized sports (at least 3 times per week) within a sports club in previous years. This question served purely informational purposes, aiming to identify respondents with an advanced athletic profile, and was excluded from the general score calculation. Furthermore, these respondents were excluded from the comparative analyses between faculties in cases where the target groups did not include formal sports training. The internal consistency of the adapted scale was tested on a pilot sample ($n = 92$), resulting in a Cronbach's alpha coefficient of 0.82, indicating good reliability.

2. Bullying and Cyberbullying Behavior Questionnaire

The second instrument was an extended version of the Illinois Bully Scale, developed by Espelage and Holt [30], previously applied in Romanian educational settings [31]. The adaptation for university settings involved both restructuring and rewording of existing items and the development of two additional subscales targeting cyberbullying phenomena, in accordance with the specific characteristics of digital communication among students.

The final questionnaire included four distinct dimensions: traditional victimization (5 items), traditional aggression (5 items), cyber-victimization (5 items), and cyber-aggression (5 items). Items used a 5-point Likert scale (1 = never; 5 = very often), matching the PAQ-A reference period.

Content validation involved review by 3 experts in digital communication and pilot testing with 92 students to ensure clarity and relevance [27,32]. The full scale showed high reliability ($\alpha = 0.84$), with subscales $\alpha = 0.78$ – 0.83 .

3. Anthropometric Measurements for BMI

To assess body status, BMI and height were measured using the Tanita MC-780 MA analyzer and a professional medical stadiometer (ADE MZ10042, ADE Germany GmbH, Hamburg, Germany). BMI classification followed the World Health Organization (WHO) criteria: underweight (<18.5), normal weight (18.5–24.9), overweight (25–29.9), and obese (>30) [33].

2.4. Ethical Considerations

All participants were informed in advance about the purpose, content, and confidentiality of the study. Participation was voluntary, and written informed consent was obtained in written form, in accordance with the Declaration of Helsinki regarding ethical principles for research involving human subjects [34].

To protect participants' identities, data were collected anonymously using numeric codes with no personal identifiers. All information was processed exclusively for scientific purposes, in compliance with national and European data protection laws (GDPR 2016/679).

The project received ethical approval from the Ethics Committee of the Faculty of Physical Education and Mountain Sports at Transylvania University of Brasov under approval number 276 on 27 September 2023.

2.5. Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics, version 26. Descriptive statistics (means, standard deviations, frequencies, and percentages) were calculated to characterize the sample and main variables.

To compare scores between athlete and non-athlete groups, independent samples *t*-tests (two-tailed) were used [35]. Effect sizes were reported as Hedges' *g* (suitable for unequal group sizes), interpreted using conventional thresholds (~ 0.20 small, ~ 0.50 medium, and ≥ 0.80 large). Multiple comparison control employed Bonferroni within each test family: (i) athletes vs. non-athletes across 6 outcomes \times 2 sexes ($\alpha_{\text{adj}} \approx 0.0042$) and (ii) BMI sub-analyses comparing the three athlete programs vs. non-athletes within sex ($\alpha_{\text{adj}} \approx 0.0167$). As an explained variance index for the group contrast, we also report point-biserial r^2 , computed as $r^2 = t^2 / (t^2 + df)$. The combined effect of sex and sports status was tested via a 2×2 factorial ANOVA (between subjects). In addition to *F* and *p*, we report partial eta-squared (η_p^2) as the explained variance index for each main effect and the sex \times sports interaction using $\eta_p^2 = (F \times df_1) / (F \times df_1 + df_2)$, where $df_1 = 1$, with df_2 specific to each analysis.

Associations between sports status (athletes vs. non-athletes) and categorical involvement in traditional/cyberbullying were examined with chi-square (χ^2) tests, separately by sex. In addition to continuous scale scores and the binary involvement cut-off ("never/rarely" vs. "sometimes/often/very often"), we derived a four-category involvement variable applied identically in traditional and cyber domains: not involved, victim only, aggressor only, and victim–aggressor.

For the non-athlete group, descriptive profiles were additionally summarized using faculty-level aggregated means and standard deviations (across 17 faculties); all inferential tests (*t*-tests/ANOVA/regressions) were conducted on individual-level data [EDITED]. To evaluate the predictive impact of physical activity, BMI, and sports status, we ran multiple linear regressions with separate models for each dependent variable [36]. Reporting at the predictor level prioritized unstandardized coefficients (B) and two-tailed *p*-values. Regarding explained variance, we used effect-level indices aligned with the design: point-biserial r^2 for athlete vs. non-athlete contrasts in the *t*-tests and partial η_p^2 for the 2×2 ANOVA (reported for each main effect (sex and sports) and their interaction (sex \times sports)).

The internal reliability of instruments was assessed using Cronbach's alpha, with values ≥ 0.70 considered acceptable [37]. The threshold for statistical significance was set at $p < 0.05$, while values below $p < 0.001$ were interpreted as highly statistically significant.

3. Results

3.1. Demographic Characteristics of the Sample

After the rigorous application of inclusion and exclusion criteria, the final analysis was conducted on a sample of 2767 first-year students from all 18 faculties of Transylvania University of Braşov. Participants were divided into two distinct groups:

- Athlete group: A total of 161 students, representing 87% of the 185 students enrolled in one of the three bachelor's programs at the Faculty of Physical Education and Mountain Sports: Physical Education and Sport (EFS), Sports and Motor Performance (SPM), and Kinesiotherapy and Special Motricity (KMS).
- Non-athlete group: A total of 2606 students selected from the remaining 17 faculties, representing approximately 67% of the eligible population. Students who practiced organized sports systematically or were absent at the time of data collection were excluded.

This division reflects the distinction between students with systematic training in sport-related academic programs and those enrolled in other specializations without professional sports training. The distribution by sex and average age is summarized in Table 1.

Table 1. Demographic distribution of participants by sex and average age.

Group	Sex	No. of Participants	Average Age (Years)
Athletes	Female	65	20.1
	Male	96	20.2
Non-athletes	Female	1472	20.0
	Male	1134	20.2
Total	-	2767	-

Note: Non-athletes = students from the 17 non-sports faculties without organized sports training.

3.2. Physical Activity—Adapted PAQ-A Score

The level of physical activity was assessed using the composite score derived from the adapted version of the PAQ-A questionnaire, as described in Section 2.3. The total score was computed as the mean of the validated items, excluding the illness-related control item.

Statistical analysis revealed significant differences between the two groups—students enrolled in sports-related programs (EFS, SPM, and KMS) and those in non-sports faculties (F1–F17)—as well as internal variations by sex and program of study. The results are presented in Table 2.

Table 2. Mean PAQ-A scores (\pm SD) by study program and sex.

Program/Group	Sex	No. of Participants	PAQ-A Score (Mean \pm SD)
EFS	Female	23	4.2 \pm 0.5 *
	Male	43	4.4 \pm 0.6 *
SPM	Female	13	4.3 \pm 0.4 *
	Male	41	4.6 \pm 0.5 *
KMS	Female	29	3.9 \pm 0.6 *
	Male	36	4.0 \pm 0.7 *
Non-athletes (F1–F17)	Female	1472	2.2 \pm 0.8
	Male	1134	2.0 \pm 0.9

Note: Non-athletes = students from the 17 non-sports faculties. PAQ-A scores range from 1 (very low activity) to 5 (very high activity). Indicative qualitative thresholds: 1.00–1.99 = very low, 2.00–2.99 = low, 3.00–3.99 = moderate, 4.00–4.49 = high, and 4.50–5.00 = very high. For reference, a mean score of 2.87 was proposed as a cut-off for meeting recommended activity levels [38]. * Significantly different from the non-athlete group of the same sex (independent samples *t*-tests, Bonferroni-adjusted within sex across the three athlete programs vs. non-athletes; $\alpha_{adj} \approx 0.0167$; all adjusted $p < 0.001$).

3.3. Body Mass Index (BMI)

To complete the somatic profile of the participants and investigate the relationships between body status and the psychosocial variables analyzed, body mass index (BMI) was evaluated. Descriptive results by program and sex are presented in Table 3.

Table 3. BMI distribution by study program and sex.

Program/Group	Sex	No. of Participants (n)	Mean BMI (\pm SD)	Underweight (n/%)	Normal Weight (n/%)	Overweight (n/%)	Obese (n/%)
EFS	Female	23	22.1 \pm 2.1 *	1/4.35	20/86.96	2/8.70	0/0.00
	Male	43	22.5 \pm 2.2 *	1/2.33	36/83.72	6/13.95	0/0.00
SPM	Female	13	21.8 \pm 2.0 *	0/0.00	12/92.31	1/7.69	0/0.00
	Male	41	22.1 \pm 2.3 *	1/2.44	35/85.37	4/9.76	1/2.44
KMS	Female	29	23.3 \pm 2.7 *	1/3.45	22/75.86	5/17.24	1/3.45
	Male	36	23.7 \pm 2.9 *	1/2.78	26/72.22	8/22.22	1/2.78
Non-athletes	Female	1472	24.3 \pm 3.4	132/8.97	913/62.01	339/23.02	88/5.98
	Male	1134	24.5 \pm 3.7	91/8.03	680/59.96	272/23.99	91/8.03

Note: BMI classification is based on WHO standards (2000) [33]: <18.5 = underweight, 18.5–24.9 = normal weight, 25.0–29.9 = overweight, and ≥ 30 = obese. Values are presented as count and percentage. “n/%” denotes the count and the percentage within each program \times sex subgroup; percentages are computed from the measured BMI using WHO cut-offs. “*” indicates mean BMI significantly different from the non-athlete group of the same sex (independent samples *t*-tests, Bonferroni-adjusted within sex for three comparisons; $\alpha_{adj} \approx 0.0167$; all adjusted $p < 0.001$).

3.4. Bullying and Cyberbullying—Estimating Direct Involvement

To assess the frequency of aggressive and victimization behaviors among students, four distinct dimensions were analyzed: traditional victimization, traditional aggression, cyber-victimization, and cyber-aggression. Proportions by program and sex are reported in Table 4 (traditional bullying) and Table 5 (cyberbullying). Associations between sports status (athletes vs. non-athletes) and involvement categories were examined using chi-square tests separately by sex:

- Traditional bullying: females, χ^2 (3, N = 1537) = 5.36, $p = 0.147$; males, χ^2 (3, N = 1254) = 13.52, $p = 0.004$;
- Cyberbullying: females, χ^2 (3, N = 1537) = 6.92, $p = 0.074$; males, χ^2 (3, N = 1254) = 10.73, $p = 0.013$

Data on cyberbullying (Table 5) showed lower overall levels compared to traditional bullying but with a similar distribution pattern. The lowest involvement was observed

in the SPM and EFS groups (below 10%) and the highest among non-athletes (25% for both sexes).

Table 4. Estimated involvement in traditional bullying.

Group	Sex	No. of Participants (n)	Not Involved n/%	Victim Only n/%	Aggressor Only n/%	Victim + Aggressor n/%	Total Involved n/%
EFS	Female	23	19/82.61	2/8.70	1/4.35	1/4.35	4/17.39
	Male	43	37/86.05	3/6.98	2/4.65	1/2.33	6/13.95
SPM	Female	13	11/84.62	1/7.69	1/7.69	0/0.00	2/15.38
	Male	41	35/85.37	3/7.32	2/4.88	1/2.44	6/14.63
KMS	Female	29	23/79.31	3/10.34	2/6.90	1/3.45	6/20.69
	Male	36	29/80.56	4/11.11	2/5.56	1/2.78	7/19.44
Non-athletes	Female	1472	1001/68.00	236/16.03	141/9.58	94/6.39	471/32.00
	Male	1134	771/67.99	181/15.96	109/9.61	73/6.44	363/32.01

Note: Percentages are within each program × sex subgroup. “Total involved” = victim only + aggressor only + victim + aggressor. Estimates are based on Illinois Bully Scale item frequencies using identical classification criteria for all participants.

Table 5. Estimated involvement in cyberbullying.

Group	Sex	No. of Participants (n)	Not Involved n/%	Victim Only n/%	Aggressor Only n/%	Victim + Aggressor n/%	Total Involved n/%
EFS	Female	23	21/91.30	1/4.35	1/4.35	0/0.00	2/8.70
	Male	43	39/90.70	2/4.65	1/2.33	1/2.33	4/9.30
SPM	Female	13	12/92.31	1/7.69	0/0.00	0/0.00	1/7.69
	Male	41	37/90.24	2/4.88	1/2.44	1/2.44	4/9.76
KMS	Female	29	25/86.21	2/6.90	1/3.45	1/3.45	4/13.79
	Male	36	30/83.33	3/8.33	2/5.56	1/2.78	6/16.67
Non-athletes	Female	1472	1104/75.00	184/12.50	110/7.47	74/5.03	368/25.00
	Male	1134	850/74.96	142/12.52	85/7.50	57/5.03	284/25.04

Note: Percentages are within each program × sex subgroup. “Total involved” = victim only + aggressor only + victim + aggressor. Estimates are based on Illinois Bully Scale item frequencies using identical classification criteria for all participants.

3.5. Comparative Analyses: Independent Samples *t*-Tests

To assess significant differences between athletes and non-athletes across the six analyzed variables—physical activity, body mass index (BMI), victimization, aggression, cyber-victimization, and cyber-aggression—independent samples *t*-tests were conducted separately by sex. Results are summarized in Table 6, including effect sizes (Hedges’ *g*). In addition, we report explained variance indices for the athlete group contrast within sex, computed as point-biserial $r^2 = t^2 / (t^2 + df)$.

All comparisons were statistically significant ($p < 0.001$). Effect sizes were large for physical activity ($g \approx 1.52$ – 1.58) and in the moderate range for BMI and bullying outcomes ($g \approx 0.68$ – 0.96). Corresponding explained variance values were $r^2 \approx 0.026$ – 0.042 for bullying/cyber outcomes, $r^2 \approx 0.03$ – 0.034 for BMI, and $r^2 \approx 0.094$ – 0.148 for physical activity.

Table 6. Results of independent samples *t*-tests (athletes vs. non-athletes). Sex-specific comparisons for physical activity, BMI, and forms of bullying.

Variable	Sex	Comparison Group	<i>t</i>	df	<i>p</i>	Hedges' <i>g</i>	<i>r</i> ² (Explained Variance)	<i>r</i> ² (%)
Physical activity	Female	Athletes vs. non-athletes	−12.45	1493	<0.001	1.58	0.094	9.41
	Male	Athletes vs. non-athletes	−14.28	1172	<0.001	1.52	0.148	14.82
BMI	Female	Athletes vs. non-athletes	−6.78	1493	<0.001	0.86	0.0299	2.99
	Male	Athletes vs. non-athletes	−6.43	1172	<0.001	0.68	0.0341	3.41
Victimization	Female	Athletes vs. non-athletes	−7.54	1493	<0.001	0.96	0.0367	3.67
	Male	Athletes vs. non-athletes	−7.19	1172	<0.001	0.76	0.0422	4.22
Aggression	Female	Athletes vs. non-athletes	−6.33	1493	<0.001	0.80	0.0261	2.61
	Male	Athletes vs. non-athletes	−6.75	1172	<0.001	0.72	0.0374	3.74
Cyber-victimization	Female	Athletes vs. non-athletes	−7.01	1493	<0.001	0.89	0.0319	3.19
	Male	Athletes vs. non-athletes	−6.88	1172	<0.001	0.73	0.0388	3.88
Cyber-aggression	Female	Athletes vs. non-athletes	−6.47	1493	<0.001	0.82	0.0273	2.73
	Male	Athletes vs. non-athletes	−6.66	1172	<0.001	0.71	0.0365	3.65

Note: Analyses are based on mean scores from Illinois Bully Scale items (no binary classification). Effect sizes are reported as Hedges' *g*. Multiple-comparison control used Bonferroni across the family of 12 tests (six outcomes × two sexes; $\alpha_{adj} \approx 0.0042$; two-tailed). Group sizes: females—athletes *n* = 65, non-athletes *n* = 1430; males—athletes *n* = 96, non-athletes *n* = 1078. Explained variance is reported as point-biserial *r*² (see Section 2.5).

3.6. Multivariate Analyses: Main Effects, Interactions, and Predictive Models

To gain a deeper understanding of the relationships between physical activity, body weight status, and bullying-related behaviors, complementary inferential statistical analyses were applied: a 2 × 2 factorial analysis of variance (ANOVA) and multiple linear regression, each offering a distinct and convergent perspective on the phenomenon.

3.6.1. Main Effects and Interactions—2 × 2 ANOVA

The ANOVA examined the main effects of gender (female/male) and sports status (athlete vs. non-athlete), as well as their interaction (gender × sports status), in relation to six dependent variables: physical activity (PAQ-A), body mass index (BMI), traditional victimization, traditional aggression, cyber-victimization, and cyber-aggression. Results are summarized in Table 7, reporting *F* statistics and *p*-values for main effects and the sex × sports status interaction. In addition, we report partial η^2 as explained variance indices for each effect.

Table 7. Results of 2 × 2 ANOVA.

Analyzed Variable	Comparison	<i>F</i>	<i>p</i>	Significant Difference?	Partial η^2	η^2 (%)
Physical activity (PAQ)	Female vs. male	20.56	<0.001	Yes	0.0074	0.74
	Athletes vs. non-athletes	682.43	<0.001	Yes	0.1981	19.81
	Interaction: sports × gender	4.21	0.041	Yes	0.0015	0.15
BMI	Female vs. male	10.22	0.001	Yes	0.0037	0.37
	Athletes vs. non-athletes	88.31	<0.001	Yes	0.0310	3.10
	Interaction: sports × gender	1.17	0.280	No	0.0004	0.04
Traditional victimization	Female vs. male	15.31	<0.001	Yes	0.0055	0.55
	Athletes vs. non-athletes	132.56	<0.001	Yes	0.0458	4.58
	Interaction: sports × gender	5.07	0.024	Yes	0.0018	0.18
Traditional aggression	Female vs. male	11.04	0.001	Yes	0.0040	0.40
	Athletes vs. non-athletes	104.25	<0.001	Yes	0.0364	3.64
	Interaction: sports × gender	2.98	0.084	No	0.0011	0.11

Table 7. Cont.

Analyzed Variable	Comparison	F	p	Significant Difference?	Partial η^2	η^2 (%)
Cyber-victimization	Female vs. male	18.65	<0.001	Yes	0.0067	0.67
	Athletes vs. non-athletes	120.12	<0.001	Yes	0.0417	4.17
	Interaction: sports \times gender	6.41	0.011	Yes	0.0023	0.23
Cyber-aggression	Female vs. male	13.55	<0.001	Yes	0.0049	0.49
	Athletes vs. non-athletes	116.89	<0.001	Yes	0.0406	4.06
	Interaction: sports \times gender	3.46	0.063	No	0.0013	0.13

Note: Analyses include PAQ-A total scores, BMI (kg/m²), and mean scores from the Illinois Bully Scale subscales. Partial η^2 was computed as $\eta^2 = (F \times df_1) / (F \times df_1 + df_2)$, with $df_1 = 1$ and df_2 specific to each analysis; F, p, and η^2 are reported for the sex, sports, and sex \times sports status effects. Sex \times sports status interactions were significant for three variables (PAQ-A, traditional victimization, and cyber-victimization) and non-significant for BMI, traditional aggression, and cyber-aggression.

3.6.2. Predictive Models—Multiple Linear Regressions

The predictors included physical activity (PAQ-A score), BMI, and membership in the sports group. Regression coefficients are reported as unstandardized B with two-tailed p-values. No binary classification was used for outcomes. Explained variance indices were cross-referenced from prior analyses (Table 6: point-biserial r²; Table 7: partial η^2).

The female models (Table 8a) showed the following:

Table 8. Multiple linear regression—(a) female students; (b) male students.

Dependent Variable	Predictor	Coefficient (B)	p	Summary Interpretation
a. female students				
Victimization	Group (1 = athlete, 0 = non-athlete)	−0.41	<0.001	Female athletes report lower victimization scores than non-athletes Higher physical activity → lower victimization Higher BMI → higher victimization
	PAQ	−0.28	<0.001	
	BMI	0.15	<0.001	
Cyber-victimization	Group	−0.44	<0.001	Female athletes have lower cyber-victimization scores Higher physical activity → lower cyber-victimization Higher BMI → higher cyber-victimization
	PAQ	−0.25	<0.001	
	BMI	0.13	<0.001	
Aggression	Group	−0.33	<0.001	Female athletes report lower aggression scores Higher physical activity → lower aggression Higher BMI → higher aggression
	PAQ	−0.22	<0.001	
	BMI	0.11	<0.001	
Cyber-aggression	Group	−0.38	<0.001	Female athletes report lower cyber-aggression Higher physical activity → lower cyber-aggression Higher BMI → higher cyber-aggression
	PAQ	−0.30	<0.001	
	BMI	0.14	<0.001	
b. male students				
Victimization	Group (1 = athlete, 0 = non-athlete)	−0.38	<0.001	Male athletes report lower victimization scores than non-athletes Higher physical activity → lower victimization Higher BMI → higher victimization
	PAQ	−0.31	<0.001	
	BMI	0.18	<0.001	
Cyber-victimization	Group	−0.40	<0.001	Male athletes have lower cyber-victimization scores Higher physical activity → lower cyber-victimization Higher BMI → higher cyber-victimization
	PAQ	−0.29	<0.001	
	BMI	0.16	<0.001	
Aggression	Group	−0.30	<0.001	Male athletes report lower aggression scores Higher physical activity → lower aggression Higher BMI → higher aggression
	PAQ	−0.25	<0.001	
	BMI	0.14	<0.001	
Cyber-aggression	Group	−0.34	<0.001	Male athletes report lower cyber-aggression Higher physical activity → lower cyber-aggression Higher BMI → higher cyber-aggression
	PAQ	−0.32	<0.001	
	BMI	0.17	<0.001	

Note: Coefficients are unstandardized (B) with two-tailed p-values. Group coding: 0 = non-athlete, 1 = athlete. Negative B indicates an inverse association with the outcome. Outcomes are mean scale scores from the Illinois Bully Scale (no binary classification). Explained variance indices used in the study: point-biserial r² (t-tests) and partial η^2 (ANOVA; see Tables 6 and 7).

- Sports status was a significant negative predictor for all forms of bullying, with the strongest effects on cyber-victimization (B = −0.44) and cyber-aggression (B = −0.38);

- Physical activity had consistent protective effects, especially regarding cyber-aggression ($B = -0.30$);
- BMI was positively associated with all forms of bullying involvement, indicating slightly increased vulnerability in the case of higher body weight status.

Explained variance reference: For the athlete group contrast within females, Table 6 reports r^2 values in the ~2.6–3.7% range across bullying/cyber outcomes and ~9.4% for physical activity, while Table 7 reports partial $\eta^2 \approx 3$ –5% for bullying/cyber and $\approx 19.8\%$ for physical activity. These indices quantify variance attributable to group status in related analyses and are provided here for completeness of “explained variance”.

In the case of male students (Table 8b), the results were similar:

- The negative effects of belonging to the sports group persisted, with a pronounced impact on cyber-victimization ($B = -0.40$) and traditional victimization ($B = -0.38$);
- The PAQ score was negatively associated with all forms of bullying, especially cyber-aggression ($B = -0.32$);
- BMI showed a positive relationship with all four behavioral dimensions, with slightly stronger effects compared to female students.

Explained variance reference: For the sports-group contrast within males, Table 6 reports $r^2 \approx 3.6$ –4.2% for bullying/cyber and $\approx 14.8\%$ for physical activity, while Table 7 indicates partial $\eta^2 \approx 3$ –5% (bullying/cyber) and $\approx 20\%$ (physical activity).

These findings confirm the hypothesis that sport and physical activity play a protective role against involvement in aggressive behaviors. At the same time, certain body characteristics may act as risk factors when social support or group inclusion is lacking.

4. Discussion

This study investigated whether structured physical activity serves as a protective factor against bullying in the university setting and how body weight status and activity levels interact in shaping psychosocial vulnerability. The results confirmed all three hypotheses: students with sports training showed significantly higher physical activity levels, lower BMI, and lower involvement in both traditional and cyberbullying. These differences were most pronounced for physical activity (large effect), moderate for BMI, and consistent for all bullying dimensions. Moreover, a protective gradient was observed across sport profiles: students in high-intensity training programs (SPM and EFS) reported the lowest bullying rates, followed by KMS, while the non-athlete group showed the highest involvement across all four bullying dimensions. These findings support the relevance of organized sport as a developmental context while also highlighting that inactivity and unfavorable body profiles may co-occur with increased social risk. The next section contextualizes these findings within the demographic and institutional characteristics of the sample.

4.1. Methodological Framing and Sample Context

Before discussing the three thematic axes of this study (physical activity, BMI, and bullying), it is necessary to contextualize the methodological framework and sample composition, which provide the foundation for interpreting the results.

The sample used in this study is robust and well defined, consisting of 2767 first-year students from all 18 faculties of Transylvania University of Braşov. This institutional diversity ensures comprehensive coverage of academic profiles and enhances the internal validity of intergroup comparisons. The analyzed groups—athletes and non-athletes—were formed based on explicit and rigorous criteria, excluding participants who engaged in long-term organized sports outside specialized curricula. This reduced the risk of contaminating the independent variable “sports status” and ensured meaningful contrasts. Such operational clarification is essential for maintaining internal validity in comparative group

designs [23,39]. Additionally, the balanced gender distribution and the close proximity of average ages (20–20.2 years in both groups) suggest a high degree of demographic homogeneity, minimizing structural variation. However, from a psychosocial development perspective, this age group falls within the stage defined as “emerging adulthood”—a period marked by unstable social transitions, increased risk behaviors, and specific psychological vulnerabilities with direct implications for relational health [40,41]. Therefore, the age context provides a shared interpretive framework for the analyzed behaviors, particularly in terms of the similar risks faced by students in both groups. Building on this methodological grounding, the next section introduces the first thematic axis: physical activity.

4.2. Physical Activity as a Protective Factor: Interpretative Perspective

The PAQ-A results from our study revealed substantial differences in physical activity levels between students enrolled in sport-related academic programs (EFS, SPM, and KMS) and those from non-sports faculties. Athletes reported average scores ranging from 3.9 to 4.6—falling into the “high” and “very high” categories—while non-athletes scored significantly lower: 2.2 for females and 2.0 for males, both within the “low” activity range. These disparities reflect not only curricular differences but also institutional influences: access to sports infrastructure, integrated training hours, and specialized instruction that supports the internalization of physical activity as a lifestyle element.

International data support this interpretation. For instance, only 5.4% of university students worldwide meet the minimum recommendation of 150 min of moderate-to-vigorous physical activity per week, and less than 0.5% meet the standard of 30 min daily, five days a week [42]. This aligns with our findings for non-athletes, reinforcing the idea that sedentary behavior is the norm in academic settings lacking compensatory sport mechanisms.

Furthermore, the post-pandemic context likely exacerbated these disparities. Spanish studies have shown that physical activity dropped by ~160 min per week during lockdown, while sedentary time increased by over 100 min, especially among students without pre-existing movement habits [43]. In this light, the inactivity seen among our non-athlete participants is not merely individual neglect but a systemic result of curricular gaps, institutional limitations, and the lingering behavioral effects of pandemic restrictions. Thus, insufficient physical activity in non-athletes may signal broader psychosocial risks, such as isolation, marginalization, or emotional disengagement. Literature on youth risk prevention emphasizes this link, positioning physical activity not only as a health behavior but also as a predictor of social adaptation and resilience [44].

These pronounced differences in physical activity have somatic correlates in body composition; accordingly, the next section examines BMI and weight status to situate lifestyle patterns within broader health and psychosocial risks.

4.3. BMI and Body Weight Risks: Somatic and Social Implications

BMI data revealed systematic differences between students in sports training programs (EFS, SPM, and KMS) and those in non-sports faculties. The average BMI in the athletic group was within the optimal range (21.8–23.7), with a favorable weight distribution (72–92% normal weight) and obesity cases being either extremely rare or absent. The best profile appeared in the SPM program, with no obesity and the lowest overweight rates (7.7% females, 9.8% males). However, the KMS program showed a less optimal trend: mean BMI values were close to the upper limit of the normal range (23.3 for females, 23.7 for males), and overweight/obese students accounted for 25% of the group. This deviation may reflect variable physical engagement or a curriculum more focused on recovery than performance—factors known to impact weight control [42]. These differences

must be considered alongside international recommendations emphasizing that youth should engage in at least 60 min of moderate-to-vigorous daily physical activity, adapted to their age and varied in form [45]. The non-athlete group presented a significantly higher BMI (24.3 for females and 24.5 for males), approaching the upper normal threshold [33]. Internal distribution revealed risk exposure: only 60% of males and 62% of females were in the optimal range, while 32% of males and 29% of females were overweight or obese. This confirms prior observations that mean values can obscure problematic internal distributions, particularly when a substantial portion of the group is at metabolic risk [46].

These data support the hypothesis that body status is linked to bullying risk and social exclusion, as shown in multiple studies. Obesity has been associated with increased bullying exposure, low self-esteem, social anxiety, and avoidant behavior [14,47]. A meta-analysis found that overweight adolescents face greater bullying risk (OR = 1.24), with even higher odds for obese youth (OR = 1.46) [48]. Still, not all studies confirm this link. A study of 1680 Turkish students found no significant differences in bullying by weight status. Authors suggested other factors—parental education, academic success, and awareness—might better explain social behavior [49]. Though based on school-aged populations, these insights remain relevant in university settings, especially where institutional support is lacking. Notably, underweight prevalence—2–9% across subgroups—raises similar concerns, which are often overlooked. Underweight status, though less visible, is linked to chronic fatigue, anxiety, isolation, and poor academic adjustment [50]. A recent qualitative study confirmed that both excess and deficient weight trigger social exclusion, harassment, and online bullying. Students strongly expressed a sense of not belonging, often accompanied by emotional distress [51]. Overall, both overweight and underweight profiles can signal poor psychosocial integration, with long-term implications for mental health and academic success. These findings justify the inclusion of anthropometric variables in institutional strategies targeting bullying prevention and student well-being.

Given the stigma and peer dynamics often linked to body status, the next section turns to bullying and cyberbullying patterns to explore how somatic vulnerabilities and social risks intersect in our cohort.

4.4. Bullying and Cyberbullying: Vulnerability Profiles by Sports Status

The analysis of bullying and cyberbullying behaviors revealed significant differences between athletes and non-athletes. The proportion of students reporting victimization, aggression, or both was clearly higher among those not involved in organized sports, with rates exceeding 30%. In contrast, involvement dropped to 13–21% among students in physical training programs, with the lowest figures in subgroups engaged in intensive motor activities. A similar pattern appeared in cyberbullying, where differences were even sharper. Among athletes, digital aggression remained below 17%, while among non-athletes it reached 25%, regardless of gender. These discrepancies suggest a possible protective effect of organized sports participation, particularly for female students. Structurally, involvement patterns differed: non-athletes were more likely to report dual roles (victim–aggressor), a profile linked to elevated psychosocial risks. Among athletes, students tended to be “victims only,” and pure aggressors were rare.

These findings align with literature confirming the protective role of physical activity in reducing aggressive behavior. The meta-analysis by Kowalski et al. synthesized relationships between traditional and online bullying, showing strong associations between digital victimization and outcomes such as stress, suicidal ideation, and social withdrawal [52]. Cyber-aggressors often exhibit violence tolerance and moral disengagement, pointing to distinct behavioral profiles [52]. In the same vein, Twyman et al. found that adolescents involved in cyberbullying display significantly higher levels of psychological distress than

their non-involved peers [53]. Recent research reinforces these findings. Liu et al., in a meta-analysis on physically active youth, reported a negative association between physical activity and the likelihood of being bullied, especially among girls [54]. Similarly, García-Hermoso et al. found a correlation between sedentary behavior and higher victimization risk, suggesting that inactivity may perpetuate social vulnerability [55].

Beyond behavioral outcomes, literature suggests that sports can serve as emotional regulators, particularly in educational settings. Physical activities fostering cooperation, empathy, and self-control contribute to reduced anxiety and stronger coping strategies—factors that may explain lower bullying prevalence among athletes [10,12]. Nonetheless, some studies caution against adverse effects in hypercompetitive contexts. Kalina et al., in a scoping review, identified risk factors such as performance pressure, unsupportive team dynamics, and internal conflicts that may foster covert harassment [56]. Similarly, Benítez-Sillero et al. reported higher aggression rates among boys in contact sports like martial arts or wrestling [57].

Overall, regular physical activity within a balanced, educational framework seems to play a dual role—both preventive and developmental—in shaping social behavior. In our university context, where sports are mainly formative and recreational, this role appears especially relevant for fostering cohesion, self-esteem, and inclusion—protective factors against both traditional and digital bullying.

Taken together, the evidence from physical activity, BMI, and bullying profiles calls for an integrative perspective; Section 4.5 addresses this by statistically testing how the three domains converge in shaping student well-being.

4.5. Physical Activity, BMI, and Bullying Involvement: Statistical Convergences and Practical Implications

Statistical analyses consistently confirmed the conceptual links outlined in Sections 4.2–4.4. Independent samples *t*-tests (with multiple-comparison control) revealed significant athletes vs. non-athletes' differences, with large effects for physical activity and moderate effects for BMI and bullying outcomes. These findings indicate that sports participation differentiates both lifestyle behaviors and psychosocial risk profiles. In line with these results, Bonferroni-adjusted mean contrasts confirmed significant BMI differences between athletes and non-athletes, while chi-square analyses highlighted sex-specific associations between sports status and bullying involvement categories, present among males but not among females. The 2×2 ANOVA converged with these results, confirming strong main effects of sports status and three significant sex \times sports interactions (PAQ-A, traditional victimization, and cyber-victimization), suggesting that some protective effects of sports participation vary by sex. These interactions suggest that protective effects of physical activity are modulated by sex. Multiple regression further reinforced these convergences: non-athlete group membership and higher physical activity were consistently associated with lower aggression and victimization, whereas higher BMI showed small, positive associations with bullying involvement. Taken together, these results support a robust tripartite pattern linking physical activity, body status, and bullying involvement. These convergences align with prior evidence that weight stigma undermines self-esteem and fosters avoidant behaviors [14], while overweight and obesity increase victimization risk [48,49]. In parallel, studies have shown that physical activity supports social and psychological adaptation, with organized sports linked to reduced involvement in both traditional and cyberbullying [8,9,52]. At the same time, nuanced perspectives emphasize that hypercompetitive or non-educational contexts may actually fuel aggression, particularly among boys [58].

Overall, the results support the interpretation that belonging to structured sport environments generates relational capital—cohesion, empathy, and shared goals—that buffers psychosocial risks associated with adverse body status or poor peer integration [19,20].

This integrative statistical perspective validates the tripartite model advanced in this study (physical activity, body weight, and bullying involvement) and closes the analytical loop of the three axes, paving the way for the critical appraisal of limitations from the next section.

4.6. Methodological Limitations and Critical Perspectives

Building on the convergences outlined in Section 4.5, it is important to recognize the methodological constraints that frame the interpretation of these findings. This study has several limitations that should be considered when interpreting the results. First, its cross-sectional design precludes causal inference and only highlights associations. It is also possible that students who engage in regular physical activity already possess personality traits such as extraversion or emotional stability, which may independently reduce bullying risk [59,60]. Second, the effects of physical activity on social and emotional development are context-dependent, influenced by leadership style, group norms, and interaction quality [60]. The lack of differentiation by sport type is another limitation: while contact or highly competitive sports may encourage aggression, team sports in educational settings tend to reduce victimization and foster cooperation [10,61]. Third, the study sample consisted of students from a single university (Transylvania University of Braşov), which limits the generalizability of findings across national or international contexts, where cultural norms and institutional climates vary. International HBSC data illustrate such differences in bullying prevalence and perception [3]. Fourth, reliance on self-report measures may introduce bias for sensitive behaviors such as victimization or aggression. Although validated instruments were used, responses can be affected by social desirability or subjective perception [62]. Anthropometric data were also limited to BMI, a proxy that does not capture body composition, and measurement timing was not standardized. These aspects may have introduced variability and attenuated observed associations.

Taken together, these limitations highlight the need for longitudinal designs, objective monitoring of physical activity, broader somatic measures, and multi-institutional samples. Such approaches would strengthen the robustness of evidence and enhance the practical value of interventions aimed at student health, inclusion, and bullying prevention.

5. Conclusions

This study highlights the protective role of organized physical activity against both traditional and digital bullying among university students. Participation in structured sport programs was consistently linked to lower victimization, aggression, and unbalanced body weight, suggesting benefits that extend beyond physical health toward emotional resilience and social integration.

Statistical convergences confirmed the tripartite model proposed here: higher activity levels predicted lower bullying involvement, whereas elevated BMI was associated with greater vulnerability. Gender effects were present, yet across all subgroups, sports participation attenuated psychosocial risks.

These findings reinforce the value of embedding sport and physical activity into university health and inclusion policies—not only as preventive strategies for physical well-being but also as institutional tools for fostering cohesion, empathy, and safer relational climates.

Future research should move beyond documenting associations to clarify the mechanisms driving these protective effects. Particular attention should be given to gender-specific pathways, institutional culture, and social environments, as well as to the type and intensity of sport practiced. Such directions would explain why and how organized activity mitigates bullying risks, providing stronger grounds for targeted prevention strategies in higher education.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/healthcare13182304/s1>, File S1: Informed Consent and Study Introduction, Physical Activity Questionnaire (Adapted PAQ-A), Bullying and Cyberbullying Questionnaire, Body Mass Index (BMI) Measurement Form, Methodology for Data Coding and Processing, Summary Data Collection Sheet (Blank and Example), and Completion Instructions for Faculty Coordinators.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. Written informed consent has been obtained from the patients to publish this paper.

Data Availability Statement: Data is contained within the article or supplementary material. The original contributions presented in this study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

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Romanian Physical Education Teachers' Perception of Formative Feedback on Their Professional Competencies

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Abstract: *The main purpose was to identify the formative perception of disciplines studied within the bachelor programs in Physical Education and Sports (PES) on the professional competence provided in the qualification sheets of the National Register of Qualifications in Higher Education (NRQHE) for the occupational qualification of Physical Education Teacher in primary and secondary education levels. Ranking the disciplines outlined in the Romanian Agency for Quality Assurance in Higher Education standards for the program in PES based on their impact on professional competencies (PC). 412 teachers: 284 junior teachers group (JTG) and 128 permanent teachers group (PTG). Online was filled out the Questionnaire (QAFISPES) for assessing the ranking of the disciplines provided in the Romanian Agency for Quality Assurance in Higher Education standards on PC in PES, structured on 3 subscales corresponding to the typology of the disciplines: fundamental, PE field, and specialized. For the Fundamental Disciplines subscale, the highest score per rank was recorded by PES Theory and Methodology at 6.66 points; Basic Gymnastics had 5.75 points. For the subscale PE field disciplines, the greatest impact for PC in PES: the Theory and Practice of Athletics 11.25 points, the Theory and Practice of Gymnastics 11.08 points. For the subscale Specialized Disciplines, the most relevant contributions were made by the Methodology of Teaching Athletics in Schools 12.16 points, and the Methodology of Teaching Gymnastics in Schools 11.83 points. Establishing a hierarchy of disciplines based on their formative significance facilitates the optimal allocation of instructional hours within the bachelor's program's Physical Education and Sports (PES) curriculum.*

Keywords: *professional competence; junior teachers; permanent teaching; fundamental disciplines; PE field disciplines; specialized disciplines.*

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Introduction

The development of the teaching career requires the extension of the fund of professional competencies and specific knowledge to optimize the human, social, and, especially, teaching actional potentialities at the current standards of the educational environment (Baumgartner, 2022; Kovalenko et al., 2021; Tul et al., 2019; Souza Neto et al., 2017). The current trends in professional training at the academic level focus on developing and extending specialized professional competencies for teaching careers (Jones-Jofré et al., 2022; Ruiz-Montero et al., 2022). A major concern of the educational system is improving the quality of the teaching act. The teaching activity is directly influenced by the professionalism of the teaching staff and by the national and international level of visibility and recognition of the scientific activity of active teachers. Teachers should permanently focus on continuous and upward professional training and development, which must be directed toward deepening and expanding professional competencies (Ferry, 2018; Molina García et al., 2024a; Molina-García et al., 2024b).

Through its content, specificity, and complexity, the discipline of Physical Education and Sports presents a series of particularities regarding the methods of transferring theoretical knowledge in developing motor skills, which requires the efficient involvement of specialized teachers (Maksimović et al., 2023; Heck et al., 2021). The teaching of Physical Education and Sports is influenced by the level of pedagogical competence and theoretical knowledge of teachers (Salcines Talledo et al., 2024; Nasrulloh et al., 2022). The role of Physical Education and Sports within the context of integrated and unified quality education is clear, focusing on maximizing human potential in response to the demands of modern society and the professionalization of the teaching career (Ivanii, 2014; Feuerman, 2014).

Experts believe that professionalizing the teaching career establishes the foundation for developing a training and lifelong learning system within an integrated European context (Kougioumtzis et al., 2011; Kårhus, 2010). The evolution and dynamics of career and professional development rely on the expansion of specialized skills that facilitate the transition from theory to practice in real educational contexts (Gordon et al., 2015; O'Sullivan, 2018). Research has shown that the professionalization of the teaching career involves a complex and dynamic process through which teachers become aware of their professional roles and responsibilities and maintain a continuous focus on their professional development to meet current educational challenges and requirements (O'Sullivan, 2018; Pozo, 2018; Tatto, 2021).

The efficiency of an educational process depends on the competence level of teachers. This process of developing specialized pedagogical competence (PC) must start from the initial professional training stage, including bachelor's and master's studies, and continue into the early years of teaching (Jones-Jofré et al., 2023; Nasrulloh et al., 2022). Junior teachers need guidance and mentorship from experienced educators, as the future effectiveness of their teaching depends significantly on the quality of this mentoring process (Baumgartner, 2022; Griban et al., 2022; Goodwin, 2021).

Current professional teaching standards emphasize professionalizing the teaching career, deepening and expanding knowledge, and continuously developing the pedagogical competencies specific to Physical Education and Sports teachers (Lohmann et al., 2023; Lohmann et al., 2021; Goodwin, 2021; Abdelkafi et al., 2020). The professional training of teachers is a major educational goal for education systems. Its development and implementation involve several aspects that require optimization, such as increasing the duration of specialized practice during university studies, enhancing the qualifications of mentor teachers, and implementing a permanent and efficient mentoring process aligned with current educational standards and the professional development requirements of teachers (Nasário et al., 2020; Cañadas et al., 2020; Demir, 2015).

Professional competencies (PC) are developed through the disciplines included in the curriculum of the bachelor's program in Physical Education and Sports. These curricula must comply with the standards set by the Romanian Agency for Quality Assurance in Higher Education (RAQAHE) for the respective specialized field (RAQAHE, 2023; Solà Santesmasés, 2021). The National Register of Qualifications in Higher Education (NRQHE) outlines six specific professional competencies (PC) for Physical Education and Sports (PES) (NRQHE, 2024). The design of educational plans requires a direct correlation between these six competencies and the disciplines accredited by RAQAHE.

The program coordinator determines each discipline's course hours, seminars, and practical work allocation. Our study is the first to explore PES teachers' formative perceptions regarding the correlation between professional competencies and the significance of subjects in undergraduate university curricula. The weight distribution among these disciplines should be informed by their formative impact on professional competencies. The effectiveness of the Physical Education and Sports (PES) discipline is influenced by multiple factors, including specific infrastructure and logistics, geographical location, teachers' professional experience, the limited duration of study, and the level of professional training attained after completing

undergraduate studies. Each aspect plays a crucial role in enhancing the efficiency of physical education activities and shaping teachers' perceptions of the PES discipline. This study contributes to the existing body of research by addressing a critical knowledge gap regarding how PES teachers evaluate the competencies acquired across various academic disciplines during their studies.

An examination of the curricula within the Romanian academic system reveals notable disparities in the distribution of course hours, seminars, and practical lessons across various programs. Enhancing the awareness of both novice and experienced teachers regarding their roles and responsibilities is essential for improving the overall effectiveness of the teaching process. Furthermore, identifying the disciplines that exert the most significant formative impact on developing teachers' professional competence profiles will serve as a foundation for optimizing the pedagogical framework in Physical Education and Sports (Duclos Bastías et al., 2023; Kida, 2019; Baghurst, 2015).

Establishing this hierarchy will, we believe, lead to a more balanced and fair allocation of time and content for disciplines in bachelor's programs based on their formative impact on developing professional competencies specific to Physical Education and Sports.

The goals of this study are:

- O1. Identifying the formative perception of the disciplines studied within the bachelor programs in Physical Education and Sports (PES) on the PC provided in the qualification sheets of the National Register of Qualifications in Higher Education (NRQHE) for the occupational qualification of Physical Education Teacher in primary and secondary education levels;
- O2. Ranking the disciplines outlined in the RAQAHE standards for the specialization program in Physical Education and Sports based on their formative perception on professional competencies, to develop a comprehensive profile of professional competence in Physical Education and Sports.

Study hypotheses:

- H01. The disciplines provided in the RAQAHE standards and implicitly in the curricula of the bachelor study programs of Physical Education and Sports contribute differentially to the training of specific PC (PC1-6) provided in the NRQHE qualification sheets in primary and secondary education;

- H02. By evaluating the formative impact of the disciplines included in the curricula for bachelor's study programs and, implicitly, in the RAQAHE standards, we aim to establish an accurate hierarchy of the disciplines based on their importance and typology.

Materials and Methods

Study design

In our cross-sectional research design, a questionnaire was applied. It analyzed a Questionnaire for assessing the formative perception (QAFISPES) of the junior teachers and permanent teachers provided in RAQAHE standards on professional competencies according to NRQHE qualification sheets for the Physical Education and Sports teachers at the secondary education level. The distribution of the questionnaire and the collection of the data were made online. Only fully completed questionnaires were quantified for the present study. This study complied with the principles of the Helsinki Declaration; the study was approved under protocol no. 400/06.12.2023 by Ethical Board of Faculty of Physical Education and Mountain Sports, Transilvania University of Brasov. All authors have contributed equally to this article and have equal contributions with the first author.

Participants

412 teachers participated in the study. They were divided into 2 groups: the junior teacher's group (mentored) (JTG) with 284 beginning teachers (121 females, 163 males; average age 22.4 years) and the permanent teacher's group (mentors)(PTG) with 128 teachers (52 females, 76 males; mean age 42.7 years). Depending on the counties where they teach Physical Education and Sports, the study teachers came from: Brasov - 66 teachers; Constanta - 60 teachers; Galati - 28 teachers; Covasna - 38 teachers; Mures 34 - teachers, Cluj - 63 teachers; Prahova - 13 teachers; Arges - 21 teachers; Iasi - 47 teachers; Bucharest - 44 teachers. Study inclusion criteria for junior teachers' group (JTG) were: age over 21 years; undergraduate studies completed with a bachelor's degree, active teachers teaching in the primary or secondary education system; full completion of the questionnaire. Study inclusion criteria for the group of permanent teachers (PTG) were: age over 30 years; bachelor's and master's studies completed with bachelors and master's degrees, active teachers teaching in the primary or secondary education system; minimum didactic degree II, full completion of the questionnaire. The strategy of cluster sampling was chosen for this study.

Teachers who partially completed the questionnaire were excluded from the study. Initially, several 427 teachers participated in the study, but only 412 (96.5%) teachers were included in the study, the remaining 15 (3.5%) teachers were eliminated because they did not out the questionnaire.

The questionnaire was applied between September 2023 and May 2024. The use of the Google Form Platform to disseminate the questionnaire and collect results was based on the email addresses of the dedicated groups of education teachers per the inclusion criteria. The completion of the questionnaire was restricted so that only one questionnaire was completed from a single email address, excluding repetitive completion.

The assessment tools

In the study, we used the questionnaire-based survey method, and the collected data were statistically processed to highlight relevant aspects. The questionnaire was named Questionnaire for assessing the formative perception of the disciplines provided in RAQAHE standards on professional competencies in Physical Education and Sports (QAFISPES). The questionnaire was designed on the Google Form platform. The questionnaire was carried out ad hoc. QAFISPES included 6 subscales corresponding to the 6 specific professional competencies provided in the NRQHE qualification sheet for the teacher of Physical Education and Sports in secondary education:

Professional competencies (PC):

- PC1 Modular designing and planning of basic contents of the field with interdisciplinary orientation;
- PC2 Organizing of integrated curriculum and instructional and learning environment, with interdisciplinary focus;
- PC3 The evaluation of physical growth and development and motor quality according to PES-specific requirements and the attitude towards independent practice of physical exercises;
- PC4 The description and demonstration of the operational systems specific to Physical Education and Sports (PES), by age groups;
- PC5 The assessment of the training level of the PES practitioners;
- PC6 The use of the specific management and marketing elements in this field.

Questionnaire scores were evaluated for the six subscales related to Physical Education competency. Only the compulsory disciplines included in most bachelor's programs in Physical Education and Sports from profile

faculties in Romania were assessed. The disciplines were structured according to the distribution from the RAQAHE standards into: fundamental disciplines (7); PE field disciplines(12) and specialized disciplines (14). Each subject was evaluated according to the formative perception of PC according to the Likert scale with a score from 1 to 5 where: 1 point – not at all; 2 points - very little; 3 points – a little; 4 points – a lot; 5 points – very much. The ranking of the disciplines - To rank the disciplines, a rank will be granted in descending order depending on the arithmetic average recorded (for example: for fundamental disciplines, which are 7 disciplines, 7 ranks will be provided, where rank 7 will be granted to the subject with the greatest formative perception in the formation of PC of PES teachers and rank 1 will be granted for the least relevant subject in terms of PS). For fundamental disciplines 7 ranks will be granted, for PE field disciplines 12 ranks will be granted and for the specialized disciplines will be granted 14 ranks. The arithmetic mean between the rank evaluations of the two samples included in the study shall be calculated. The final average value will be the final benchmark value for ranking the disciplines according to the formative perception of the development of the professional competencies of the PES teachers.

The Statistical Analysis of Data

We used SPSS 24 software to calculate the following statistical parameters: arithmetic mean (\bar{X}), difference in arithmetic means (ΔX), Cronbach's Alpha for internal consistency; Cronbach's Alpha value of over 0.8 was considered appropriate for the present study. To rigorously assess the validity and reliability of the questionnaire, Cronbach's Alpha was utilized as a metric of internal consistency. The analysis yielded a coefficient exceeding 0.8, signifying a high degree of reliability and demonstrating strong internal coherence among the measured constructs. This result substantiates the robustness of the instrument, ensuring its suitability for accurately capturing and evaluating the targeted dimensions within this study.

Results

The statistical indicator Cronbach's Alpha (α) ranged between 0.940 and 0.986 (Table 1) at all subscales of the Questionnaire for assessing the formative perception of the disciplines studied and included in the RAQAHE standards on professional competencies in PES provided in the NRQHE qualification sheet (QAPCPEST), the internal consistency was very

good. Cronbach's Alpha values reflected that the questionnaire results were statistically validated for both groups of the study (JTG and PTG).

Table 1. Internal consistency of the Questionnaire for assessing the formative perception of disciplines included in RAQAHE standards on specific professional competencies from the NRQHE qualification sheet in PES (QAFISPES).

PES professional competencies	JTG	PTG
	Cronbach's alpha	Cronbach's alpha
PC1 Modular designing and planning of basic contents of the field with an interdisciplinary orientation	.940	.956
PC2 Organising of integrated curriculum and instructional and learning environment, with an interdisciplinary focus	.953	.957
PC3 The evaluation of physical growth and development and motor quality according to PES-specific requirements and the attitude towards independent practice of physical exercises	.959	.969
PC4 The description and demonstration of the operational systems specific to Physical Education and Sports (PES), by age groups	.964	.976
PC5 The assessment of the training level of the PES practitioners	.963	.975
PC6 The use of the specific management and marketing elements in this field	.970	.985

JTG –junior teachers group; PTG –teachers group; PC – professional competence

In Table 2 we highlighted the arithmetic averages (\bar{x}) and the ranks of the main disciplines from RAQAHE standards for all 6 professional competencies specific to the Physical Education and Sports teacher from secondary education. For JTJG, the subject PES Theory and Methodology scored highest for all professional competencies PC1-6, rank 7. For PTG, PES Theory and Methodology has a major formative role for PC1-3. Respectively for PC4-6 the Basic Gymnastics subject was considered the most important (rank 7). The Kinesiology discipline had the lowest score for JTJG; for all PCs, it ranked 1. For PTG, the lowest score was Kinesiology, rank 1 at PC1,2,3,6, and Health Education and First Aid subject at PC4,5.

Table 2. Descriptive statistics - Questionnaire for assessing the formative perception of the main disciplines from RAQAHE standards on professional competencies (PC) in PES

Main disciplines	PC1		PC2		PC3		PC4		PC5		PC6		
	X	R	X	R	X	R	X	R	X	R	X	R	
Kinesiology	JTG	2.74	1	3.06	1	3.13	1	2.97	1	2.95	1	2.94	1
	PTG	2.57	1	2.53	1	2.74	1	2.87	2	2.81	2	2.76	1
Psychopedagogy	JTG	2.94	2	3.65	3	3.33	2	3.20	3	3.15	3	3.12	3
	PTG	3.12	3	3.14	3	2.87	3	2.94	3	2.95	3	2.88	3
PES Theory and Methodology	JTG	4.19	7	3.77	7	3.85	7	3.76	7	3.73	7	3.71	7
	PTG	4.28	7	3.66	7	3.27	7	3.34	5	3.35	6	3.27	7
Health Education and First Aid	JTG	3.30	3	3.46	2	3.18	3	3.05	2	2.99	2	2.98	2
	PTG	3.11	2	2.98	2	2.80	2	2.83	1	2.80	1	2.79	2
General Basics of Athletics	JTG	3.59	4	3.66	4	3.72	4	3.54	5	3.54	4	3.50	4
	PTG	3.95	5	3.36	5	3.35	5	3.37	6	3.34	5	3.19	5
Basic Gymnastics	JTG	4.17	5	3.76	6	3.72	5	3.54	4	3.56	5	3.51	5
	PTG	3.98	6	3.38	6	3.41	6	3.49	7	3.48	7	3.30	6
Scientific Foundations of Sports Games: Basketball, handball, volleyball, football	JTG	4.18	6	3.76	5	3.76	6	3.63	6	3.62	6	3.58	6
	PTG	3.61	4	3.14	4	2.98	4	3.07	4	3.06	4	3.02	4

JTG –junior teachers group; PTG –teachers group; R- rank of disciplines; X- arithmetic mean.

For field disciplines, we found that JTG considered the Theory and Practice of Gymnastics' Branches subject as having the greatest formative perception on PC1, ($x=3.66$; rank 12); and the Theory and Practice of Athletics subject had a major formative perception on PC2-6. The PTG considered that the Theory and Practice of Athletics subject (rank 12) contributed most to the formation of all PC of the PES teachers in secondary education (Table 3). The lowest arithmetic averages, respectively rank 1, were recorded by JTG for: PC1,2,4 in the Theory and practice in combat sports subject, respectively in the Functional Anatomy subject for PC3,5,6. In the case of PTG, the most irrelevant disciplines (rank 1) with a formative role in the formation of PC were: the Theory and Practice of Combat Sports subject for PC1,2,3,5, the Functional Anatomy subject for PC4, respectively the Theory and Practice in Water Sports subject for PC6 (Table 3). We consider that the disciplines that have a low formative perception of the professional competencies of the PES teacher are because they are not provided in the national curriculum at PES for primary and secondary school and, in this context, the disciplines of the study consider them to have a low formative contribution.

Table 3. Descriptive statistics - Questionnaire for assessing the formative perception of the disciplines from RAQAHE standards on PC in PES

PE field disciplines		PC1		PC2		PC3		PC4		PC5		PC6	
		X	R	X	R	X	R	X	R	X	R	X	R
Motor and Somato-Functional Assessment	JTG	3.04	10	3.46	8	3.50	8	3.40	7	3.41	8	3.37	8
	PTG	3.11	8	3.03	8	2.76	5	2.95	10	2.98	10	2.91	2
Functional Anatomy	JTG	3.28	8	3.46	9	3.17	1	3.09	2	3.11	1	3.09	1
	PTG	3.20	11	3.14	10	2.88	7	2.85	1	2.84	5	2.80	6
Physiology	JTG	3.26	4	3.27	3	3.44	6	3.39	10	3.37	7	3.36	7
	PTG	3.20	10	3.13	9	2.99	10	2.98	2	2.95	9	2.90	11
Theory and Practice of Athletics	JTG	4.16	11	3.86	12	3.91	12	3.75	12	3.75	12	3.70	12
	PTG	3.89	12	3.34	12	3.15	12	3.16	12	3.16	12	3.03	12
Theory and Practice of Gymnastics Branches	JTG	3.76	12	3.86	11	3.82	11	3.73	11	3.73	11	3.69	11
	PTG	3.13	9	3.20	11	3.10	11	3.13	11	3.13	11	3.04	5
Theory and Practice of Winter Sports	JTG	3.16	3	3.28	6	3.53	9	3.44	9	3.43	9	3.42	9
	PTG	2.70	4	2.72	4	2.73	4	2.84	4	2.82	4	2.88	9
Theory and Practice of Water Sports	JTG	3.27	5	3.38	7	3.46	7	3.37	4	3.36	5	3.35	5
	PTG	2.92	7	2.91	6	2.80	6	2.95	9	2.91	7	2.93	1
Theory and Practice of Combat Sports	JTG	2.76	1	3.08	1	3.26	2	3.17	1	3.17	2	3.17	2
	PTG	2.20	1	2.23	1	2.40	1	2.52	5	2.48	1	2.59	3
Theory and Practice of Expressive Sports	JTG	3.28	7	3.28	5	3.40	5	3.38	3	3.36	6	3.36	6
	PTG	2.70	3	2.66	2	2.59	2	2.79	6	2.74	2	2.80	8
Practical Lessons in Winter Sports	JTG	3.16	2	3.18	2	3.38	4	3.32	5	3.31	4	3.31	4
	PTG	2.64	2	2.67	3	2.91	8	2.95	7	2.93	8	2.92	10
Practical Lessons in Water Sports	JTG	3.27	6	3.28	4	3.26	3	3.29	6	3.27	3	3.27	3
	PTG	2.86	5	2.88	5	2.91	9	2.94	3	2.91	6	2.96	4
Theory and Practice of Other Sports	JTG	3.38	9	3.58	10	3.64	10	3.59	8	3.57	10	3.55	10
	PTG	2.91	6	2.95	7	2.73	3	2.76	8	2.77	3	2.82	2

JTG –junior teachers group; PTG –permanent teachers group; R- rank of disciplines; X- arithmetic mean.

According to Table 4, we found that the specialized subject with the greatest formative role for PTG was the Internship in Educational Units subject for PC1-6 (rank 14) because it is the subject in which theoretical concepts are applied in concrete conditions of teaching PES in school to different classes of primary or secondary school students. In the case of JTG, the situation is

different compared to PTG, They considered that for PC1 and PC6 the most important formative role was played by the Methodology of Teaching Gymnastics in Schools subject (rank 14); for PC2 by the Methodology of Teaching Basketball in Schools subject ($\bar{x}=4.28$; rank 14); for PC3 and PC5 by the Methodology of Teaching Athletics in Schools subject (rank 14); for PC4 by the Fitness subject ($\bar{X}=3.74$, rank 14). The differences between PTG and JTG regarding the disciplines with the greatest formative role of PC were due to practical experience in schools. PTG appreciated the experience gained during specialized practice. JTG appreciated various disciplines (Athletics, gymnastics, sports games, and fitness), which they considered to have increased applicability in school based on their experience during undergraduate studies and reduced teaching experience in school. For both groups of the study, the lowest formative input regarding the PC specific to the PES teacher had the disciplines (rank 1): Fitness for PC1 and Leisure Motor Activities for PC4,5,6. For PC2, JTG considered that the Body Expression and Eurythmy subject is the most irrelevant from the point of view of training PC, and for PTG, the Internship in Tourism Activities subject was the most irrelevant. We noticed that both groups rated almost the same the disciplines with the lowest formative perception of professional competencies, with one exception for PC2.

Table 4. Descriptive statistics - Questionnaire for assessing the formative perception of specialized disciplines from RAQAHE standards on PC in PES

Specialized disciplines		PC1		PC2		PC3		PC4		PC5		PC6	
		X	R	X	R	XD	R	X	R	X	R	X	R
Adapted motor activities	JTG	3.48	3	3.58	6	3.62	10	3.61	10	3.60	9	3.57	9
	PTG	3.25	6	3.20	6	3.09	8	3.17	6	3.19	6	3.15	9
Leisure Motor Activities	JTG	3.50	4	3.38	2	3.35	1	3.37	1	3.35	1	3.33	1
	PTG	2.83	3	2.80	4	2.63	1	2.75	1	2.73	1	2.79	1
Body Expression and Eurythmy	JTG	3.59	6	3.35	1	3.44	2	3.70	12	3.44	3	3.50	11
	PTG	3.03	5	3.06	5	3.04	5	3.00	5	3.01	5	2.97	3
Fitness	JTG	3.38	1	3.56	5	3.53	4	3.74	14	3.54	4	3.42	3
	PTG	2.77	1	2.78	2	2.90	4	2.77	2	2.80	2	2.82	2
Methodology of Teaching Athletics in Schools	JTG	4.38	13	3.77	10	3.82	14	3.56	6	4.22	14	3.67	13
	PTG	4.02	13	3.45	12	3.21	12	3.42	13	3.38	13	3.20	13
Methodology of Teaching Basketball in Schools	JTG	3.77	12	4.28	14	3.64	8	3.56	5	3.55	5	3.52	7
	PTG	3.34	10	3.31	10	3.06	6	3.23	7	3.20	7	3.10	7
Methodology of Teaching Football in Schools	JTG	3.66	9	3.78	13	3.46	3	3.45	2	3.44	2	3.41	2
	PTG	3.25	8	3.23	8	3.13	9	3.30	10	3.26	9	3.14	8
Methodology of Teaching Gymnastics in	JTG	4.39	14	3.78	12	3.82	13	3.46	3	3.71	13	3.68	14
	PTG	3.52	12	3.46	13	3.22	13	3.34	12	3.30	12	3.17	11

Romanian Physical Education Teachers' Perception of Formative Feedback...
Sorin DRUGAU et al.

Schools													
Methodology of Teaching Handball in Schools	JTG	3.69	11	3.67	8	3.55	6	3.58	9	3.56	8	3.52	6
	PTG	3.33	9	3.30	9	3.16	10	3.31	11	3.27	10	3.17	10
Methodology of Teaching Volleyball in Schools	JTG	3.68	10	3.68	9	3.55	5	3.58	8	3.56	7	3.51	5
	PTG	3.25	7	3.23	7	3.09	7	3.23	8	3.20	8	3.10	6
Practice and Methodology of Motor Activities by Age Groups	JTG	3.61	7	3.78	11	3.73	11	3.73	13	3.71	12	3.66	12
	PTG	3.50	11	3.42	11	3.18	11	3.29	9	3.29	11	3.20	12
Internship in Tourism Activities	JTG	3.48	2	3.49	4	3.62	9	3.57	7	3.55	6	3.55	8
	PTG	2.80	2	2.78	1	2.82	2	2.84	4	2.81	4	3.03	5
Internship in Leisure Facilities	JTG	3.59	5	3.49	3	3.64	7	3.55	4	3.63	11	3.62	4
	PTG	2.89	4	2.88	4	2.87	3	2.82	3	2.80	3	3.01	4
Internship in Educational Units	JTG	3.66	8	3.67	7	3.73	12	3.64	11	3.62	10	3.61	10
	PTG	4.28	14	4.15	14	4.01	14	4.09	14	4.09	14	3.97	14

JTG –junior teachers group; PTG –permanent teachers group; R- rank of disciplines; X- arithmetic mean.

According to Table 5, analyzing the results for PC1-6, we found that the arithmetic means of JTG were higher than those recorded by PTG at all subscales corresponding to the disciplines' typology. For PC1, the most significant differences between JTG and PTG occurred at subscales of the PE field and specialized disciplines with 0.41 points. The most considerable average difference was for subscales PE Field disciplines at PC2 with 0.50 points, PC3 with 0.57 points, PC4 with 0.50 points, PC4 with 0.51 points, and PC6 with 0.50 points. Analyzing Cronbach's alpha values, we found that at all the subscales of the questionnaire, for all the professional competencies (PC1-6), the values ranged between 0.802 and 0.979, which reflects a very good internal consistency. Cronbach's Alpha values reflected that the questionnaire results were statistically validated for both groups of the study (JTG and PTG).

Table 5. The statistical analysis of PC about the disciplines' typology

PC	Disciplines' typology	Group	X	ΔX (JTG-PTG)	Cronbach's alpha
	Fundamental disciplines	JTG	3.47	0.23	.803
		PTG	3.24		.802
PC1	PE Field disciplines	JTG	3.32	0.41	.933
		PTG	2.91		.952
	Specialized disciplines	JTG	3.63	0.41	.911
		PTG	3.21		.922
	Fundamental disciplines	JTG	3.58	0.41	.880
		PTG	3.17		.804
PC2	PE Field disciplines	JTG	3.41	0.50	.894
		PTG	2.90		.950
	Specialized disciplines	JTG	3.62	0.44	.894
		PTG	3.18		.923
	Fundamental disciplines	JTG	3.52	0.46	.802
		PTG	3.05		.814
PC3	PE Field disciplines	JTG	3.40	0.57	.943
		PTG	2.82		.948
	Specialized disciplines	JTG	3.60	0.54	.909
		PTG	3.06		.946
	Fundamental disciplines	JTG	3.38	0.25	.844
		PTG	2.12		.820
PC4	PE Field disciplines	JTG	3.40	0.50	.954
		PTG	2.90		.963
	Specialized disciplines	JTG	3.57	0.39	.961
		PTG	3.14		.952
	Fundamental disciplines	JTG	3.36	0.25	.838
		PTG	3.11		.811
PC5	PE Field disciplines	JTG	3.40	0.51	.949
		PTG	2.88		.959
	Specialized disciplines	JTG	3.56	0.43	.961
		PTG	3.13		.959
	Fundamental disciplines	JTG	3.33	0.30	.867
		PTG	3.02		.925
PC6	PE Field disciplines	JTG	3.38	0.50	.961
		PTG	2.88		.979
	Specialized disciplines	JTG	3.54	0.44	.966
		PTG	3.09		.967

PC – professional competence, X- arithmetic mean, ΔX – difference of arithmetic means between groups, JTG – junior teachers group, PTG – permanent teachers group.

Based on the ranks assigned to the disciplines included in each subscale about the arithmetic means, we made a hierarchy of disciplines on subscales to highlight the importance of these disciplines in terms of the

formative aspect of the professional competencies of the PES teacher in the secondary education cycle. We found that for the Fundamental Disciplines' subscale, the highest score per rank 7 was recorded by PES Theory and Methodology with 6.66 points, followed by Basic Gymnastics with 5.75 points and by Scientific Fundamentals of Sports Games: basketball, handball, volleyball, and football with 4.91 points. In the opinion of the study disciplines, for the subscale Fundamental Disciplines, Health Education and First Aid with 2 points and Kinesiology with 1.16 points (Table 6) had the lowest impact in PC training. For the subscale PE field disciplines, we found that the Theory and Practice of Athletics, with 11.25 points, the Theory and Practice in Branches of Gymnastics, with 11.08 points, and the Motor and Somato-Functional Evaluation, with 7.91 points, had the greatest formative role for the PC in PES. The following undergraduate disciplines contributed the least to the training of PC: the Theory and Practice in Expression Sports with 5.50 points, and the Theory and Practice in Combat Sports with 1.66 points.

In Table 6, for the subscale, Specialized disciplines were recorded as the highest ranks, reflecting a major formative perception on PC at the Methodology of Teaching Athletics in School with 12.16 points, the Methodology of Teaching Gymnastics in Schools, and Internship in Educational Units with 11.83 points. Fitness recorded the lowest formative role in the subscale Specialized Disciplines with 3.67 points and Leisure Motor Activities with 1.75 points. This hierarchy of disciplines corresponding to the three subscales will facilitate understanding the formative perception. It will implicitly contribute to rethinking the content and the number of hours assigned for courses, seminars, and practical lessons for all disciplines. The better ranking of some disciplines is related to the formative role in the perception of PES teachers. The ranking of the disciplines will have to determine the allocation of a more significant number of course hours or practical work in the curricula for the bachelor's program. Increasing the workload of the disciplines will ensure the training of the specific professional skills necessary for teaching PES in the school.

Table 6. The ranking of the disciplines according to X – ranks in the Questionnaire for assessing the formative perception of the disciplines from RAQAHE standards on professional competencies (PC) training in PES in both groups of the study (PTG and JTG)

Professional competence	PC1	PC2	PC3	PC4	PC5	PC6	XPC
Disciplines	Rank of disciplines						
Fundamental disciplines							
Theory and Methodology of PES	7	7	7	6	6.5	6.5	6.66
Basic Gymnastics	5.5	6	5.5	5.5	6	6	5.75
Scientific Foundations of Sports Games: Basketball, handball, volleyball, football	5	4.5	5	5	5	5	4.91
General Basics of Athletics	4.5	4.5	4.5	5.5	4.5	4.5	4.66
Psychopedagogy	2.5	3	2.5	3	3	3	2.83
Health Education and First Aid	2.5	2	2.5	1.5	1.5	2	2.00
Kinesiology	1	1	1	1.5	1.5	1	1.16
PE Field disciplines							
Theory and Practice of Athletics	11.5	12	12	12	12	8	11.25
Theory and Practice of Gymnastics Branches	10.5	11	11	11	11	12	11.08
Motor and Somato-Functional Assessment	9	8	6.5	8	9	7	7.91
Physiology	7	6	8	8.5	8	5	7.08
Theory and Practice of Other Sports	7.5	8.5	6.5	6	6.5	5.5	6.75
Theory and Practice of Winter Sports	3.5	5	6.5	6.5	6.5	12	6.66
Functional Anatomy	9.5	9.5	4	3	3	9	6.33
Theory and Practice of Water Sports	6	6.5	6.5	6	6	6.5	6.25
Practical Lessons in Winter Sports	2	2.5	6	6.5	6	12	5.83
Practical Lessons in Water Sports	5.5	4.5	6	4.5	4.5	8	5.50
Theory and Practice of Expressive Sports	5	3.5	3.5	4.5	4	12.5	5.50
Theory and Practice of Combat Sports	1	1	1	1.5	1.5	4	1.66
Specialized disciplines							
Methodology of Teaching Athletics in Schools	13	11	13	9.5	13.5	13	12.16
Methodology of Teaching Gymnastics in Schools	13	12.5	13	7.5	12.5	12.5	11.83
Internship in Educational Units	11	10.5	13	12.5	12	12	11.83
Practice and Methodology of Motor Activities by Age Groups	9	11	11	11	11.5	12	10.92
Methodology of Teaching Handball in Schools	10	8.5	8	10	9	8	8.91
Methodology of Teaching Basketball in Schools	11	12	7	6	6	7	8.16
Adapted motor activities	4.5	6	9	8	7.5	9	7.33
Methodology of Teaching Volleyball in Schools	8.5	8	6	8	7.5	5.5	7.25
Methodology of Teaching Football in Schools	8.5	10.5	6	6	5.5	5	6.91
Body Expression and Eurythmy	5.5	3	3.5	8.5	4	7	5.25

Internship in Leisure Facilities	4.5	3.5	5	3.5	7	4	4.58
Internship in Tourism Activities	2	2.5	5.5	5.5	5	6.5	4.50
Fitness	1	3.5	4	8	3	2.5	3.67
Leisure Motor Activities	3.5	3	1	1	1	1	1.75

PC – professional competence.

Discussion and limit

The first purpose of the study was to identify the formative perception of the disciplines studied within the bachelor programs in Physical Education and Sports (PES) on the PC provided in the qualification sheets of the National Register of Qualifications in Higher Education (NRQHE) for the occupational qualification of Physical Education Teacher in primary and secondary education levels. The results show that the disciplines from the RAQAHE standards contribute to different PC training for PES teachers. Also, there were differences of opinion in assessing the formative perception of PC depending on the typology of disciplines between study groups (PTG and JTG). Thus, PTG emphasizes disciplines that make the transfer between theory and current practice specific to PES teaching in schools. At the same time, JTG values more disciplines with a higher degree of attractiveness, based on experience in undergraduate studies and their little teaching experience in school.

The secondary purpose of our study is to rank the disciplines outlined in the RAQAHE standards for the specialization program in Physical Education and Sports based on their formative perception of professional competencies to develop a comprehensive profile of professional competence in PES. This ranking aimed to create a profile of professional competencies in PES. Using the study results, we categorized the disciplines into the three groups provided in the RAQAHE standards (fundamental, PE field, and specialized disciplines). We ranked them according to their formative role in developing the professional competencies of PES teachers. This hierarchy supports revising and optimizing curriculum content and its distribution for university-level PES specialization programs.

The study complements previous research highlighting the importance and necessity of updating the process of training professional competencies to align with current school contexts (Quilindo, 2023; Asún et al., 2020; Ward et al., 2016; Ennis, 2013). In the Romanian school system, Athletics, Gymnastics, and Sports Games (handball, basketball, volleyball, and football) are the main activities (Murathan, 2017; Kovač et al., 2008). Various studies have explored integrating holistic approaches in teaching physical exercises, enabling students to adapt effectively to new practice contexts (Yildiz et al., 2021; Murathan, 2017;

Kovač et al., 2008; Richardson et al., 2018). The traditional approach to training professional competencies in PES must continuously evolve to meet modern educational requirements and adapt to emerging practice forms, such as fitness (Huhtiniemi et al., 2022; Davis, 2020).

We believe that the curricula specific to bachelor programs in PES should be updated periodically to align with societal needs (Protsenko et al., 2024; Ponciano Nuñez et al., 2023, Shivorov et al., 2017; Marinho et al., 2017) and modernize teaching and exercise activities (Protsenko et al., 2024; Gheorghe et al., 2023; Harju et al., 2016). Studies conducted in various European countries have examined the correlation between the professional competencies of PES teachers and different professional training factors, including training volume, the compactness of specific content, and the typology of disciplines (Hurtado Almonacid et al., 2024; Protsenko et al., 2024; Ahmed et al., 2017; Litoi, 2016). These studies have highlighted differences in competencies among PES teachers based on curriculum content and experience level, consistent with our study's findings on the importance of aligning professional competencies with the number of hours allocated to PES degree program disciplines (Hurtado Almonacid et al., 2024; Protsenko et al., 2024; Cañadas et al., 2019; Ahmed et al., 2017).

Study limits

The limitations of the study: active students in the I-III years of their Field' in PES and future teachers were not included in the study; the analysis of transversally specific competencies was not targeted; the geographic location where the disciplines of the study came from (urban or rural) was not taken into account, the school infrastructure where the disciplines teach was not taken into account; the material base influences the way of organizing the teaching process and the typology of physical activities; the optional disciplines were not included in the evaluation due to their diversity in the curricula; the urban or rural environment of the schools where the teachers come from was not analyzed in the study; the reasons why there are differences in the ranking of PES disciplines according to PC between JTG and PTG have not been analyzed.

Practical implication

The allocation of hours to courses, seminars, and practical lessons should be aligned with the formative perception of professional competencies (PC) among Physical Education and Sports (PES) teachers in the gymnasium education cycle. This original contribution aims to facilitate the reassessment of curricular content and enable the restructuring of time

and resource allocation for each subject within the curricula of specialized faculties. Such adjustments will enhance their impact on the development of specialized professional competencies, thereby optimizing teacher preparation and instructional effectiveness. This study addresses an important issue in the training of PES teachers because depending on the formative perception of the subjects studied, the weight of the subjects in the curriculum should be restructured; the practical experience of teachers in schools should be the main criterion for allocating the number of hours for each specific discipline of the PED program: until now, no study has been carried out to rank the disciplines according to their formative role for teachers, the distribution of hours for each the discipline being at the discretion of the study program coordinator; the study results should be taken into account for the modernization of the PES curriculum.

Conclusions

The site study's results reveal differences of opinion in assessing the formative perception of PC depending on the typology of the disciplines between study groups (PTG and JTG). Thus, PTG emphasizes the disciplines that make the transfer between theory and current practice specific to PES teaching in schools. At the same time, JTG values the disciplines with a higher degree of attractiveness based on their experience in undergraduate studies and the reduced teaching experience in schools. Based on the relevant results, we identified the formative perception of the compulsory disciplines provided in the RAQAHE standards for the specialization of Physical Education and Sports about the specialized PC provided in the NRQHE qualification sheets for the teacher of Physical Education – secondary education.

The Disciplines were structured as in RAQAHE standards into fundamental disciplines, PE field disciplines, and specialized disciplines, and the granting of the ranks according to the arithmetic average recorded in the study allowed us to rank these disciplines from the perspective of their formative perception on the development of PC of PES teachers. The results of the study reveal that the disciplines with the greatest formative role on the PC of PES teachers were the fundamental disciplines: the PES Theory and Methodology, Basic Gymnastics, the Scientific Foundations of Sports Games Basketball, Handball, Volleyball, Football the PE field disciplines: the Theory and Practice of Athletics, the Theory and Practice of Gymnastics' Branches, the Motor and Somato-Functional Evaluation; among the specialized disciplines: the Methodology of Teaching Athletics in Schools, the Methodology of Teaching Gymnastics in Schools and the

Internship in Educational Units. The lowest formative role on PC, on subscales, has the disciplines Kinesiology, Theory, and Practice in Combat Sports, respectively, the Motor Leisure Activities.

Currently, the distribution of hours by subjects in the bachelor's programs in Physical Education and Sport (EPS) curricula is determined not by their formative significance but by the administrative preferences of the department heads when they constitute the didactic norms. This approach may negatively affect professional skills development in future PES teachers, as the training volume does not align with current teaching requirements in schools. The ranking of the disciplines according to their formative role will be able to determine the improvement of allocating the weight of hours (the number of course hours and seminars/practical work) for each discipline in the PES curriculum for the bachelor's program.

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Article

Evaluating the Effectiveness of the Annual Physical Training Plan for Masters +45 Women Half Marathon Athletes: A Guideline Model for Good Practices for Programming Effort Volume and Intensity

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Abstract: This study presents the implementation and results of the Annual Physical Training Program for Masters +45 Half Marathoners (PAsm-12), focused on optimizing athletic performance through rigorous planning of training volume and intensity. PAsm-12, structured over 12 mesocycles and 52 microcycles, was applied to 6 female runners with over 10 years of experience. The results indicate that the total running volume achieved (2347 km) was 90.2% of the volume proposed by PAsm-12 (2603.2 km), with statistically significant differences in most mesocycles (Cohen's $f^2 = 6.24$, $t = -5.997$, $p = 0.002$, indicating a large effect size). The training intensity was achieved at an average of 94.8% of what was proposed by PAsm-12, with significant differences in several mesocycles (Cohen's $f^2 = 0.45$, $t = -1.972$ to -3.984 , $p < 0.05$, indicating a moderate to large effect size). The female runners' performances in field tests generally showed faster times than the maximum and average values proposed in PAsm-12, with the exception of the final competition, where performance was slightly lower due to external competitive factors (Cohen's $d = -0.53$, $t = -1.192$, $p = 0.3$). This plan, demonstrating good practice, could serve as a guideline model for amateur runners who do not have specialist counseling. PAsm-12 can reduce the risk of injury, prevent excessive fatigue, and support ongoing participation in sports activities. Additionally, the implementation of this plan could provide amateur runners with a safe and effective training structure, contributing to improved health and athletic performance.

Keywords: annual physical training program; half marathon; master +45; women; training volume planning; training intensity; athletic performance



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1. Introduction

A half marathon is an athletic event involving a 21.0975 km race, half the distance of a marathon [1]. In sports terms, a half marathon is a road race, also called non-stadia. Non-stadia events are sports events organized outside the stadium, including mountain, road, or sand races [2].

Two categories of participants compete in half marathons: amateur runners and performance runners. Amateurs are passionate runners who become competitive over time. Competitors are classified into age groups—18–34, 35–44, 45–54, 55–64, 65+ [3]—while master runners compete in the following categories, regardless of gender identity (men, women, non-binary): 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95 years [4]. Participation rates and performance vary by age group.

Although not currently included in the Olympic Games, the half marathon has become popular among amateur runners in recent decades [5]. Its current popularity is driven by

the large number of amateur runners, with an increasing number of women participating in such sports events [6]. A few studies shows that the number of women and men participating in half marathons and marathons increased significantly between 1999 and 2014, more so in half marathons and especially among women (123 times more women participate in half marathons than in marathons, and 75 times more men register for half marathons than for marathons) [5,6]. Similarly, in the USA, in 2019, the proportion of women (60%) surpassed that of men (40%) in half marathons, with more significant increases among master runners compared to younger runners [6]. Other studies also show that participation in competitions is relatively higher among women than men, especially in the 50+ age groups, with higher performance frequencies achieved at older ages [7–10].

In Romania, trends align with global ones, but the number of female participants in such races is still lower compared to other countries. The Romanian Athletics Federation (FRA) website indicates that the number of participants in the Bucharest Half Marathon has progressively increased since 2016, with a simultaneous increase in the number of female participants. Most women finished the race at the Cluj-Napoca Half Marathon from 2016–2022, with their numbers constantly growing, representing 29.06% of the total participants in 2022 [11].

Romanian master runners are registered with sports clubs affiliated with the FRA, also known as “veterans” [12] or senior runners [13]. As worldwide, in Romania, the scale and popularity of the half marathon are driven by amateurs, with fewer performance runners.

The increase in the number of endurance race participants and the diversification of participant groups (age, gender, profession, etc.) pose challenges in training design, monitoring, and execution, requiring adaptation to the specific needs of amateur runners. For women, training is conducted amidst numerous professional and family responsibilities [14]. Running many kilometers almost daily and weekly can interfere with their professional or family obligations or specific age-related needs. Additionally, women are more susceptible to injuries compared to men [15]. Training programs for master amateur runners should focus not only on physical performance but also on reducing physiological and relational stress. On the other hand, the heterogeneous profile of amateur half marathoners has led to diverse training models to adapt to the anatomical, physiological, or psychosocial factors influencing endurance runners’ performance and well-being, whether amateur or professional [10]. Unlike professional athletes, amateur half marathon runners—although they often have some prior running experience, most of them are not coached by a trainer—tend to exceed their upper physical capacity limits, frequently experiencing overtraining syndrome [16], lack of physiological adaptation [17], or deterioration of physical fitness [18,19]. The disadvantage of amateur runners is highlighted in other studies, showing that many performance-related factors and finish time predictions are under-researched [20,21]. Additionally, another drawback is the fact that systematic analyses of training plans primarily focus on professional runners [22], while those intended for amateur athletes are much rarer, though not entirely absent [10,20]. Under these conditions, although the half marathon as an event for amateurs has impressively developed, there is no consensus on the best training practices that would allow for the optimization of physical performance in a healthy manner [23]. However, there is a lot of empirical data that is not necessarily based on scientific studies [24]. As a result, controversies among specialists regarding the effectiveness of various training models and the need to adapt them to amateur runners’ particularities complicate the choice of optimal training type for a category or individual practitioners [25].

Sports training is a long-term activity carried out through a laborious process of planning and programming [26]. Training planning is a predictive process, based on experience and scientific knowledge, aimed at the rational, systematic, and sequential organization of training tasks and the recovery process to achieve performance objectives at specific times [27]. This involves paying special attention to the volume and intensity of effort, as these two variables are closely linked to the effectiveness and safety of training, directly influencing the capacity for adaptation and athletic progress [28]. The objective of

training is to improve the athlete's athletic skills and, ultimately, their performance level. The correct use of knowledge, experience, and principles of sports training leads to the design of effective training programs.

As revealed by a previous study that we conducted [29], many Romanian amateur athletes are interested in achieving faster race times and gaining social recognition for their efforts. In this context, they are concerned with optimizing their training efficiency. The importance of properly scheduling volume and intensity in this context is crucial, as it allows for the adjustment of training sessions to maximize performance without compromising the athletes' health [27]. The same study showed that 55.9% of runners become injured during training or competitions or engage in demanding training exceeding 100 km per week, often followed by excessive fatigue, making it difficult to maintain motivation and diminishing running satisfaction. This further emphasizes the need to carefully regulate the volume and intensity of training to prevent overtraining and ensure proper recovery, which are essential for maintaining long-term physical and mental well-being [30]. Amateur female athletes have varied perceptions of effective training, lacking consensus on the optimal patterns of training methods, as well as on the volume and intensity of effort applied during each training phase at any given time [29]. In other words, it is important to consider that both the volume and intensity of effort are essential components of planning the sports training process, being fundamental to structuring an effective training program. Numerous training programs highlight various solutions for achieving performance. These training programs aim to develop economical training strategies for half marathoners, maintaining sports efficiency within optimal limits and positive effects on physical and mental health [31–33]. The impact of the strategies used is controversial, with evidence suggesting that moderate-intensity training enhances athletic performance similarly to high-intensity training. However, high-intensity training shows more significant differences in the physiological adaptation of the body to exertion [34,35].

Regarding the timing and scheduling of training programs, from the study of various sources, we have found that the time intervals for which these training plans are developed vary: 12/15/32 weeks [32,36], 12 weeks [37,38], 20 weeks [23], or 4–6 months [39]. Some believe that a one-year training program is essential [17]. However, verifying these training programs' efficiency through experiments or quasi-experiments is rare or limited to elite runners [40].

As mentioned earlier, most training plan models target professional athletes, with far fewer tailored for amateur athletes. Generally, the traditional endurance training programming model is linear, featuring progressively structured training intervals in a predetermined sequence, including sessions, microcycles, and mesocycles that culminate in a macrocycle. Training periodization requires different training objectives, with its sequencing occurring during preparatory phases (focused on general and specific physical preparation, pre-competition, and competition preparation), concluding with a transition and recovery phase [28]. In the same context, another source emphasizes that scientifically approached training design and management should focus on key aspects of the training process, such as periodization, which require strategic adjustments to the volume and intensity of effort to optimize performance and physiological adaptation, along with training methods and monitoring, performance prediction, running technique, and the prevention and remediation of health issues associated with endurance running [23]. However, in practice, some half marathon runners employ a non-periodized strategy characterized by a fixed number of kilometers predetermined by repetitions throughout a training cycle [41]. This approach, while simplifying planning, may overlook critical aspects such as adjusting the volume and intensity of effort based on the athlete's physical condition and specific goals, which can limit the optimization of performance and proper physiological adaptation.

In this complex context of planning and training practice for amateur female runners, our study aims to develop, apply, and confirm the efficiency of a staggered physical training program over one year (macrocycle) for female Master (+45) half marathoners, aiming to generalize the experience and good practices of nationally and internationally recognized

runners adaptively. We believe their common training strategy can serve as a medium-term training model for amateur runners without a coach's counseling benefits. The emphasis placed on volume and intensity in this plan highlights our belief that precise management of these dimensions is essential for achieving the desired sports performance, without compromising the health and well-being of the female athletes.

Based on these considerations, for the application of our annual physical training plan, we have formulated three research questions, each associated with a specific research direction. Question 1 (Q1): To what extent does the volume of effort performed by athletes align with the planned volume of effort in the annual physical training plan? The research direction for this question is to assess the congruence between planning and execution of training volume, evaluating the effectiveness of the programming. Question 2 (Q2): How does the intensity of effort performed by athletes compare with the proposed intensity of effort in the training plan for each mesocycle? This research direction aims to determine if the intensity of the training is appropriately adjusted to promote physiological adaptations without inducing risks of overtraining. Question 3 (Q3): Do the performances achieved in field tests meet the expectations established by the proposed average times in the training plan? The research direction for this question explores the relationship between scheduled preparation and actual performances, highlighting the importance of calibrating time goals according to the athletes' real capabilities.

2. Materials and Methods

2.1. Study Design

The approach we implemented is ameliorative/formative in nature, as it aims to shape behavior [42], with the goal of improving or at least maintaining athletic performance in the half marathon event for master women (45+). Additionally, given that this is a physical training plan spread over the course of a year and considering that we have not found any macrocycle-type planning in the specialized literature, we consider our study to be a pilot one.

2.2. Study Subjects and Research Team

Within the study, female master athletes aged 45 and over were selected because, as mentioned earlier, several studies indicate that their participation in competitions has increased significantly globally over the past three decades [43–45]. From an age perspective, different age categories are considered to ensure some heterogeneity of the sample and, consequently, greater internal validity of research [42].

The subject group includes six female amateur runners (S1–S6) who practice long-distance running both indoor and outdoor, road and mountain running, and fall into the 45–49 and 50+ age categories. They are Master runners registered with Romanian sports clubs affiliated with the FRA, and at the study's outset, they had over 10 years of endurance running experience (Table 1). Being amateur runners, they do not have personal coaches. All participants live in urban areas and have different professions. The profession of the participants includes three physical education teachers, one doctor, one marketing specialist, and one museum curator. These characteristics were inclusion criteria, while health status and injuries were exclusion criteria.

Table 1. Socio-demographic characteristics of the runners who followed PAsm-12 (October 2021).

Athlete	Age (Years)	Residence	Sports Club	Running Experience
S1	50	Braşov	Brasov University Sports Club	13
S2	44	Bucharest	Bucharest Railway Sports Club	10
S3	48	Mediaş	Star Athletics Club Mediaş	30
S4	55	Bucharest	Locomotiva Sports Club Bucharest	12
S5	57	Bistriţa Năsăud	Municipal Sports Club Bistriţa	38
S6	47	Sibiu	Sibiu Community Club	10

For this study, the Romanian female runners (S1–S6) were recruited at the World Masters Mountain Running Championships (Telfes, Austria 2021), where the Romanian team, including these female runners, placed third after Italy and Germany. In 2021, all six female runners were active, participating in national and international competitions, with one (S5) also participating in two virtual competitions.

To assess the health status of the six female runners, they underwent an initial laboratory diagnosis (in the first part of mesocycle 1; 4–31 October 2021) at the SZJA Sportlab Center in Cârța, Harghita County [46]. The specialized anamnesis showed no cardio-respiratory pathologies or injury history in the last six months. To determine the female runners' maximum heart rate (MHR) for establishing the training intensity and training zones, an effort test was conducted using a professional treadmill (HP Cosmos—pulsar[®]3p, h/p/cosmos sports & medical gmbh/Nußdorf, Germany) following the Brucea protocol at the same location [47]. The HP Cosmos treadmill is equipped with a chest strap connected to an external monitoring system, which displays the data on the screen in real time.

As study coordinators (the research team), five faculty members from the Faculty of Physical Education and Mountain Sports, Transilvania University of Braşov, participated in designing PAsm-12, approving and adjusting its content as needed and monitoring the training process of the six female runners. Our research approach was approved by the Department of Physical Education and Special Motricity of the faculty (no. 332/1/23.09.2021, approved on 23 September 2021) and was based on the Helsinki Declaration regarding research ethics, ensuring the rights, safety, and well-being of the participants. Informed consent of the participants was obtained. Additionally, during the implementation of PAsm-12, periodic consultation was sought from a sports nutrition specialist (Superfit Center in Bucharest) [48].

2.3. Procedure

Throughout the training program, periodic non-specific and specific tests were applied to the six female runners for more rigorous control and regulation of the staggered physical training process over one year.

The independent variable consists of the content of the annual physical training program for Masters +45 half marathoners (PAsm-12) and was largely followed independently (self-training) by each study participant through a personalized training program derived from PAsm-12, monitored, and staggered over 12 training mesocycles. Since PAsm-12 is applied in the runners' natural environment, the control of the independent variable is not very strict, but the research has the advantage of being an ecological intervention, making its results and conclusions more suitable for practical problem-solving compared to laboratory experiments [49].

Dependent variables include the participants' performances in applying the dependent variable, i.e., running distances achieved, the intensities at which they were performed, with both effort indicators reported to the corresponding values proposed by PAsm-12. Additionally, partial or complete test times in five field tests conducted in non-competitive and competitive environments, where the runners gathered at predetermined locations during PAsm-12 design, also represented elements of the dependent variable.

After selecting the subject group, participants were informed about the study's general objectives and the annual physical training program's structure and content—as well as the competition calendar (2021–2022)—were agreed upon, with potential adjustments depending on the evaluations/results obtained from the scheduled/designed tests.

2.3.1. The Presentation of the Annual Physical Training Plan for the Half Marathon (PAsm-12)

Considering various training models and debates regarding the advantages or disadvantages of certain periodization methods, as well as the consequences of different training volumes (kilometers covered) and intensities (execution times/tempo, expressed as a percentage of maximum effort capacity per subject) on performance and maintaining

female runners' health, we opted for a traditional linear hierarchical training model in our study. We chose this training–planning strategy given the selected female runners' already-developed motor skills (technical), appropriate physical preparation level, and well-defined training routines.

As structured, PAsm-12 spans 12 mesocycle comprising 52 microcycles, each microcycle consisting of 4 or 5 training sessions per week, depending on the training period. The methodology for planning the annual physical training plan for women Master 45+ runners, covering the period 4 October 2021–30 September 2022, proposes a progressive, cross-sectional arrangement of cycles/periods/phases of training [27,28,30]. Structurally, PAsm-12 features a preparatory period (PP 4 October 2021–30 January 2022) developed into two phases: general physical preparation (GPP, 4–31 October 2021) and specific physical preparation (SPP, 1 November 2021–30 January 2022). This is followed by a pre-competition period (PCP, 31 January–3 April 2022), a competition period (CP, 4 April–18 September 2022), and concludes with a transition period (TP, 19–30 September 2022). In our planning model, training volume and intensity increase gradually in GPP, while in SPP and PCP, volume decreases to medium, and intensity increases to an optimal level according to event-specific demands. In CP, intensity fluctuates from high (submaximal) to optimal for the half marathon event, while volume fluctuates from high to medium, depending on runners' performance objectives related to the significance of tests/competitions in the pre-set calendar. PAsm-12 is structured to allow the runners' functional recovery in a permanent and controlled manner as they progress toward the main period (CP) and the major objective competition [30,50].

The plan initially proposes moderate training intensity (about 70% of the maximum heart rate per athlete) and relatively small training volume (about 40 km/week), with indicators progressively increasing during the training process. Training sessions were planned to allow physiological recovery for participants and facilitate the body's functional adaptation to effort.

For the agreed-upon preparation period, a unanimously agreed competition calendar was developed, correlated with PAsm-12's quantitative and qualitative indicators (volume/intensity). The collaborative development of the competition calendar is justified by the need to harmonize runners' professional, family, and financial activities. Thus, the competition calendar included five field tests (Table 2), with the final one representing an official competition, termed the major objective.

Table 2. Common competition calendar for the annual physical training program for the half marathon (PAsm-12) 2021–2022.

No.	Month	Competition Name—Field Test	Test Type	Location
1	January	Road running—10 km	Non-specific test	Zărnești (Romania)
2	February	Road running—21 km	Specific test	Cluj-Napoca (Romania)
3	March	Road running—21 km	Specific test	Oradea (Romania)
4	April	Road running—21 km	Specific test	Brașov (Romania)
5	May	European Masters Athletics Championships Non-Stadia—21 km	Specific test	Grosseto (Italy)

For each of these tests, the PAsm-12 pre-established the race time (referred to by us as the “proposed running time”) with a tempo/km range set between a minimum and maximum limit, aiming to achieve an average reference value. These times were fixed as an anticipated consequence of the training plan's content periods. Thus, for the Zărnești test, scheduled in mesocycle IV/microcycle 17 (3–30 January 2022), a running tempo for the 10 km distance was set at 5'10"/km (maximum limit, slower time)–4'50"/km (minimum limit, faster time), equating to 3100 s/10 km and 2900 s/10 km respectively, with an average between the two values of 3000 s/10 km (50 min). For the other 4 tests—scheduled in Cluj-Napoca—mesocycle V/microcycle 19 (7–13 February 2022), Oradea—mesocycle VI/microcycle 24 (14–20 March 2022), Brașov—mesocycle VII/microcycle 28

(11–17 April 2022)—a running tempo for the regulation distance of the half marathon was projected between 5'40"/km (maximum) and 5'30"/km (minimum), resulting in 7140 s maximum/21 km and 6930 s minimum/21 km, with an average test time of 7035 s/21 km (117 min and 15 s). For EMACNS—Grosseto—mesocycle VIII/microcycle 32 (9–15 May 2022), a running tempo of 5'10"/km (maximum) and 4'50"/km (minimum) was established, with a maximum time for completing the full race distance of 6510 s/21 km and a minimum of 6090 s/21 km. The proposed finishing average time (finish time) for the race was 6300 s/21 km (105 min).

Macroindicators for PAsm-12 (training days, mesocycles, microcycles, number of field tests, laboratory tests) are presented in Table 3. In terms of content and training means, it should be noted that some microcycles in the plan are identical, while others vary based on the training objectives assigned to each mesocycle.

Table 3. Quantitative macro-indicators of PAsm-12.

No.	Indicator	Model—Women +45
1	Training days (no.)	235
2	Training sessions (no.)	235
3	Macrocycles (no.)	1
4	Mesocycles (no.)	12
5	Microcycles (no.)	52
6	Field tests—allocated to the study (no.) *	5
7	Laboratory test (no.)	1

* In addition to the tests scheduled in PAsm-12, following the official test in Grosseto (specific test 5), each athlete also underwent additional unaccounted tests through participation in various competitions—this option for participating in the verification process was driven by the athletes' familial, professional, and financial constraints.

For an overview of the programmed means in PAsm-12 and the volume indicators (distance covered/km, execution duration), as well as the intensity of effort (average percentage intensity of effort/mesocycles) predetermined for the plan, we summarize some relevant characteristics in Table 4 and the dynamics of the proposed volume and intensity distribution in Figure 1.

Table 4. Training means and effort indicators proposed for PAsm-12.

Training Means	Mesocycles/Quantitative Effort Indicators												Total Proposed Volume (km)
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Long-duration run with pre-set tempo (5'10"–4'50"/km)		40	50	30		10	10		10				150
Run with elevation difference (km)			60	56	11		10		10				147
Interval run (km)				24	32	18.6	37.8	6.6	24.2	47.8	55.2		246.2
Long-duration run with pre-set tempo (5'40"–5'10"/km)					25				52	18	20	5	120
Long-duration run with pre-set tempo (5'40"–5'30"/km)		40	70	40	68	115	116	16	90	160	187	11	913
Moderate tempo long-duration run (km)	160	48	50	24	43	69	24	41	88	68	72	13	700
Fartlek run (km)		40			31	13	25	10	38	52	24		233

Table 4. Cont.

Training Means	Mesocycles/Quantitative Effort Indicators												Total Proposed Volume (km)	
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII		
Test run (km)				10	21	21	21	21						94
Total proposed running volume (km/mesocycle)	160	168	230	184	231	246.6	244	94.6	312.2	346	358.2	29	2603.2	
Proposed intensity averages (% MHR)	70.0	75.0	70.0	76.3	77.6	72.8	80.8	71.0	76.2	80.5	80.5	78.3	-	

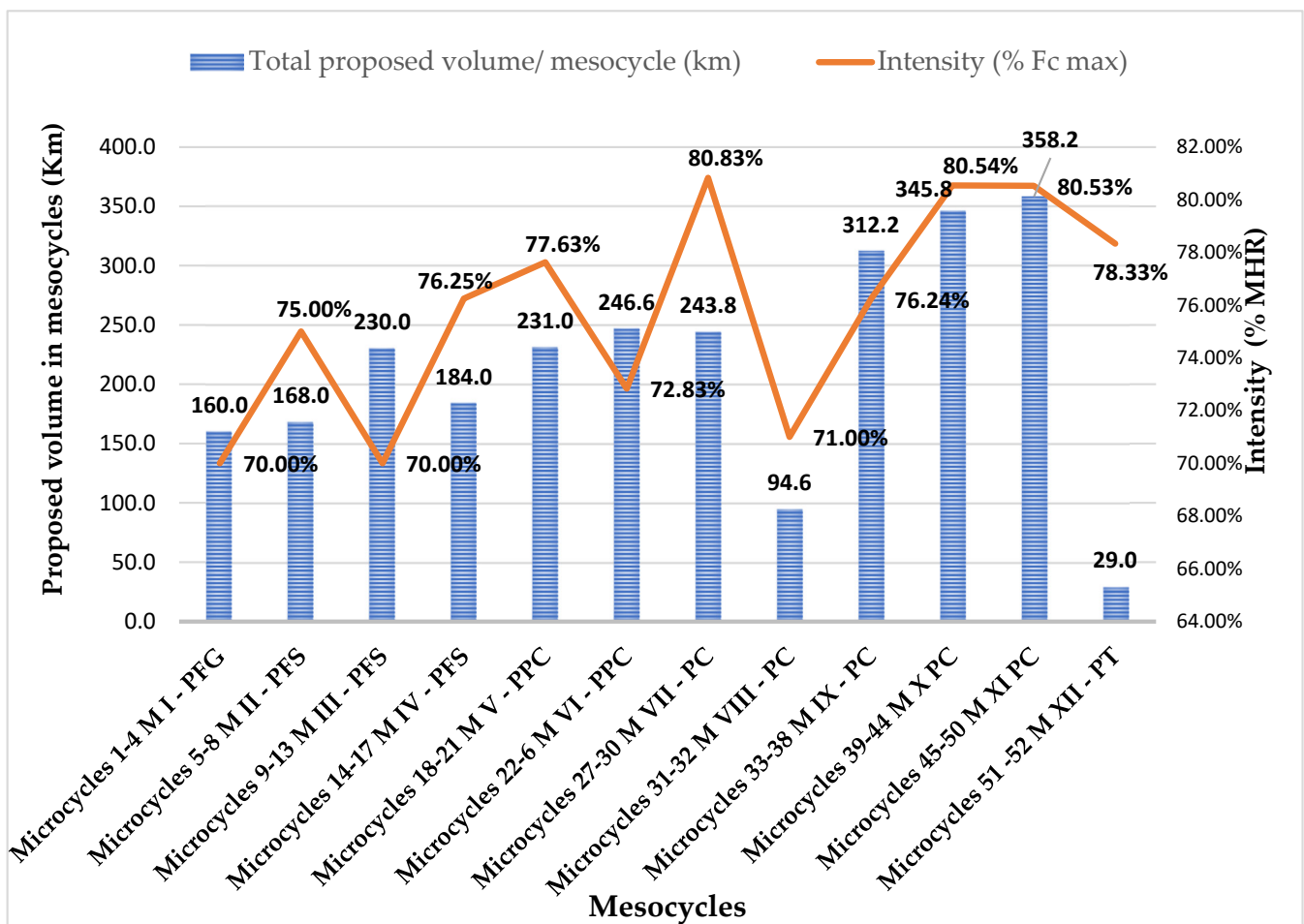


Figure 1. Dynamics of proposed training volume and intensity—average values/mesocycle in PAsm-12.

2.3.2. Remote Monitoring Equipment for Runners’ Activity

A necessary step in conducting our study, which was largely monitored remotely, involved the acquisition of six Garmin Fenix 6S PRO watches (Garmin Ltd., Olathe, KS, USA) with GPS technology. Currently, a growing number of running enthusiasts use technology for self-monitoring. An online study with a sample of 3723 participants analyzed how endurance runners use technology for training monitoring [51]. The results indicate that approximately 6 out of 10 respondents (59.5%) used a sports watch, 28.4% used a running app, and only 12.1% did not use either a watch or a running app. The watches were used to monitor distance (96.20%), time (90.0%), speed (85.5%), and calories (8.8%). Another study indicates that, although Garmin Fenix 6 watches may have a tendency

to underestimate HR at low intensities and overestimate it at high intensities, they still provide useful and relevant data, especially in contexts where continuous monitoring and portability are essential [52]. In our study, throughout the entire application period of PAsm-12, all training indicators considered relevant—training days and hours, distance covered, volume parameters per athlete (distances, effort durations), and effort intensity per athlete (pace, heart rate, etc.)—were continuously monitored and centralized weekly via Bluetooth by the research team for each athlete through the data provided by the Garmin Connect (Version 5.5) app. The watches were acquired through the “Life Quality and Human Performance” Research Laboratory of the Faculty of Physical Education and Mountain Sports in Braşov.

2.4. Statistical Analyses

The collected data were analyzed using SPSS v.23 for Windows. The significance level was set at $p \leq 0.05$. Descriptive data are reported as mean and standard deviation (SD) and sometimes as percentages (%). Differences in continuous variables (volume, intensity, tempo, test execution times) were analyzed using the paired *t*-test. Given the small sample size, we used bootstrapping, where the statistical software creates simulated samples similar to the analyzed one, increasing result accuracy and stability. The ideal is to use 1000 samples, which we applied in our data processing [42].

In addition, we calculated the effect size using two distinct methods, tailored to the specific context of each indicator, with the aim of ensuring a rigorous and appropriate evaluation of the obtained data. Thus, for the indicators of effort volume and intensity, we chose to apply Cohen’s f^2 , as this method allows for a comprehensive assessment of the variance explained by our training model in relation to the proposed volume and intensity. For the comparison between the proposed and achieved times in the five tests, we opted for the Cohen’s *d* formula, which is suitable for measuring the differences between two means, taking into account the standard deviation, thereby ensuring an accurate evaluation of individual performances against the expected values. The effect size serves to evaluate the impact of the intervention and to facilitate the justification of the necessary number of participants in future studies as well as to estimate the magnitude of the differences that other researchers might expect [42].

3. Results

3.1. The Level of Fulfillment of the Annual Physical Training Plan for Half Marathon Runners Aged 45+—PAsm-12

Compared to what was proposed in PAsm-12, the six research subjects reported the volume and intensity indicators they actually achieved in varying proportions. The following results will be presented accordingly: effort volume, determination of maximum heart rate (MHR) and establishment of training zones, as well as effort intensity and the testing times obtained.

3.1.1. Comparison of Proposed and Realized Training Volume through PAsm-12 (Q1)

In Table 5, the data show that athlete S3 achieved the highest training volume (2478 km) while athlete S1 achieved the lowest (2232 km). These data allow us to assert that PAsm-12 was not fully applied, only at 90.2%.

If the significance of the comparison test is greater than $p = 0.05$, we accept that the data do not provide sufficient evidence to conclude that the volume of effort performed by the athletes aligns with the planned volume of effort in the annual physical training plan. On the other hand, if $p \leq 0.05$, we reject the null hypothesis, suggesting that there is sufficient evidence to conclude that the volume of effort performed by the athletes is congruent with the planned volume, indicating the effectiveness of the scheduling.

Table 5. Effort volume realized by runners and proposed by PAsm-12.

Mesocycles	Effort Volume Realized per Athlete (S)/km						Proposed Training Volume/km
	S1	S2	S3	S4	S5	S6	
I	132	156	160	130	148	142	160.00
II	146	150	162	142	160	136	168.00
III	162	162	178	158	170	172	230.00
IV	172	178	180	168	176	168	184.00
V	178	202	220	185	206	201	231.00
VI	212	230	236	228	232	240	246.60
VII	228	227	230	228	230	235	243.80
VIII	90	150	95	90	93	95	94.60
IX	302	320	332	308	280	310	312.20
X	310	320	340	300	298	345	345.80
XI	270	308	315	290	265	310	358.20
XII	30 *	50 *	30 *	20 *	40 *	20 *	29.00 *
Total effort volume achieved per athlete (km)	2232	2453	2478	2247	2298	2374	2603.2
Effort volume achieved per athlete from the proposed effort volume (%)	8.7	94.2	95.2	86.3	88.3	91.2	90.2

* Note: In the proposed volume value, the athletes also accounted for mountain hiking activities to a greater or lesser extent. To verify if the proposed training volume in each mesocycle is statistically equivalent to the training volume performed (Q1), we used the paired *t*-test to compare the means of the two training volumes (proposed/realized) across the sample/12 mesocycle, employing the bootstrapping method for small samples (Table 6).

Table 6. Differences between realized and proposed training volume through PAsm-12.

Pair	Volume Indicator Variable Compared/Mesocycle/Realized-Proposed	Mean S1–S6 (km)	Difference	t	p
1	Realized training volume mesocycle I Proposed training volume mesocycle I	144.7 160.00	−15.33	−3.052	0.028
2	Realized training volume mesocycle II Proposed training volume mesocycle II	149.33 168.0	−18.67	−4.495	0.006
3	Realized training volume mesocycle III Proposed training volume mesocycle III	167.00 230.00	−63.00	−20.40	0.001
4	Realized training volume mesocycle IV Proposed training volume mesocycle IV	173.67 184.00	−10.33	−4.939	0.004
5	Realized training volume mesocycle V Proposed training volume mesocycle V	198.67 231.00	−32.33	−5.247	0.003
6	Realized training volume mesocycle VI Proposed training volume mesocycle VI	229.67 246.60	−16.93	−4.290	0.008
7	Realized training volume mesocycle VII Proposed training volume mesocycle VII	229.67 243.08	−14.13	−12.041	0.001
8	Realized training volume mesocycle VIII Proposed training volume mesocycle VIII	102.17 94.60	7.57	0.787	0.467
9	Realized training volume mesocycle IX Proposed training volume mesocycle IX	308.67 312.20	−3.53	−0.493	0.643
10	Realized training volume mesocycle X Proposed training volume mesocycle X	318.83 345.80	−26.97	−3.302	0.021

Table 6. Cont.

Pair	Volume Indicator Variable Compared/Mesocycle/Realized-Proposed	Mean S1–S6 (km)	Difference	t	p
11	Realized training volume mesocycle XI Proposed training volume mesocycle XI	293.00 358.20	−65.20	−7.414	0.001
12	Realized training volume mesocycle XII Proposed training volume mesocycle XII	31.67 29.00	2.67	0.559	0.600
Total effort volume achieved (macrocycles)		2347.00			
Total proposed effort volume (macrocycles)		2603.20	−256.2	−5.997	0.002

Regarding the effect size, the calculated R^2 value is 0.8619, indicating that 86.19% of the variation in the realized training volume can be explained by the proposed training volume through PAsm-12. This shows a strong correlation between the two sets of data. Additionally, the Cohen's f^2 value for the mean difference in training volume is approximately 6.24, indicating a large effect size. This suggests that the difference between the proposed and realized training volume is not only statistically significant but also has a substantial practical impact.

3.1.2. Determination of Maximum Heart Rate (MHR) and Establishment of Training Zones for the Research Subjects

Based on the laboratory tests presented in the procedure section, individual training zones were established for each athlete, including maximum heart rate (MHR), which are essential for monitoring and adjusting the intensity of effort during the application of PAsm-12 (Table 7).

Table 7. Training zones and maximum heart rate determined through the Bruce test for female runners S1–S6.

Athlete	Training Zone	Heart Rate (bpm)	Tempo/Speed (min/km)
S1	RL/LDL	125	slower than 6:32
	MDL	126–144	6:32–5:30
	TDL	145–155	5:30–5:01
	ETL	156–162	5:01–4:41
	ITL	163–168	4:41–4:24
	SB	169–max.	faster than 4:24
S2	RL/LDL	162	slower than 5:33
	MDL	163–169	5:33–4:55
	TDL	170–175	4:55–4:24
	ETL	176–178	4:24–4:06
	ITL	179–181	4:06–3:58
	SB	182–max.	faster than 3:58
S3	RL/LDL	134	slower than 5:40
	MDL	135–148	5:40–4:48
	TDL	149–158	4:48–4:20
	ETL	159–166	4:20–4:01
	ITL	167–173	4:01–3:39
	SB	174–max.	faster than 3:39
S4	RL/LDL	90	slower than 9:39
	MDL	91–115	9:39–7:03
	TDL	116–126	7:03–6:30
	ETL	127–145	6:30–5:07
	ITL	146–151	5:07–4:48
	SB	152–max.	faster than 4:48

Table 7. Cont.

Athlete	Training Zone	Heart Rate (bpm)	Tempo/Speed (min/km)
S5	RL/LDL	147	slower than 7:19
	MDL	148–153	7:19–6:31
	TDL	154–164	6:31–5:14
	ETL	165–167	5:14–4:52
	ITL	168–170	4:52–4:39
	SB	171–max.	faster than 4:39
S6	RL/LDL	133	slower than 6:20
	MDL	134–144	6:20–5:36
	TDL	145–154	5:36–5:13
	ETL	155–168	5:13–4:20
	ITL	169–174	4:20–4:04
	SB	175–max.	faster than 4:04

RL/LDL: Low-intensity distance (low-intensity running, recovery pace); MDL: medium-intensity distance (medium-intensity running, base pace); TDL: threshold distance (threshold running, anaerobic threshold pace); ETL: endurance tempo (endurance pace, tempo running); ITL: interval training (interval training, high-intensity pace); SB: speed burst (speed bursts, sprints). The bold value represents the maximum heart rate for each athlete. These values serve as benchmarks for calculating individual percentage values in the case of the scheduled effort intensity.

Based on initial laboratory data, we proposed and then monitored PAsm-12's training intensity for each athlete. Each mesocycle and microcycle had pre-set training intensity values (proposed values) applied in practice (realized values) through PAsm-12.

3.1.3. Comparison of Proposed and Realized Training Intensity through PAsm-12 (Q2)

The intensity indicator considered was based on the physiological response of the body to the strength of the stimulus/the physical exercise performed, specifically reflected by the heart rate (HR), expressed as the average percentage per mesocycle per athlete. This percentage value is related to the maximum heart rate (MHR) of each athlete (Table 8).

Table 8. Effort intensity realized by runners and proposed by PAsm-12.

Mesocycles	Effort Intensity (Average %) Realized/ Athlete (S)						Realized Training Intensity Average S1–S6/Proposed (%)	
	S1	S2	S3	S4	S5	S6	Realized	Proposed
I	65%	75%	75%	60%	67%	70%	69%	70.0%
II	66%	76%	77%	62%	67%	70%	70%	75.0%
III	65%	67%	68%	63%	71%	72%	68%	70.0%
IV	69%	70%	70%	65%	70%	71%	69%	76.3%
V	68%	78%	74%	70%	72%	77%	73%	77.6%
VI	75%	65%	65%	70%	67%	70%	69%	72.8%
VII	75%	78%	75%	80%	76%	70%	76%	80.8%
VIII	75%	65%	65%	70%	67%	70%	69%	71.0%
IX	80%	75%	70%	76%	71%	70%	74%	76.2%
X	77%	72%	77%	81%	79%	75%	77%	80.5%
XI	79%	75%	72%	80%	78%	72%	76%	80.5%
XII	75%	66%	65%	70%	78%	70%	71%	78.3%

These values, taken as the average percentage values of realized training intensity by S1–S6/mesocycle (relative to MHR/S), were compared with the proposed percentage values of mesocycle averages by PAsm-12 (Table 9, Figure 1). Data analysis shows that training intensity was realized at 94.8%, indicating almost complete plan application.

Table 9. Differences between realized and proposed training intensity through PAsm-12.

Pair	Effort Intensity Variable Compared/Mesocycle/Realized-Proposed	Mean S1–S6 (%)	Difference	t	p
1	Realized training intensity mesocycle I Proposed training intensity mesocycle I	69 70.0	−1.0	−1.283	0.128
2	Realized training intensity mesocycle II Proposed training intensity mesocycle II	70 75.0	−5.0	−0.867	0.213
3	Realized training intensity mesocycle III Proposed training intensity mesocycle III	68 70.0	−2.0	−2.904	0.017
4	Realized training intensity mesocycle IV Proposed training intensity mesocycle IV	69 76.3	−7.3	−2.961	0.016
5	Realized training intensity mesocycle V Proposed training intensity mesocycle V	73 77.6	−4.6	0.885	0.208
6	Realized training intensity mesocycle VI Proposed training intensity mesocycle VI	69 72.8	−3.8	−1.972	0.053
7	Realized training intensity mesocycle VII Proposed training intensity mesocycle VII	76 80.8	−4.8	2.833	0.018
8	Realized training intensity mesocycle VIII Proposed training intensity mesocycle VIII	69 71.0	−2.0	−1.972	0.053
9	Realized training intensity mesocycle IX Proposed training intensity mesocycle IX	74 76.2	−2.2	1.164	0.148
10	Realized training intensity mesocycle X Proposed training intensity mesocycle X	77 80.5	−3.5	3.984	0.005
11	Realized training intensity mesocycle XI Proposed training intensity mesocycle XI	76 80.5	−4.5	2.956	0.016
12	Realized training intensity mesocycle XII Proposed training intensity mesocycle XII	71 78.3	−7.3	−0.526	0.311

To verify if the proposed training intensity/mesocycle is statistically equivalent to the realized training intensity (Q2), we used the same statistical comparison procedure of the two effort intensities' means (realized/proposed) for the entire sample S1–S6/12 mesocycle, using the paired *t*-test and the bootstrapping method (1000 samples) (Table 9).

We observe that, similar to the training volume, the realized training intensity by runners (average value S1–S6/mesocycle) is generally lower than the proposed intensity, with mostly negative differences. However, there are some exceptions where the realized intensity is close to or even higher than the proposed (mesocycle V, IX, and XII). The significance of differences is statistically significant for most mesocycle, except for mesocycle I, II, V, VIII, IX, and XII, where differences are not statistically significant. We conclude that the statistical differences were insignificant in most mesocycle, indicating good conformity with the initial plan (PAsm-12).

By calculating the effect size, the R^2 value is 0.314, indicating that 31.4% of the variation in the dependent variable (realized effort intensity) can be explained by the independent variable, namely the proposed effort intensity through PAsm-12. This is a relatively moderate coefficient, indicating a significant, but not very strong, relationship between the variables. However, the Cohen's f^2 value is 0.45, which indicates a large effect, and the independent variable (PAsm-12) has a substantial impact on the dependent variable (average intensities per mesocycle/S1–S6). This suggests that the plan was robust enough to guide the athletes towards achieving most of the proposed objectives, also demonstrating that, even with deviations from the initial plan, PAsm-12 managed to maintain a coherent direction in our female athletes' training.

3.1.4. Comparison of Realized Test Times with Proposed Execution Times in PAsm-12 (Q3)

To answer the question: How are runners' performances influenced by the partial application (90.2% of the proposed training volume and 94.8% of the requested intensity) of PAsm-12? We chose to compare the realized test times of runners in the five tests with the proposed times in the microcycle within the mesocycle corresponding to the testing moments in PAsm-12. We started from the premise that if these compared time values do not indicate significant statistical differences, and the test execution times and those proposed by PAsm-12 are statistically equivalent, we can affirm that the training volume and intensity realized by runners are sufficient to achieve the planned performance goals for the major objective competition (EMACNS Grosseto).

Results expressed in race times in the five tests conducted by the six female runners are presented in Figure 2. The female runners participated in all tests (except S2 in test 5), namely the non-specific 10 km test and four specific 21 km tests. In PAsm-12, for the non-specific test (Zărnești 10 km), the proposed and initially accepted tempo by runners was 5'10–4'50"/km, with an average of 5 min/km, converting to 3000 s/10 km for the entire test. For the specific tests in Cluj-Napoca, Oradea, and Braşov (21 Km), the proposed tempo by PAsm-12 for the entire half marathon was 5'40"–5'30"/km, with an average tempo of 5'35"/km, equivalent to 7035 s/21 km. For the European Masters Athletics Championships Non-Stadia (EMACNS Grosseto—Italy), the proposed training program tempo was 5'10"–4'50"/km, with an average of 5'/km—thus, 6300 s/21 km.

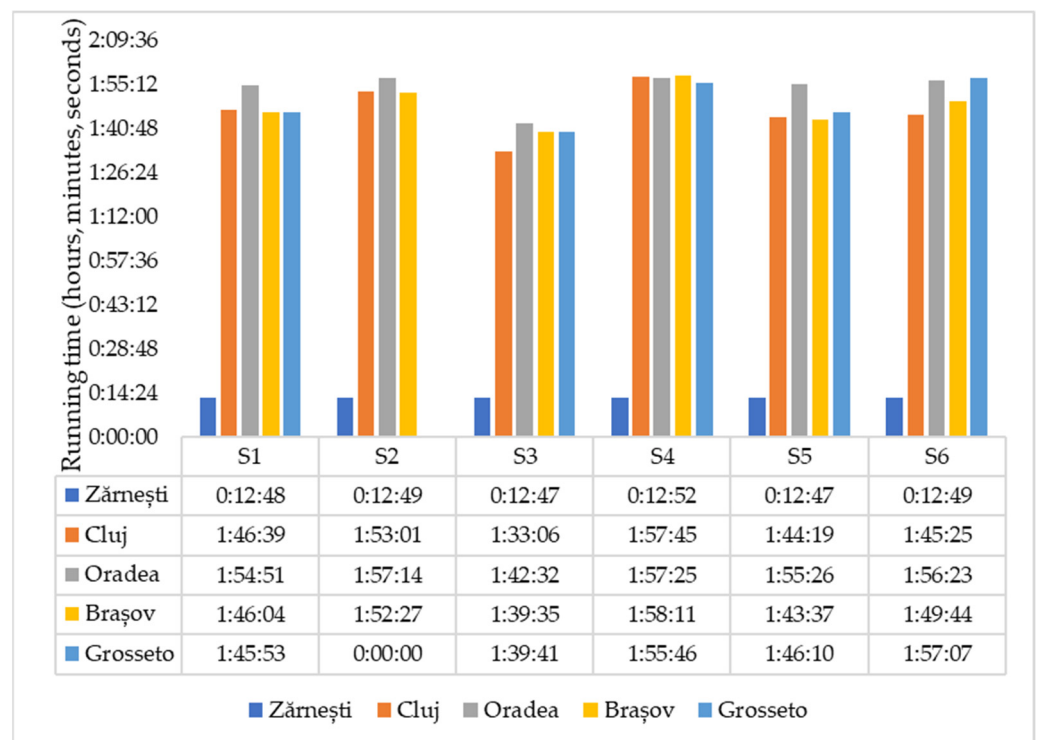


Figure 2. Results of the five tests in the 2020–2021 competition year.

To verify Q3, we used the paired *t*-test to compare the realized test times (average value/test S1–S6) with the proposed average times per km (running tempo/km) at the five testing moments included in PAsm-12. Calculations show that these times, except for the Grosseto test, are shorter, thus better, compared to the projected average test times in PAsm-12 in the corresponding mesocycle/microcycle. Four differences between the two series of times are positive, and the time obtained at EMACNS—Grosseto (Italy) is longer than the proposed time, with a negative but statistically insignificant difference (Table 10).

Table 10. Differences between the average realized test times by runners S1–S6 and the proposed average times in PAsm-12 (H3.b).

Test No.	Sports Event/Test km/Location	Proposed PAsm-12 Average Time s (I)	Realized Average Time S1–S6 s (J)	Difference I–J	SD	t	p
1	Zărnești 10 km test	3000	2951.6	48.40	110.97	0.975	0.39
2	Cluj-Napoca 21 km test	7035	6458	576.20	344.297	3.742	0.02
3	Oradea 21 km	7035	6858	177.00	433.06	0.914	0.41
4	Brașov 21 km	7035	6446.8	588.20	422.96	3.110	0.04
5	Grosseto 21 km	6300	6535.2	−235.20	441.19	−1.192	0.3

Note: N = 6, bootstrapping—1000; execution time averages are described in seconds; SD—standard deviation.

In the case of proposed average times (s/km/test) as a performance benchmark in executing the tests, analysis of these differences indicates varied results in testing: for three tests (Zărnești, Oradea, and Grosseto), the average differences are not significant ($p > 0.05$), meaning the runners achieved the overall “finish time” indicator at the projected average value set by PAsm-12. For the tests in Cluj-Napoca and Brașov, the average differences are statistically significant, with p being less than 0.05; in these tests, the runners had weaker overall performance (S1–S6) than proposed by PAsm-12. Therefore, it cannot be concluded with certainty regarding achieving the “average test times/km” proposed in PAsm-12 and the actual test times, taken as an average value for the six runners in executing the tests.

The effect size for each test, specifically the differences between the planned times and the actual times achieved, is as follows: for the 10 km test in Zărnești, Cohen’s d was 0.44, indicating a small to moderate difference; for the 21 km test in Cluj-Napoca, Cohen’s d was 1.68, indicating a large difference, favorable to the actual times achieved; for the 21 km test in Oradea, Cohen’s d was 0.41, indicating a small difference, with actual times close to those planned; for the 21 km test in Brașov, Cohen’s d was 1.39, showing a large difference, favorable to the actual times achieved, which were shorter; and for the 21 km test in Grosseto, Cohen’s d was -0.53 , suggesting a moderate difference, with the actual times being longer than those planned.

After executing the main test—the objective (EMACNS—Grosseto), the entire group agreed to continue monitoring the training process through PAsm-12 until its full completion without participating in common competitions imposed by PAsm-12. This request was largely due to family and professional responsibilities and financial constraints. However, all runners agreed to participate in the study until the full execution of PAsm-12 contents and to report continuously via smartwatches both the requested training parameters and competition participation within the competition period defined by PAsm-12, even if these were not always exclusively related to the half marathon event. Data collected from S1–S6 show that female runners continued competitive activity (except S1—due to professional and academic reasons), participating in both national and international competitions (Table 11).

Table 11. Number of competitions conducted by female runners S1–S6 during the competition period not included in PAsm-12.

Competition Level	Subjects						Total
	S1	S2	S3	S4	S5	S6	
National competitions	0	9	9	3	1	6	28
International competitions	0	0	1	3	1	1	6
Total	0	9	10	6	2	7	34

From these quantitative data, it is observed that the participation of each subject varies in number (between 0–10), with the predominant ones being at nationally scheduled competitions.

4. Discussion

The purpose of this study was to design and implement an annual physical training plan for master athletes aged 45 and above, specifically focusing on the half marathon (PASm-12) event. This age category generally includes amateur practitioners who often lack a scientifically grounded training program, at least as a guiding framework, to meet the multiple demands associated with this event. Moreover, they often do not benefit from the counseling of a specialized coach to coordinate the complex aspects of sports training and continuously adapt training methods and means to the efficiency and safety requirements necessary for the event. To apply and validate such a medium-term (over one calendar year) plan, we involved six Master amateur runners (+45 years), each with at least 10 years of competitive experience. We considered their experience and competition results prior to the study as a guarantee for both good practice of the specialized training process within our approach and future confidence from other amateur runners regarding the sustainability of the sports training model followed by our athletes.

4.1. Discussions on the Structure, Content, and Effort Indicators of PASm-12 Compared to Other Planning Documents Presented in the Specialized Literature

Compared to what is mentioned in Section 2.3.1, other studies applying endurance event (half marathon, marathon) training programming based on the same linear planning model present somewhat simplified periodization strategies compared to PASm-12. For example, planning sequences include four stages with a preparatory period (November to February), a pre-competition period (March to the end of April), and a competition period (May to September) [22] or a single 20-week competition macrocycle (“evolutionary periodization”) following a 3-month preparatory period. In this case, the competition macrocycle is divided into two mesocycles, each of 10 weeks, with the training process applied to a single performance athlete aged 50 [53]. Another planning method on a relatively short term involves a three-phase plan—base phase, training phase, and recovery phase [54]—or recommends 4–6 months of preparation until competition day [39]. Another study suggests a 12-week preparation plan for an experienced athlete [37]. In planning PASm-12, we considered a one-year training program to provide a comprehensive strategy for training and allow the practitioner to form a continuous anticipatory behavior focused on the provided methodology.

From the perspective of the number of training sessions, in PASm-12 we proposed that the amateur athletes undertake four or five training sessions per week. In other training models—for example, for the marathon distance—11–13 training sessions have been scheduled for high-performance athletes [22]. For the half marathon distance, other sources suggest either 5–6 training sessions per week for a 50-year-old performance athlete [53], 6 training sessions per week for advanced half marathoners [39], or 5 weekly training sessions with 2 rest days [54].

The means/exercises most commonly used by half marathon runners, according to studies focused on this direction, include easy running, alternating walking and easy running, acceleration runs, repeated sprint training, aerobic–anaerobic threshold running, progressive reduction in distance running, aerobic threshold long runs, Fartlek, steady-tempo running, interval running, strength endurance training—circuit type, jumps, etc. [32,35,36,39,53–56]. In PASm-12, similar means/exercises were largely utilized. In summary, we applied steady-tempo running at a pace of 5'40"–5'30"/km (the most frequently used specific method in PASm-12, representing 35.1% of total means used), moderate-paced long-distance running (making up 26.9% of the total), interval running (9.5%), Fartlek running (9% of total training means), steady-tempo running at 5'10"–4'50"/km (programmed at 5.8%), whereas hill running and steady-tempo running at 5'40"–5'10"/km were the least

used exercises in PAsm-12, representing 5.6% and 4.6% of the total means programmed, respectively. Additionally, competitive races conducted as tests in PAsm-12 account for 3.6%. In contrast to PAsm-12, another study recommends replacing 25–30% of running volume with other training options [54], which is agreed upon in our case.

The Dynamics of Volume and Intensity Indicators in PAsm-12

The most important training indicators targeted by PAsm-12 were the volume and intensity of effort. Quantitative parameters—volume indicators such as running distance and duration (when applicable)—were considered, while execution times, related with the predetermined tempo and the athlete's functional demand (heart rate relative to maximum heart rate—MHR), provided data on the qualitative component of effort, i.e., its intensity (the functional demand of the body in response to effort). In PAsm-12, during the preparatory period (PP, October–January/mesocycle I–IV), we proposed a volume of 160 km in GPP and 194.00 ± 32.18 km in SPP, with runners running an average of 40–46 km per week, 4 times per week, at an average intensity of up to 70% (72.8%) of MHR/athlete (monitored via Garmin watches). In the pre-competitive period (PPC, February–March/mesocycle V–VI), a larger running volume of 238.8 ± 11.03 km was proposed, to be completed over 5 training sessions per week, with weekly volumes ranging from 36 km to 64.8 km and intensities between 65% and 82% of each athlete's capabilities (with an average of 75.2%/PPC mesocycle). During the competitive period (CP, April to mid-September/mesocycle VII–XI), the proposed training volume was 270.92 ± 108.11 km, with runners running 42–67 km per week at intensity levels ranging from 68% to 85% of MHR/athlete (average of 77.8%). In the transition period (TP, mid-September, mesocycle XII), a volume of 29 km was proposed, with weekly training intensity ranging from 70% to 77% of MHR/athlete, averaging 78.2% per mesocycle. Our effort parameter phasing strategy in PAsm-12 is similarly noted in other studies. For example, for an experienced half marathoner, weekly running volumes of 32, 48, or 64 km are recommended [37], and for training intensity, combining moderate- and high-intensity sessions is considered an effective approach [40]. In another study on endurance runners, combining volume and intensity of effort showed no consensus on the most effective practices for maintaining or developing health and performance in amateur runners: either increase intensity by 10% per week or run 70 km per week [53]. In PAsm-12, we aimed to facilitate progressive biological adaptation to effort by scheduling shorter distances and times at the beginning of the training period to prevent early dropouts, often justified by amateur runners due to lack of time, injuries, or dissatisfaction with training due to fatigue [29]. Running more than 65 km per week for men and between 48–63 km per week for women is associated with higher health risks for amateur runners [57–59], and preventing these risks involves reducing training volume [60]. Excessive training volume can be detrimental, leading to fatigue, reduced training efficiency, uneconomic muscle effort, and increased injury risk [17]. Some authors, however, find current research results inconclusive in this regard [61].

4.2. Discussions on Comparison of Effort Volume and Intensity Indicators Proposed by PAsm-12 and Those Achieved by S1–S6

4.2.1. Comparison of Proposed and Achieved Volume—The Response to Q

To analyze the implementation of PAsm-12 in terms of volume, we compared the total running volume completed by the six runners (2347 km) with the volume proposed by the annual plan (2603.2 km). The comparison shows a difference of 256.2 km between the proposed and achieved volumes over the macrocycle, corresponding to a 90.2% implementation rate of PAsm-12 (Table 5). Generally, the female runners ran less than the proposed volume, with differences mostly negative and only twice positive in mesocycle VIII and XII. The differences are statistically significant at $p = 0.05$ for most mesocycle, except for VIII, IX, and XII (Table 6). Thus, we accept that for mesocycles VIII, IX, and XII, the differences between the proposed and the actual volume of effort are not statistically significant. In other words, in these three mesocycles, the athletes ran, on average, dis-

tances statistically equivalent to those proposed in PAsm-12. Conversely, we reject that the differences between the proposed and actual volume are not statistically significant for the other mesocycles, where the proposed volume is greater than what was actually achieved. Therefore, we can state that the annual training plan (PAsm-12), from the perspective of running volume, was implemented, but not fully. Periodic reports show that the overall training volume was achieved by the runners as follows: 85.7% by S1; 94.2% by S2; 95.2% by S3; 86.3% by S4; 88.3% by S5; and 91.2% by S6.

The analysis of the effect size for the observed differences in the training volume achieved compared to the proposed one highlighted a significant effect size (Cohen's $f^2 = 6.24$). The large effect size indicates that variations in training volume are sufficiently pronounced to have observable consequences on performance and athletes' adaptation. This finding emphasizes not only the statistical significance and substantial practical impact of the differences but also their relevance in the context of training planning for female master 45+ amateur athletes. Furthermore, the importance of this effect size extends beyond the validation of the PAsm-12 training program, serving as a guiding tool for researchers planning similar studies and contributing to the improvement of reliability and validity in future research on this area.

4.2.2. Comparison of the Intensity Percentage Value Proposed in PAsm-12 and That Achieved by S1–S6—The Response to Q2

The training intensity achieved by the runners was implemented on average (S1–S6) at 94.79% of the proposed PAsm-12 intensity. This high percentage indicates that although the achieved intensity (mesocycle I–XII/S1–S6: 69%; 70%; 68%; 69%; 73%; 69%; 76%; 69%; 74%; 77%; 76%; 71%) was slightly lower than the proposed intensity (70.0%; 75.0%; 70.0%; 76.3%; 77.6%; 72.8%; 80.8%; 71.0%; 76.2%; 80.5%; 80.5%; 78.3%) in most mesocycles, the annual training program implementation was very close to the established objectives. Thus, we accept that for mesocycles I, II, V, VIII, IX, and XII, the actual intensity of effort is statistically equivalent to the proposed intensity of effort. Conversely, we reject that the actual intensity of effort is equivalent to the proposed intensity for the other mesocycles, where the proposed intensity is significantly higher than what was actually achieved. Therefore, while PAsm-12 was largely followed in terms of training intensity, it was not fully implemented (94.8%), indicating the need for some adjustments in future applications to ensure that the proposed intensity is met in all mesocycle.

The results of the effect size calculation and the coefficient of determination (R^2) highlight several important aspects in evaluating the effectiveness of the PAsm-12 plan, especially in the context of self-managed training and athletes' self-reporting of data. With an R^2 of 0.314 and Cohen's f^2 of 0.45, it can be said that the independent variable (the training intensity proposed by PAsm-12) explains a moderate portion of the variation in the achieved training intensity and has a large effect on this variable. This means that the proposed training intensity plays a significant role in determining the achieved training intensity. Although the R^2 coefficient, calculated at 0.314, indicates a discrepancy between the proposed and achieved values, it should be emphasized that this does not necessarily represent a limitation of the PAsm-12 plan itself but rather reflects the inherent variability in a long-term training program involving athletes who self-manage their training. This variability actually demonstrates the flexibility of the PAsm-12 plan, which allowed for personalized adaptation of the training to the needs and capabilities of each athlete without compromising the overall objectives of the plan.

In principle, for both indicators of effort analyzed, we agree with studies that claim that a high training volume and a high training pace (intensity) are predictors of a better race finish time [57,59,62,63].

4.2.3. Comparison of Test Results and Proposed Times in PAsm-12 (The Response to Q3)

We aimed to assess the efficiency of PAsm-12, considering that it was not fully implemented (as expected for an intervention conducted under natural conditions over a relatively long period). We compared the average times per km from the field tests of the six athletes to the average time per test proposed by PAsm-12. If these comparisons show no significant statistical differences, indicating the times achieved and proposed are statistically equivalent, we can affirm that the achieved volume and intensity of effort are sufficient to meet the planned performance. Following data analysis, we consider the results satisfactory, as they indicate that most of the times achieved in the field are lower than the average times proposed by PAsm-12 (Table 9). Corroborating the results obtained from the responses to Q3, it can be asserted that PAsm-12 is suitable for training for the half marathon, as the athletes' performances in the five tests were either better than or equivalent to the proposed times. Compared to the average proposed time per test, which is between the maximum and minimum (Table 9), the times obtained per test (average value S1–S6) are as follows: four of the recorded times are lower than the proposed time (with two differences being statistically significantly smaller), and the time recorded in Grosseto is weaker, but the difference is statistically insignificant. Thus, we consider the times to be equivalent.

From the perspective of effect sizes for the times achieved compared to those proposed across the five tests, a valuable insight into the actual effectiveness of the PAsm-12 plan can be drawn. The variation in effect sizes among the five tests reflects the direct impact of the plan on performance, highlighting the athletes' ability to adapt and respond to the specific demands of competitions. For most tests, except Grosseto, effect sizes (Cohen's *d*) indicate improved performance, where athletes achieved better times than those proposed. This demonstrates the effectiveness of PAsm-12 in preparing athletes for competitions, validating its scientific and tailored approach to master athletes. A notable exception was the Grosseto test, where the negative effect size (-0.53) suggests that performance was below expectations. This finding indicates that competition performance is often influenced by a range of external factors related to the competitive environment. Factors such as course conditions, psychological pressure, and competition dynamics can affect results, causing them to differ from those obtained in non-competitive tests. This variation necessitates a deeper analysis of the factors that might be responsible for this deviation.

As such, although the indicators of training volume and intensity were adhered to only 90.2% and 94.8% throughout the entire macrocycle/year of preparation as outlined in PAsm-12, the female athletes managed to perform unequivocally at the average level accepted by consensus and projected by PAsm-12. Therefore, following PAsm-12 to a large extent results in positive outcomes for the performance of the female athletes in our subject group, even under conditions of international competition. This fact is also demonstrated by the placements achieved at the target competition set by PAsm-12 (European Masters Athletics Championships Non Stadia, held in Grosseto, Italy, from 12–15 May 2022), where our female athletes achieved the following rankings: S1 finished 6th (W50), recording her personal best time of 01:45:52 (PB) during the study period; S2 did not participate in the EMACNS—Grosseto due to family issues; S3 recorded a time of 01:39:41, placing 3rd (W45); S4 completed the race with a time of 01:55:46, placing 8th (W55); S5 achieved a time of 01:46:10, finishing 12th (W50); and S6 obtained a time of 01:57:07, placing 17th (W45).

In conclusion, we believe that the study results underscore the potential of the PAsm-12 plan to serve as an effective model for preparing master female athletes for half marathon events, encouraging continuous adaptation and adjustment of training plans based on real feedback obtained through testing. This approach not only enhances performance but also improves athletes' motivation and satisfaction, which are essential for sustaining long-term commitment to the sport.

4.3. Limitations

Despite these positive results supporting the practical viability of PAsm-12, our study has limitations. The primary limitation is the small sample size, resulting from the difficulty of finding participants willing to follow a common training program over a year through self-instruction. This small sample size may affect the generalizability of the results. It is possible that the use of a control group may have contributed to the reporting of more relevant data. We attempted to mitigate this by using the statistical bootstrapping method, as is done in case studies [42,49]. Another limitation is the use of self-reported data by the athletes, which can negatively affect objectivity and, consequently, the quality of the research. However, this method of data transfer was the only feasible way to explore the training indicators of interest. Additionally, there are opinions suggesting that the accuracy of measurements performed by smartwatches, a procedure we also adopted, is influenced by errors, varying in magnitude depending on the measured variable and the device used [52]. However, the validation of several such devices, including those from Garmin's range, has been conducted in various sports activities, and clinical study results have highlighted those wearable devices are important for improving athlete performance and preventing adverse cardiovascular events [64]. Additionally, it seems that at least distance measurement—one of the data directions we also adopted—appears to be the most reliable [65]. The use of heart rate belts might provide more accurate data for HR measurement, but the device we used, the Garmin Fenix 6S PRO, offers additional data that a chest belt cannot directly provide, such as: running route, altitude and terrain variation monitoring, training time and environmental conditions, pace and running speed monitoring, recovery monitoring function, etc. These features were useful to us in monitoring (adjusting) the training process.

In this context of limitations, as a subjective evaluation of intensity, we could have also used the rate of perceived exertion (RPE) as an alternative mechanism for controlling effort pace. We believe that this method could have provided valuable information, especially in situations where GPS technology or heart rate monitoring might have been limited by external interference or individual variability.

Another limitation is that the runners participating in validating PAsm-12 are not solely road runners but also engage in mountain running. The five tests conducted in PAsm-12 were road runs, so the plan should be viewed as an indicative strategy for half marathon preparation and execution. On the other hand, we believe that explaining the performances of the six athletes in our group is not only attributed to the use of PAsm-12 or the variety of training methods and tools it includes, but also to other factors that are difficult to control in a study with a single group. Among these, we mention a healthy lifestyle, manifested through appropriate nutritional strategies, suitable professional equipment, and academic education, all of which are often enhanced by domain-specific readings or the frequency of distances covered in hiking as alternative, complementary training. These aspects, interacting variably in the runners' daily routines, could be subjects of future studies. Last but not least, while PAsm-12 was designed for women, it could also be adapted for use with other categories, including men and non-binary individuals.

Additionally, some experts might consider that establishing and following a common training plan, even if only indicative, with fixed indicators of physical preparation such as volume and intensity of effort, would not only be difficult but also inefficient, as each athlete is unique in their own way.

5. Conclusions

The implementation of the annual physical training plan for master athletes aged 45+ (PAsm-12), created with the hope of becoming a model of good practice for amateur half marathon runners who do not have the guidance of a specialist, has proven to be an effective action. Although the volume and intensity of effort were not fully achieved compared to what was proposed in PAsm-12, the data from the *t*-test and the effect size analysis

indicated a substantial practical impact of the observed differences, demonstrating that the program successfully achieved results that are both statistically and practically significant.

From a methodological perspective, these indicators were progressively and judiciously scheduled, avoiding a chaotic self-training process. This facilitated the athletes' biological adaptation, reduced (practically eliminated) the risk of injury, and resulted in the maintenance or improvement of athletic performances, including competitive ones.

PASm-12 also demonstrated its ability to maintain or improve performances in real competitive conditions, even though the results in competitions, such as the Grosseto test, were influenced by external factors specific to the competitive environment, which is often difficult to replicate in non-competitive testing conditions. The success of PASm-12 underscores the complexity and comprehensiveness of this specialized sports training model, structured over a 12-month period, divided into distinct periods correlated with a competition calendar. This methodological approach provides an additional training framework compared to the short-term programming models cited in the referenced studies.

For future applications of PASm-12, it would be beneficial to include additional monitoring tools, such as more advanced wearable technologies and real-time feedback mechanisms, which could further optimize individual biological adaptations. This would allow for more personalized training adjustments, ensuring that each athlete's performance level is both challenging and achievable. Additionally, exploring the inclusion of motivational and psychosocial support within the program could enhance adherence and long-term success in this type of sports training.

By continuing to refine and adapt PASm-12, this program has the potential to become a benchmark for training master athletes, not only in the self-coaching of half marathon runners but also in various other endurance sports. It offers a solid framework for improving athletic performance while also maintaining the health and well-being of the athletes.

Additionally, researchers and practitioners who wish to replicate or test the PASm-12 model in the context of their own studies or training can receive access to all necessary supplementary information by contacting any of the authors of this study.

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SELF-PERCEPTION OF SKILLS SPECIFIC TO PROFESSIONAL DEVELOPMENT IN PHYSICAL EDUCATION AND SPORTS

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Abstract: *The aim of our study was to identify the perception of the role of mentors and mentees in the initial vocational training process (mentoring process). Differences between the amounts of scores obtained in the questionnaire for self-assessment of the perception of specific competencies in physical education and sports (EFS) between the two samples of the preliminary study was 3.09 points, the group of mentees registered 115.17 points, and the group of mentors 118.26 points. The total cumulative value recorded by both samples is between 160-105 points according to the score of the questionnaire, which indicates that both samples have a very good perception of the level of development and manifestation of EFS specific competencies in carrying out initial teaching and training activities. The development and implementation of an effective mentoring process during the initial training period is impetuous and we believe that it will ensure the premises of a teaching career focused on continuous and effective professional development, and implicitly by expanding professional skills specific to physical education and sports.*

Key words: *mentoring, mentored, physical education, specialized skills, inter-transdisciplinary skills.*

1. Introduction

The modern approach of general education must be correlated with the tendencies of updating and dynamizing

the contents and on permanent professionalization of the teachers. The permanent updating and extension of teachers' competencies facilitates the modernization and improvement of the

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complex process of physical education which has as major objectives: social integration, health optimization, physical development and optimization of motor skills [6], [7], [9], [10]. The challenges of modernizing and adapting physical and sports education are complex and involve changes in the specific objectives, forms of organization and technologies and methods used and aim at both the training of teachers and the work of students [2], [4], [5]. The training of teachers specialized in physical education and sports with high professional qualification is a desideratum of the current education, and this objective can be achieved only by the innovative reform of the process of training and development of the teaching career, especially in the beginning. The mentoring process requires establishing a relationship directed between the mentor and the mentored person and must be based on a mutual appreciation of the involvement, role and responsibilities of each party.

2. Materials and Methods

2.1. Hypotheses of preliminary study

The specific hypothesis of this preliminary study was based on the assumption that by identifying the perception of mentors and mentees on the level of development of specific professional skills in physical education and sports they can be aware and optimized in the initial training process (mentoring process).

2.2. Research organization

This preliminary research was conducted between March and July 2016, and included two sessions: one for mentors

and one for mentees. Mentored sample - 40 beginning and / or master students in the master's degree programs in school physical education and leisure activities at the Faculty of Physical Education and Mountain Sports of the Transilvania University of Braşov ". Sample of mentors - 24 mentors / tutors of specialized practice (pedagogical practice), coordinating university teachers for specialized internships and teachers with experience in coordinating students during the internships of specialized practice / pedagogical practice (first grade teachers, collaborators at the faculty) profile from Braşov). Specialists who have been mentoring and guiding the pedagogical / specialized practice in the last 3 years have been eligible for inclusion in the group of mentors.

2.3. Evaluation tools

In the study we used a standardized and validated questionnaire called - The self-assessment questionnaire for the perception of specific EFS competencies by mentors and mentees, included 40 items, divided into two subscales [8-10]. The questionnaire was developed in Google Form and distributed online to respondents. The questionnaire consists of 3 parts: one demographic, one on general skills and the last on specific skills. In our preliminary study we analyzed only the last part about self-perception skills specific to vocational training in physical education and sports. For the evaluation of each item of the questionnaire, the Likert scale with 4 levels of assessment was used, where mentors and mentees assessed their level of specific competencies, so the scores were: 1 point - completely incompetent, 2 points - less

competent, 3 points - competent, 4 points - very competent. Questionnaire score (personal contribution): between 160-105 points have a very good perception of the level of development and manifestation of specific EFS skills; between 105-50 points the perception is a good one that needs to identify the aspects that need revision or improvement; below 50 points the perception of the mentors and mentees regarding the specialized competencies is unsatisfactory and requires a major involvement and theoretical and practical activity in order to improve the specialized competencies and to optimize the level of professional competence.

2.4. Statistical analysis

In the preliminary research we used the bibliographic method: survey, statistical method and graphic method. The results were processed in SPSS 24, and the calculated statistical parameters were:

Cronbach's Alpha (α), arithmetic mean (X), standard deviation (SD), difference of arithmetic means (ΔX), sum of points (Σ), difference of sums ($\Delta \Sigma$), Student's test (T), confidence coefficient with the two levels lower and upper (95% CI), the probability level selected for this preliminary research was $p = 0.05$.

3. Results

For the questionnaire for the perception of specific physical and sports education competencies, the value of Cronbach's Alpha (α) for the sample of mentees was 0.802, and for the sample of mentors of 0.834 which shows a very good internal consistency, the questionnaire being statistically validated and we decided to use it in our preliminary and final research.

Table 1

Descriptive statistics of the Questionnaire for self-assessment of the perception of specific competences EFS, subscale 1- Specialized didactic competences

Items	Group	X	SD	t	P	95% CI	
						Lower	Upper
1. Recognizing and mentoring students with athletic talent	Mz	3,450	,638	34,173	,000	3,245	3,654
	M	3,416	,653	25,599	,000	3,140	3,692
2. Qualification to demonstrate skills that are part of the curriculum	Mz	3,225	,831	24,525	,000	2,959	3,491
	M	3,166	,816	19,000	,000	2,821	3,511
3. Respect for the principles of inclusion, individualization and differentiation	Mz	2,800	,911	19,429	,000	2,508	3,091
	M	2,875	,850	16,566	,000	2,516	3,234
4. Qualification for the pedagogical management of the class at EFS	Mz	3,175	,843	23,795	,000	2,905	3,444
	M	3,416	,816	19,000	,000	2,821	3,511
5. Qualification for first aid in the event of injury	Mz	2,650	,948	17,667	,000	2,346	2,9534
	M	3,041	,750	19,852	,000	2,724	3,358
6. Qualification to demonstrate skills that are not part of the program	Mz	2,600	1,007	16,319	,000	2,277	2,922
	M	2,958	,907	15,963	,000	2,575	3,341
7. Qualification for different ways of assessing and grading knowledge in SAI	Mz	2,600	,955	17,211	,000	2,294	2,905
	M	3,000	,884	16,613	,000	2,626	3,373
8. Ability to use different teaching methods and forms of teaching EFS	Mz	3,125	,852	23,171	,000	2,852	3,397
	M	3,208	,779	20,176	,000	2,879	3,537

Items	Group	X	SD	t	P	95% CI	
						Lower	Upper
9. Qualification to encourage students to be active in leisure sports	Mz	2,625	1,102	15,063	,000	2,272	2,977
	M	3,083	,880	17,154	,000	2,711	3,455
10. Organizational skills and knowledge for the implementation of school and extracurricular programs	Mz	3,075	,888	21,893	,000	2,790	3,359
	M	3,208	,832	18,869	,000	2,856	3,560
11. Qualification for the evaluation of one's own pedagogical activity in education	Mz	3,175	,843	23,795	,000	2,905	3,444
	M	3,333	,761	21,448	,000	3,011	3,654
12. Qualification for setting objectives according to the curriculum	Mz	3,050	,985	19,568	,000	2,734	3,365
	M	3,250	,846	18,798	,000	2,892	3,607
13. Qualification to encourage a student's personal progress	Mz	3,325	,729	28,813	,000	3,091	3,558
	M	3,333	,761	21,448	,000	3,011	3,654
14. Qualification for planning a process according to the analysis of the status, the curriculum	Mz	3,100	,871	22,505	,000	2,821	3,378
	M	3,250	,794	20,053	,000	2,914	3,585
15. Qualification for the formation and transmission of feedback information	Mz	2,775	,946	18,533	,000	2,472	3,077
	M	3,250	,794	20,053	,000	2,914	3,585
16. Qualification for the efficient transmission of theoretical content in SAI lessons	Mz	2,625	1,074	15,392	,000	2,280	2,970
	M	3,208	,832	18,869	,000	2,856	3,560
17. Qualification to encourage creativity in finding solutions to motor tasks	Mz	3,075	,888	21,893	,000	2,790	3,359
	M	3,041	,858	17,354	,000	2,679	3,404
18. Qualification for connecting EFS with other subjects	Mz	3,075	,888	21,893	,000	2,790	3,359
	M	3,083	,829	18,206	,000	2,733	3,433
19. Qualification to encourage student learning in an instructive and creative way	Mz	2,975	,973	19,324	,000	2,663	3,286
	M	3,208	,832	18,869	,000	2,856	3,560
20. Qualification for diagnosis of physical condition	Mz	3,375	,704	30,284	,000	3,149	3,600
	M	3,291	,690	23,362	,000	3,000	3,583

Mz- group mentees, M – group mentors

The best values given by the group of mentors (Table 1) were recorded at: item 1 - Recognition of students with sports talent and their guidance with 3.25 points, item 20 - Qualification for diagnosing physical condition with 3,375 points and item 13 - Qualification to encourage a student's personal progress by 3.25 points. The lowest results recorded by the sample of mentors were in item 6 - Qualification to demonstrate skills that are not part of the program and in item 7- Qualification for different ways of assessing and grading knowledge in EFS

with 2.6 points. For the sample of mentors, at subscale 1, the highest score was registered in item 1- Recognition of students with sports talent and their guidance and in item 4 - Qualification for the pedagogical management of the class at EFS, both with 3,416 points (Table 1). The good scores recorded by the sample of mentors in most of the items reflect a good concern for the further professional development and implicitly for the formation and extension of the specialized didactic competences in physical and sports education.

Table 2

Descriptive statistics of the Questionnaire for self-assessment of the perception of specific competences EFS, subscale 2- Inter-trans-disciplinary competences

	Items	Group	X	SD	T	P	95% CI	
							Lower	Upper
1.	Understanding methodological ways in teaching skills that are not part of the program	Mz	3,125	,852	23,171	,000	2,852	3,397
		M	3,041	,858	17,354	,000	2,679	3,404
2.	Understanding the historical aspects of EFS	Mz	2,600	,955	17,211	,000	2,294	2,905
		M	2,583	,880	14,373	,000	2,211	2,955
3.	Understanding the physical and motor development of children and adolescents	Mz	3,075	,858	22,641	,000	2,800	3,349
		M	3,041	,806	18,477	,000	2,701	3,382
4.	Understanding the methodical ways of teaching motor skills in the curriculum	Mz	3,175	,812	24,701	,000	2,915	3,435
		M	3,166	,761	20,375	,000	2,845	3,488
5.	Understanding the EFS curriculum.	Mz	2,750	1,006	17,282	,000	2,428	3,071
		M	2,750	,989	13,621	,000	2,332	3,167
6.	Understanding the general didactics of the EFS process	Mz	3,050	,875	22,031	,000	2,770	3,330
		M	3,041	,858	17,354	,000	2,679	3,404
7.	Understanding the functional anatomy aspects of EFS	Mz	2,675	1,022	16,546	,000	2,348	3,002
		M	2,875	,991	14,201	,000	2,456	3,293
8.	Understanding first aid health issues	Mz	2,500	1,012	15,612	,000	2,176	2,823
		M	2,500	,978	12,523	,000	2,087	2,913
9.	Understanding how to use different pedagogical strategies	Mz	2,4750	1,109	14,113	,000	2,120	2,829
		M	2,333	1,049	10,892	,000	1,890	2,776
10.	Understanding the importance of continuous professional development for the EFS teacher	Mz	3,200	,911	22,204	,000	2,908	3,491
		M	3,208	,883	17,788	,000	2,835	3,581
11.	Understanding the physiological aspects of EFS	Mz	2,750	1,080	16,102	,000	2,404	3,095
		M	2,541	1,178	10,563	,000	2,043	3,039
12.	Understanding the psychological aspects of EFS	Mz	2,575	1,106	14,714	,000	2,221	2,929
		M	2,375	1,134	10,252	,000	1,895	2,854
13.	Understanding the theory of playing sports	Mz	2,725	1,109	15,539	,000	2,370	3,079
		M	2,583	1,138	11,112	,000	2,102	3,064
14.	Understanding social circumstances in EFS lessons	Mz	3,350	,802	26,410	,000	3,093	3,606
		M	2,916	1,017	14,037	,000	2,486	3,346
15.	Understanding financial flow in EFS	Mz	2,850	1,001	18,002	,000	2,529	3,170
		M	2,625	,969	13,262	,000	2,215	3,034
16.	Understanding the biomechanical aspects of EFS	Mz	2,675	1,071	15,789	,000	2,332	3,017
		M	2,416	1,212	9,761	,000	1,904	2,928
17.	Understanding the influence of the media on EFS	Mz	2,450	1,153	13,432	,000	2,081	2,818
		M	2,208	1,062	10,183	,000	1,759	2,656
18.	Understanding the cultural aspects of EFS	Mz	2,350	,948	15,668	,000	2,046	2,653
		M	2,333	1,007	11,349	,000	1,908	2,758
19.	Understanding the philosophical aspects of EFS	Mz	2,125	1,113	12,067	,000	1,768	2,481
		M	2,083	1,138	8,961	,000	1,602	2,564
20.	Understanding the social importance of EFS	Mz	2,825	1,106	16,143	,000	2,471	3,179
		M	2,500	1,142	10,724	,000	2,017	2,982

Mz- group mentees, M – group mentors

The most significant results of the mentors (Table 2) were recorded in items: 34 - Understanding social circumstances in EFS lessons with 3,125 points, item 30 - Understanding the importance of continuous professional development for the EFS teacher and item 21 - Understanding the methodical methods in teaching skills that are not part of the program with 3,125 points. Items that scored high were considered by mentors to define the professional competence profile of beginning teachers in the initial vocational training stage. The lowest results of the auditors were obtained in item 29 - Understanding the philosophical aspects of the SAI with 2,125, in item 38 - Understanding the cultural aspects of the EFS with 2.35 points.

In the research, the most significant results obtained by mentors at subscale 2 - Inter-trans-disciplinary competences in the self-assessment of the EFS-specific perception of competence questionnaire (Table 2) were recorded in item 30 - Understanding the importance of continuous professional development for the teacher of EFS with 3,208 points, item 24 - Understanding the methodical ways of teaching motor skills in the curriculum with 3,166 points. Item 39 - Understanding the philosophical aspects of EFS and item 37 - Understanding the influence of the media on EFS had the lowest score of 2,083 points and 2,208 points respectively.

Table 3

Centralization of the results in study 3 - Self-assessment questionnaire of perception of specific EFS competencies

Subscala	Groups	X	ΔX	Σ	$\Delta \Sigma$	α
1. Specialized teaching skills	Mentored group	5,98	0,34	59,87	3,41	,764
	Mentoring group	6,32		63,26		,860
2. Inter-trans-disciplinary skills	Mentored group	5,53	0,03	55,30	0,30	,804
	Mentoring group	5,50		55,00		,817

The analysis of the total scores for both competence subscales allows us to interpret the results from the perspective of the perceptual impact of the mentors and mentors on the professional competencies specific to physical education and sports. For subscale 1 of the survey, the total score achieved by the sample of mentors was 59.87 points lower by 3.41 points compared to the total score of the sample of mentors which was

63.26. In the case of sub-scale 2 on cross-disciplinary skills, the difference between the two samples was very small of only 3 points, which highlights the fact that both have similar perceptions of the importance of developing these skills in the initial training process (Table 3). The two subscales of the questionnaire for both samples had a good and very good internal consistency, Cronbach's Alpha values being between 0.764 and 0.860.

Table 4

Amount of the total score for the Self-Assessment Questionnaire on the perception of professional competences in EFS

Sample	Σ total score	$\Delta\Sigma$ total score
Mentored group	115,17	3,09
Mentoring group	118,26	

The differences between the sums of the scores obtained in the self-assessment questionnaire of the perception of specific EFS competencies between the two samples of the preliminary study was 3.09 points, the group of mentors registered 115.17 points and the group of mentors 118.26 points (Table 4). The total cumulative value recorded by both samples is between 160-105 points according to the score of the questionnaire, which indicates that both samples have a very good perception of the level of development and manifestation of specific EFS skills in the initial teaching and professional activities.

4. Discussion

The results of our preliminary study contribute to expanding the knowledge of the field of physical education and sports and confirm the trends identified in previous studies on the importance of the mentoring process. Mentoring programs have been introduced to improve the professional experiences of teachers at different stages of their careers, mainly in the early stages, in the initial stage and consists in providing continuous and specific assistance for the professional development of teachers [11]. The motivations for starting and continuing the teaching career are very important, being influenced by a series of institutional, financial, human and personal factors. According to studies, the

decision to develop a teaching career depends on financial conditions, school infrastructure, school location, the harmony of the teaching staff, etc., but a determined role is played by the intrinsic motivations of each teacher [8], [12]. The didactic activity represents an activity of facilitating the interactions between all the factors involved in the school instructive-educational process. An important role in the teaching career is played by the quality and variety of professional experiences in the beginning period, which represent the foundations of a dynamic and efficient teaching career.

5. Conclusions

The hypothesis specific to the preliminary study was confirmed, namely the identification of the perception of mentors and mentors on the level of development of professional skills specific to physical education and sports can determine their awareness and optimization in the initial vocational training process (mentoring process). Regarding subscales 1 - Specialized teaching competencies, we consider that the differences in perception registered between the sample of mentors and the mentors are due to the level of experience and expertise in the teaching activity of physical education and school sports. The results at subscale 2 were approximately equal between the two research samples, reflecting a correct perception of inter- and trans-disciplinary

competencies. The role of these competencies is major and contributes to completing the profile of professional competence of teachers with specialization in physical education and sports.

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