Journal of Human Kinetics volume 104/2026, 313–327 DOI: 10.5114/jhk/216046

Section IV – Psychological and Sociological Aspects of Sport and Exercise

Comparative Patterns of Youth Sports Specialization, Training Characteristics, and Injuries in Team vs. Individual Sports

by

Bartosz Wilczyński [1,], Jakub Buler [2], Rafał Buler [2], Michał Grochowski [2,3], Bartosz Puchalski [2], Rodrigo Ramirez-Campillo [4,5,6], Mariola Gepfert [7], Katarzyna Zorena [1]*

The increasing specialization of youth sports has raised concerns about higher injury rates and emotional burnout, with conflicting research on whether the risks differ between team and individual sports. This study examined patterns of sports specialization, injury history, and training characteristics among youth athletes in Poland. A total of 271 athletes aged 8–16 years (41% female) from clubs and schools participated in the study. Measures included injury history, the specialization level, training volume, and demographic factors (age, sex, and residence). Team sport athletes showed higher specialization levels than those in individual sports (2.23 ± 0.65 vs. 1.83 ± 0.79, $p < 0.001$) and trained more weekly hours in their main sport (10.54 ± 3.65 vs. 5.62 ± 2.93, $p < 0.001$). No significant differences in injury history were found between groups ($p = 0.15$). Factors significantly associated with team sport participation included being male (odds ratio [OR] = 4.28, 95% confidence interval [CI]: 2.47–7.40), older age (OR = 2.56, CI: 1.99–3.30), and urban residence (OR = 4.45, CI: 2.09–9.45). Machine learning analysis (SHAP) identified weekly training volume in the main sport as the most influential predictor of the sport type. In summary, team sport athletes exhibited greater training loads and higher specialization levels than individual sport athletes. Demographic factors were also strongly associated with sport type selection. Weekly training volume in the main sport emerged as the most critical indicator of participation in either team or individual sports.

***Keywords**: sports injuries; adolescent; sports performance; physical fitness*

Introduction

Early specialization in sports among youth athletes is becoming more prevalent and could have substantial, not necessarily beneficial, implications for public health (Bell et al., 2019; Kliethermes et al., 2021; Wunderlich et al., 2021). In the United States, up to 20 million youth athletes may be highly specialised, with healthcare costs from related injuries estimated at from $800 million to $5.2 billion annually (Bell et al., 2019). Sports specialization is typically defined as focused participation in a single sport for most of the year, limiting engagement in other athletic activities (Bell et al., 2021). In one of the most widely adopted classification systems, i.e., a three-point specialization scale, athletes are asked whether they (1) have quit other sports to focus on one discipline, (2) consider one sport more important than others, and (3) train in that sport for

[1] *Department of Immunobiology and Environmental Microbiology, Medical University of Gdansk, Gdansk, Poland.*
[2] *Department of Intelligent Control Systems and Decision Support, Faculty of Electrical and Control Engineering, Gdansk University of Technology, Gdansk, Poland.*
[3] *2nd Department of Radiology, Medical University of Gdansk, Gdansk, Poland.*
[4] *Exercise and Rehabilitation Sciences Institute, School of Physiotherapy, Faculty of Rehabilitation Sciences, Universidad Andres Bello, Santiago, Chile.*
[5] *Sport Sciences and Human Performance Laboratories, Instituto de Alta Investigación, Universidad de Tarapacá, Arica, Chile.*
[6] *Department of Physical Activity Sciences, Universidad de Los Lagos, Osorno, Chile.*
[7] *Department of Sports Training, Institute of Sport Sciences, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland.*
* Correspondence: bartosz.wilczynski@gumed.edu.pl

more than 8 months per year. Based on the number of 'yes' responses, their degree of sports specialization is categorized as low (0–1), moderate (2), or high (3) (Jayanthi et al., 2015).

Sports specialization has been associated with musculoskeletal overuse injuries (Bell et al., 2018; Jayanthi et al., 2015, 2019) and emotional burnout (Difiori et al., 2014). Furthermore, high training volumes can increase the risk of both overuse and acute injuries, regardless of the specialization level (Agel and Post, 2021). Exceeding a weekly number of training hours equal to an athlete's age has also been associated with greater injury risk (Jayanthi et al., 2015).

However, existing evidence on the relationship between training characteristics, specialization, and injury varies across different types of youth sports (Frome et al., 2019; Moseid et al., 2019; Pasulka et al., 2017). For instance, Theisen et al. (2013) reported that team sport athletes had a higher incidence of injuries, whereas others (Bell et al., 2019; Murday et al., 2024; Pasulka et al., 2017) found that athletes specialised in individual sports faced more overuse injuries and higher training volume.

Additionally, team sports are associated with better health outcomes compared to individual activities (Eime et al., 2013). Thus, it is important to consider the various factors that may influence child's preference for either individual or team sports. In this case, not only demographic factors might have an impact, but also the injury history, training characteristics and sports specialization.

It is also worth noting that many studies rely on recall questionnaires filled out by youth athletes without assistance from coaches or parents, which could help with reliability (Smith et al., 2017). The issues outlined above highlight a clear need for in-depth research analysing the causes and factors contributing to injuries of youth athletes, both in individual and team sports.

Traditional statistical methods often rely on linear assumptions and are limited in handling high-dimensional, nonlinear, or collinear data, conditions common in sports performance and injury research. In contrast, machine learning (ML) techniques can automatically detect complex, nonlinear patterns and interactions between multiple variables without predefined assumptions. ML has recently gained prominence in sports science (Hojka et al., 2016; Van Eetvelde et al., 2021; Xiang et al., 2023). This applies to game analysis, performance, outcome predictions as well as injury risk (Amendolara et al., 2023; Hubáček et al., 2019; Rossi et al., 2021; Van Eetvelde et al., 2021).

Therefore, the purpose of this study was to examine the patterns of sports specialization, injury history, and training characteristics among youth athletes participating in both individual and team sports.

Methods

Design and Procedures

This cross-sectional study was conducted in northern Poland, from 2023 to 2024, following the STROBE guidelines (von Elm et al., 2007). Participants were recruited via voluntary response sampling during educational meetings involving parents, coaches, and youth athletes. These meetings were conducted as part of the "Science of Healthy Sport for Children and Adolescents" project. The study received prior approval from the Bioethics Committee for Scientific Research of the Medical University of Gdansk, Gdansk, Poland (protocol code: NKBBN/241/2023; approval date: 26 April 2023) and was registered in clinicaltrial.gov database (NCT06325228). Participants and parents/guardians provided written informed consent. The manuscript was evaluated using the Checklist for statistical Assessment of Medical Papers (CHAMP) (Mansournia et al., 2021). Inclusion criteria were: i) signed consent for participation and information about the study, ii) participants actively engaged in organised sports with current approval from a sports physician, and iii) participants aged between 8 and 16 years, iv) a minimum 6 months of sports training experience. All supplementary materials (additional Figures, Table, and Files) are available at https://osf.io/5zb8y.

Measures

Questionnaires were administered during meetings and through face-to-face interviews. Researchers assisted participants during questionnaire completion, and coaches and parents/guardians were also available to help, particularly with retrospective questions (e.g., injury history). Face-to-face interviews with parents and coaches of youth athletes offer a

valuable method to reduce recall bias and minimize reporting inaccuracies. The paper versions of the questionnaires were collected with the signatures of participants and their parents/guardians. These responses were then transcribed into an Excel file, fully anonymized, and uploaded to the cloud for analysis. Researchers verbally explained the topics, including injury interpretation and training volume, before distributing the questionnaires. Demographic information and training volume data, including the average weekly hours of all sports (including PE classes or other extracurricular sports) and the main sport, were collected. Based on the age and weekly training hours data, it was determined whether athletes exceeded the weekly hours-to-age training rule (Jayanthi et al., 2020), and a dichotomous classification (yes or no) was performed. Responses regarding the main sport practised enabled classification into individual vs. team sports. Questions about sports specialization were prepared according to recommendations by Jayanthi et al. (2020), and classified on a three-point scale (low = 0–1, moderate = 2, high = 3): i) "Is your main sport more important to you than other sports? (if you practised only one sport, choose 'yes')"; ii) "Do you train one main sport for more than 8 months a year?"; iii) "Have you given up another sport to focus more on one main sport?" Participants (and/or their parents/guardians) reported the age at which they began their main sport (in years) to determine their training experience in this sport discipline.

The questionnaire also included open-ended questions about the injuries and a dichotomous question about injury history in the last 12 months (yes/no). Participants were asked about the location of injuries (e.g., a knee, an ankle, a shoulder, the lower back), which were then classified as upper, lower, and torso, and the type of injuries (acute or overuse). Participants were also asked whether they had experienced multiple injuries (yes/no). The geographical factor was determined based on the locations of training sessions, meetings, and residences. This classification was simplified into two categories: rural or urban.

Participants and Study Characteristics

Of the 373 respondents, those with incomplete or inconsistent answers were excluded. Consequently, complete data were obtained from 271 participants (mean age 12.36 ± 1.73 years, 41% girls; including 188 team and 83 individual sport athletes). A total of 114 participants (42.1%) reported a history of injury (over the last year), mostly (n = 80) involving the lower limbs. Overuse injuries were observed in 16.6% of all participants, while acute injuries accounted for 25.5% of the total sample. Additionally, 21 participants experienced multiple injuries in the past 12 months. Detailed data on demographics, sports specialization, training volume, and injury history are presented in Table 1. The most practised sports were soccer (37.8%), handball (24%), swimming (17.6%), and gymnastics (9%). Team sport participants were older (12.96 ± 1.45 years vs. 10.99 ± 1.53 years, $p < 0.001$) and had more training experience (5.01 ± 2.63 years vs. 4.23 ± 2.12 years, $p < 0.05$). Geographic differences showed individual sport athletes were more often from urban areas ($p < 0.001$).

Equality, Diversity and Inclusion Statement

We included all eligible participants, irrespective of sex, race/ethnicity, culture, or socioeconomic background. The analysis did not account for disparities related to gender, race, socioeconomic status, or marginalized groups. Our research team was composed of scientists from various disciplines, encompassing both junior and senior researchers.

Statistical Analysis

All analyses were conducted in Python (v3.12.2) using the SciPy (v1.11.3), Statsmodels (v0.14.2) and SHapley Additive exPlanations (SHAP) (v0.45.1). Descriptive statistics (means and standard deviations) summarised the characteristics of individual and team sports youth athletes. The independent variables were age, years of training experience in the main sport, sex, training volume (all sports and main sport), injury history, the type (overuse/acute) and the location (lower/upper/torso), a geographic factor (rural/urban), sports specialization (low/moderate/high) and related question-answer criteria. The outcome was the sport type (individual or team).

Means and standard deviations were calculated for continuous variables, while mean ranks with standard deviations were used for ordinal variables. Proportions were calculated for

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categorical variables (e.g., geographic factor, sports specialization-related criteria, injury history). Before performing comparative statistical tests, normality and homogeneity of variance was checked using the Shapiro-Wilk test and the Levene's test, respectively.

The Student's *t*-test assessed mean differences between two independent groups when data were normally distributed, and variances were equal. When variances were not equal, the Welch's *t*-test was used. The Mann-Whitney U test compared medians between two groups for non-normally distributed data. The Chi-square test was employed to compare differences in the proportions of categorical variables between two groups. In cases where the number of samples was less than five in at least one group, the Fisher's exact test was used instead.

Univariate and multivariate logistic regression (LR) analyses were conducted to obtain odds ratios (OR) to assess the likelihood of an athlete participating in individual versus team sports based on independent variables (i.e., sex, age, geographical factors, training volume, athlete experience, and specialization-related criteria). Multivariate models were adjusted for potential confounders by including relevant sets of variables, i) demographic characteristics, ii) weekly time allocated to sports, iii) athlete's experience, iv) athlete's specialization. The OR was considered statistically significant when the *p*-value was < 0.05 and the 95% confidence interval (CI) did not include 1.

To differentiate between youth athletes in individual versus team sports, we used an LR model with all independent variables. Although the model coefficients demonstrate the influence of alterations in the input features, they are unsuitable for measuring overall importance due to discrepancies in the scale of measurements. To better understand features significance, we employed SHAP (Lundberg and Lee, 2017), which uses SHAP values derived from cooperative game theory (Shapley, 1953). The SHAP values represent the average impact of a feature on independent variables by considering all possible feature combinations. This approach requires the model output to be linear with respect to input data, which is true for the log-odds result of an LR model. By averaging absolute SHAP values for each feature within the analysed data, we determined the global importance of each variable.

Results

Injury History

Chi-square analysis showed a non-significant difference in overall injury history between groups (team: 85 (45.2%) vs. individual: 29 (35.4%), $p = 0.15$) (Table 1). LR, adjusted for age, sex, and training experience, also indicated non-significant differences in the prevalence of acute and overuse injuries or their locations (upper, lower, torso) ($p > 0.05$). Figure 1 shows standardised sports injury data by group and injury type.

Training Characteristics

Individual sport athletes trained significantly fewer hours for their main sport and overall (Mann Whitney U test, $p < 0.001$) (Figure 2a). For the main sport, team athletes trained 10.54 ± 3.65 h per week, whereas individual athletes trained 5.62 ± 2.93 h per week. Data distributions by group, sex, and weekly training volume for the main sport are shown in Figures 2 and 3.

Additionally, the number of athletes exceeding the weekly hours-to-age training rule was significantly greater (Fisher's exact test, two-sided, $p < 0.001$) for team sport athletes (n = 52, 27.7% from total) compared to individual sport athletes (n = 4, 4.8% from total) (Figure 3b).

Sports Specialization

The distribution of sports specialization in groups is shown in Figure 2. Mann-Whitney test results showed lower overall sports specialization among individual sport athletes (team: 2.23 ± 0.65 vs. individual: 1.83 ± 0.79, Mann Whitney U test, $p < 0.001$). In the three-level classification, LR adjusted for age, sex, and training experience revealed a significant difference only for the "low" specialization category (team: 16 [8.5%] vs. individual: 28 [33.7%], $p < 0.05$) (Table 1, Figure 2). When breaking down specialization into questions (main sport more important than others, training > 8 months/year), Chi-square values indicated fewer affirmative responses among individual sport athletes. The question regarding giving up another sport for the main sport showed no significant difference between groups. Additionally, individual sport athletes started their main sport

significantly earlier (team: 7.81 ± 2.28 years vs. individual: 6.46 ± 1.65 years, Mann Whitney U test, $p < 0.001$).

Factors Influencing Participation in Team Sports

Table 2 presents the results of univariate and multivariate analyses comparing factors influencing the likelihood of participating in individual versus team sports. The analyses were grouped into four categories: demographic characteristics, weekly training time, athlete's specialization criteria, and the overall specialization score.

Demographic Characteristics (Group A)

Males were more likely to participate in team sports (univariate OR = 4.28, CI: 2.47–7.40; multivariate ORs = 3.02–12.17). Older age was also associated with higher odds of participating in team sports (univariate OR = 2.56, CI: 1.99–3.30; multivariate ORs = 2.09–2.43). The geographical factor showed a significant association in both univariate (OR = 4.45, CI: 2.09–9.45) and multivariate models (ORs = 2.72–5.31).

Weekly Training Time (Group B)

The hours-to-age training rule had the highest OR in univariate analysis (OR = 7.55, CI: 2.63–21.67), indicating a strong likelihood of participating in team sports. This association remained significant in multivariate analyses (ORs = 7.60–8.57). Greater total training volume was associated with team sports (univariate OR = 1.29, CI: 1.19–1.39) and remained consistent in all multivariate models. Higher training volume in the main sport was also associated with team sports (univariate OR = 1.52, CI: 1.37–1.69; multivariate ORs 1.36–1.56).

Athlete's Experience and Specialization Criteria (Group C)

Group C included individual items from the sports specialization scale and questions related to athletes' experience. The "Gave up another sport for main sport" question initially showed a potential association with team sports participation in univariate analysis (OR = 1.72, CI: 0.97–3.04), becoming statistically significant after adjusting for weekly training time (OR = 2.12, CI: 1.04–4.32). The "Main sport considered most important" variable consistently exhibited a strong association with team sports (univariate OR = 3.43, CI: 1.78–6.58; multivariate OR = 3.20, CI: 1.35–7.60). Although the univariate analysis indicated a strong association for "Trains more than 8 months per year" (OR = 3.01, CI: 1.24–7.28), this was not significant in multivariate models (ORs = 2.71–1.76). Additionally, athletes who started their main sport at an older age were more likely to participate in team sports (univariate OR = 1.36, CI: 1.19–1.56; multivariate ORs = 1.28–1.48).

Athlete's Specialization (Group D)

Specialization was strongly associated with participation in team sports (univariate OR = 2.63, CI: 1.72–4.02). This remained significant in multivariate analyses (ORs = 1.91–7.13).

Shapley Additive Explanations

According to SHAP values in the model's prediction, the most important feature (SHAP value = 1.62) indicating whether a participant was involved in an individual or team sport, was the weekly training volume (i.e., hours-to-age training rule) devoted to the main sport (Figure 4).

Discussion

The aim of this study was to examine the patterns of sports specialization, injury history, and training characteristics among youth athletes participating in both individual and team sports. In summary, the results indicated that demographic factors (especially being male and older age), more weekly training hours, greater training volume, and specialization were strongly associated with participation in team sports. These associations were robust across both univariate and multivariate models, highlighting the statistical relevance of these patterns between individual and team sport athletes.

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Table 1. Participants' characteristics by the sport type.

	Total	Team sports	Individual sports	*p*-value
Demographics				
Participants	271	188	83	–
Male sex, N (%)	160 (59.0)	131 (69.7)	29 (34.9)	**<0.001**
Chronologic age, y	12.36 ± 1.73	12.96 ± 1.45	10.99 ± 1.53	**<0.001**
Experience in the main sport, y	4.77 ± 2.51	5.01 ± 2.63	4.23 ± 2.12	**<0.05**
Geographic factor, n (%) Urban Rural	196 (72.3) 75 (27.7)	122 (64.9) 66 (35.1)	74 (89.2) 9 (10.8)	**<0.001**
Training				
Training volume considering the main sport, h/week	9.03 ± 4.12	10.54 ± 3.65	5.62 ± 2.93	**<0.001**
Training volume considering all sports, h/week	11.65 ± 4.50	12.92 ± 4.00	8.79 ± 4.27	**<0.001**
Hours-to-age training rule, N (%)	56 (20.7)	52 (27.7)	4 (4.8)	**<0.001**
Sport specialization				
Age at which the main sport was started, y	7.40 ± 2.20	7.81 ± 2.28	6.46 ± 1.65	**<0.001**
Given up a sport for their main sport, N (%)	94 (34.7)	72 (38.3)	22 (26.5)	0.08
Main sport more significant, N (%)	225 (83.0)	167 (88.8)	58 (69.9)	**<0.001**
Trains more than 8 mth/yr, N (%)	249 (91.9)	178 (94.7)	71 (85.5)	**<0.05**
Sports specialization, mean rank (SD)	2.11 (0.72)	2.23 (0.65)	1.83 (0.79)	**<0.001**
High, N (%)	81 (29.9)	65 (34.6)	16 (19.3)	0.12
Moderate, N (%)	146 (53.9)	107 (56.9)	39 (47.0)	0.91
Low, N (%)	44 (16.2)	16 (8.5)	28 (33.7)	**<0.05**
Injuries				
Injury history, N (%)	114 (42.1)	85 (45.2)	29 (34.9)	0.15
Upper	23 (8.5)	15 (8.0)	8 (9.6)	0.22
Lower	80 (29.5)	64 (34.0)	16 (19.3)	0.87
Torso	11 (4.1)	6 (3.2)	5 (6.0)	0.06
Overuse Acute	45 (16.6) 69 (25.5)	35 (18.6) 50 (26.6)	10 (12.0) 19 (22.9)	0.24
More than one injury	21 (7.7)	18 (9.6)	3 (3.6)	0.14

Note: Values in bold indicate statistical significance: [a] $p < 0.001$; [b] $p < 0.01$; [c] $p < 0.05$, *N: number of participants, y: years, h/week: hours per week, SD: standard deviation*

Table 2. Odds ratios (95% CI) from univariate and multivariate logistic regression models adjusted for groups of variables.

		Univariate	Multivariate *Models adjusted for a group of variables*			
			Group A	Group B	Group C	Group D
	Individual vs team	Odds ratio (95% confidence interval)				
Demographic characteristics Group A	Sex (M)	**4.28 (2.47–7.40)[a]**		**3.02 (1.55–5.87)[a]**	**12.17 (5.70–25.99)[a]**	**4.91 (2.73–8.84)[a]**
	Age	**2.56 (1.99–3.30)[a]**		**2.09 (1.57–2.78)[a]**	**2.31 (1.79–2.99)[a]**	**2.43 (1.88–3.15)[a]**
	Geographical factor	**4.45 (2.09–9.45)[a]**		**5.31 (2.15–13.09)[a]**	**2.72 (1.10–6.67)[c]**	**4.06 (1.88–8.78)[a]**
Weekly time allocated to sports Group B	Hours-to-age training rule	**7.55 (2.63–21.67)[a]**	**8.57 (2.41–30.43)[a]**		**6.67 (2.19–20.35)[a]**	**7.60 (2.60–22.25)[a]**
	Training volume considering all sports	**1.29 (1.19–1.39)[a]**	**1.17 (1.07–1.29)[a]**		**1.26 (1.16–1.37)[a]**	**1.26 (1.17–1.37)[a]**
	Training volume considering the main sport	**1.52 (1.37–1.69)[a]**	**1.36 (1.21–1.53)[a]**		**1.56 (1.38–1.76)[a]**	**1.51 (1.36–1.69)[a]**
Athlete's experience / specialization related criteria Group C	Gave up another sport for the main sport	1.72 (0.97–3.04)	1.48 (0.72–3.04)	**2.12 (1.04–4.32)[c]**		**0.39 (0.17–0.93)[c]**
	Main sport considered most important	**3.43 (1.78–6.58)[a]**	**2.88 (1.14–7.23)[c]**	**3.20 (1.35–7.60)[b]**		1.59 (0.70–3.61)
	Trains more than 8 months per year	**3.01 (1.24–7.28)[c]**	2.71 (0.78–9.10)	1.76 (0.46–6.70)		1.16 (0.43–3.18)
	Age at which the main sport was started	**1.36 (1.19–1.56)[a]**	**1.28 (1.04–1.58)[b]**	**1.48 (1.23–1.77)[a]**		**1.36 (1.18–1.57)[a]**
Athlete's specialization Group D	Specialization score (1–3)	**2.63 (1.72–4.02)[a]**	**1.91 (1.09–3.34)[b]**	**2.39 (1.40–4.08)[a]**	**7.13 (1.36–37.34)[b]**	

Note: Values in bold indicate statistical significance: [a] $p < 0.001$; [b] $p < 0.01$; [c] $p < 0.05$

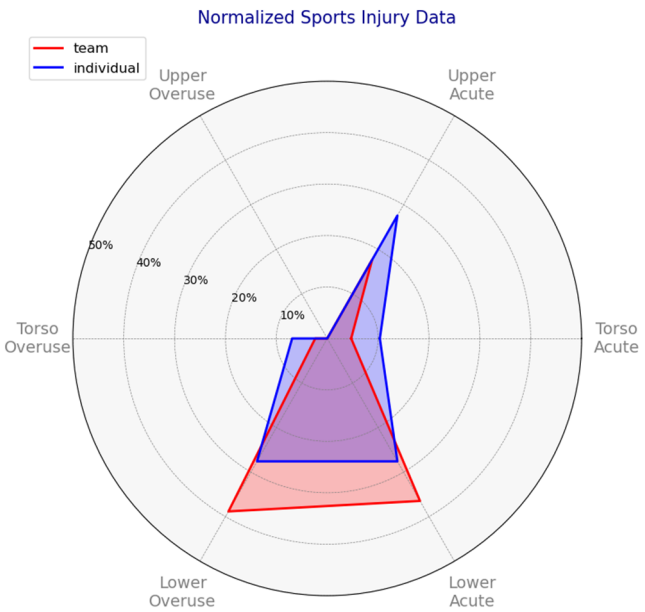

Figure 1. Radar plot comparing the injury type and localization between team and individual sport athletes.

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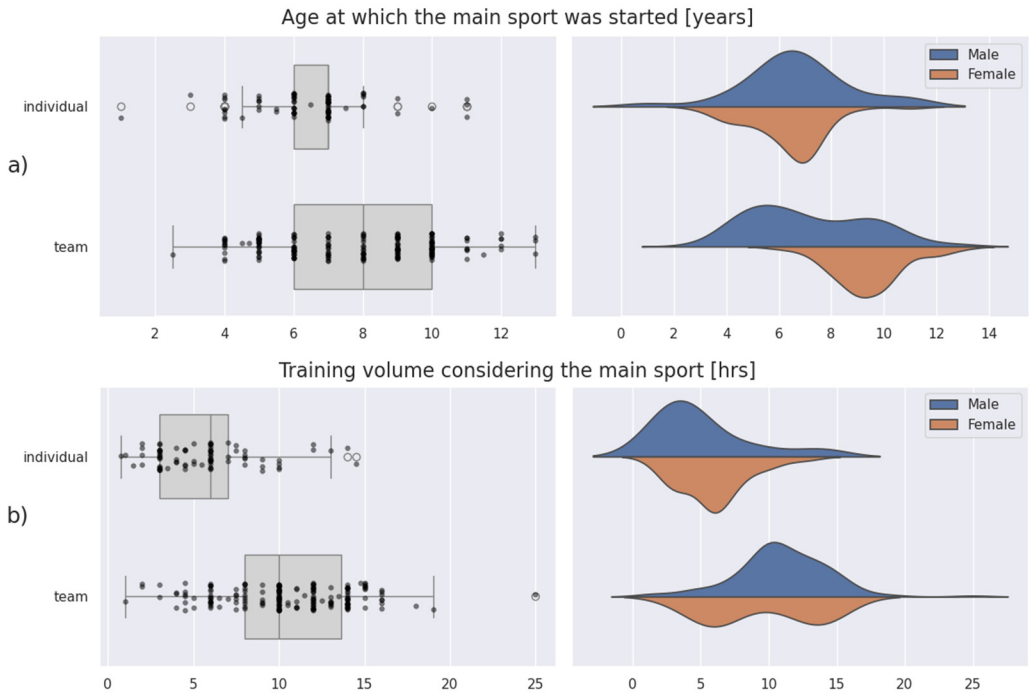

Figure 2. a) Age at which athletes began training their main sport by group and gender; b) Weekly training volume for the main sport by group and gender.

Blue = male athletes; Orange = female athletes. Left panels show boxplots with individual data points; right panels show violin plots illustrating distribution density

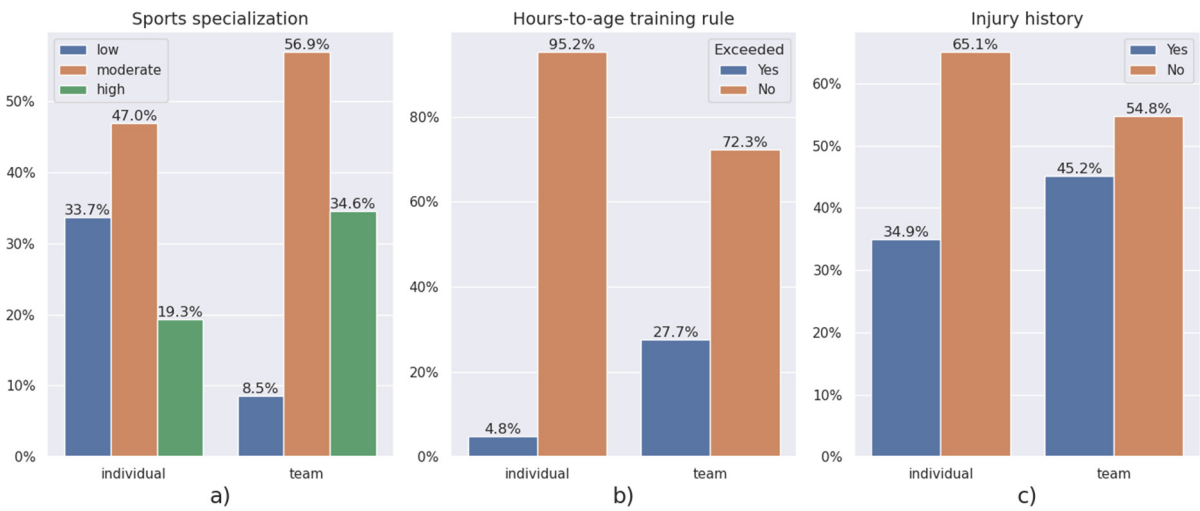

Figure 3. Distribution of individual and team sports athletes according to a) sports specialization, b) exceeding training hours indicated by the hours-to-age training rule considering the main sport, c) injury history.

Panel a shows distribution of specialization levels (low, moderate, high); Panel b indicates whether weekly training hours exceeded the age ratio; Panel c presents proportion of athletes with or without previous injuries. Percentages represent group proportions

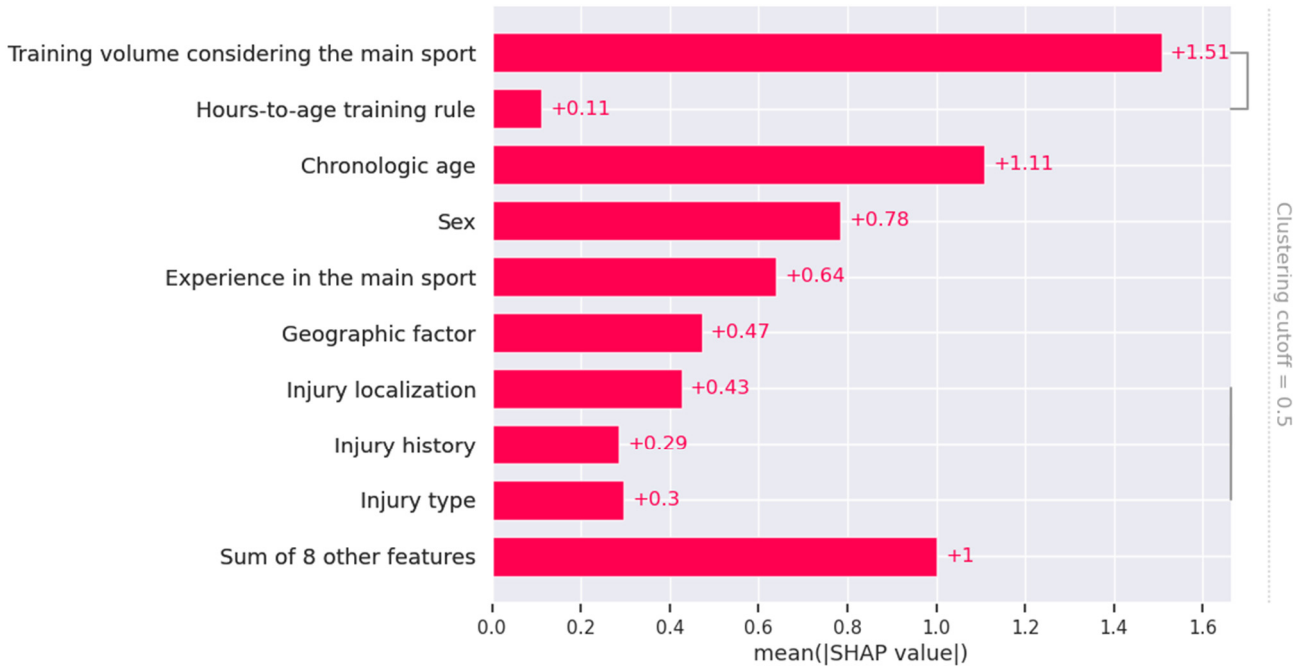

Figure 4. Aggregated importance of features derived from SHAP values, with clustering based on their correlation.

Bars represent mean absolute SHAP values, where higher values indicate stronger predictive contribution. Features are clustered by correlation, with a cut-off value of 0.5 defining cluster separation

Injury History

Previous studies suggested higher injury rates among specialised individual athletes (Bell et al., 2018; Jayanthi et al., 2015; Murday et al., 2024; Pasulka et al., 2017). Our findings showed no significant difference in overall injury history between individual and team sport participants. This contrasts with Murday et al. (2024) who reported that individual sport athletes—especially those with higher specialization and greater training volumes—were at increased injury risk, likely due to earlier and more exclusive sport engagement. Similarly, Post et al. (2017) found that highly specialized youth athletes were more likely to report both overuse and general injuries, particularly when training exceeded recommended thresholds in duration or frequency. Other studies not categorising by specialization reported higher injury prevalence in team sports. Specifically, Theisen et al. (2013) found greater injury risk in team sports, whether overuse or traumatic. In our study, there was a trend toward more acute than overuse injuries in both groups (69 vs. 45). Surprisingly, 85% of basketball players, 54% of gymnasts, and 47.5% of soccer players reported injuries in the past year. The lack of significant differences in injury prevalence aligns with recent findings that injury risks may be more influenced by training volume, intensity, and competition frequency (Agel and Post, 2021; Post et al., 2017; Theisen et al., 2013). Moreover, exceeding 16 hours of training per week has been identified as a risk factor for injury (Brenner, 2016; Myer et al., 2016). In our study, none of the athletes surpassed this threshold when

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considering both their primary sport and total physical activity.

Training Characteristics

Individual sport athletes trained significantly fewer hours for their main sport and overall compared to team sport athletes, differing from earlier studies that suggested higher training volumes for individual sports (Bell et al., 2018; Pasulka et al., 2017). For instance, Pasulka et al. (2017) found that specialised individual athletes trained 11.8 h per week versus 10.3 h for team sport athletes. In our study, team athletes trained similarly (10.54 ± 3.65 h), but individual athletes trained only 5.62 ± 2.93 h. This may be because those authors included a wider age of participants (7 to 18 years). In our study, 21% of participants exceeded the recommended training volume, team sport athletes more often than individuals ($p < 0.001$). This suggests team sports may require more practice to develop numerous technical and tactical skills (Theisen et al., 2013). Moreover, Valenzuela-Moss et al. (2024) reported decreased sports participation and increased specialization from middle to high school, possibly explaining higher training volume in team sports.

Sports Specialization

Our analysis showed lower overall sports specialization among individual compared to team sport athletes. This contrasts with earlier reports linking individual sports to higher specialization levels (Myer et al., 2015; Pasulka et al., 2017), likely due to varying definitions and evaluation of specialization (Smith et al., 2017). Pasulka et al. (2017) defined specialization only as training in a single sport for over 8 months per year. However, after adjusting for age, gender, and training volume, no significant differences were observed between high and moderate specialization levels, but a difference was noted in low specialization (Pasulka et al., 2017). In our study, individual sport athletes began training in their primary sport discipline earlier (mean age 6.5 years) than team sport athletes (7.8 years), likely due to the skill-based nature of individual sports (e.g., gymnastics, swimming) (Rugg et al., 2021). A recent cohort study found early specialization, defined as starting before the age of 15, did not increase scholarship opportunities or affect career length, but was associated with higher burnout and attrition rates, especially among female athletes (Rugg et al., 2021).

Factors Influencing Participation in Sport

Our study found that male and older individuals were more likely to participate in team sports, which is consistent with the literature suggesting these groups prefer the social interaction, teamwork, and competitive play offered by team sports (Eime et al., 2013; Woods et al., 2023). Another possible explanation is that societal norms also encourage boys and older children to engage in competitive activities (Eime et al., 2013). Furthermore, the geographical factor also plays a significant role, indicating that regional sports culture and availability may influence participation patterns. The significant association between geographical factors and the sport type suggests that urban areas might provide more opportunities and facilities for individual sports. This is supported by studies highlighting the impact of socio-environmental factors on sports engagement (Eime et al., 2013).

Specialization was strongly associated with participation in team sports, both in univariate and multivariate analyses. This finding aligns with early literature suggesting that team sports often require early specialization to develop specific skills and strategies essential for high-level competition (Baker et al., 2003; Mendes et al., 2025). Early sports specialization is particularly prevalent in skill-intensive sports such as soccer, basketball, and gymnastics, where early and focused training is critical for success (Jayanthi et al., 2015). Despite the relative high proportion of female gymnasts in our study, team athletes were more specialised.

Our results indicate that athletes who gave up other sports to focus on their main sport were more likely to participate in team sports, particularly when adjusted for weekly training time. This trend towards early specialization in team sports can enhance skill development and competitive advantage, but also may increase the risk of burnout and overuse injuries (Jayanthi et al., 2015; Dell'Antonio et al., 2025). The strong association of variables such as "Main sport is more significant" and "Training for more than eight months per year" with team sports participation further supports this notion. Weekly training time emerged as a strong independent variable of participation in team sports. Athletes training

more hours per week than their age showed the highest OR in both univariate and multivariate analyses, underscoring the importance of training volume in determining sports participation.

Our study proposed that the ML approach could automate the identification of key patterns in both team and individual sports. The most significant factor in determining whether a participant was involved in an individual or a team sport, based on SHAP values, was the weekly training volume dedicated to the main sport. This factor was also closely related to the hours-to-age training rule. These features jointly had the highest mean SHAP value of 1.62, highlighting their strong influence on the model's predictions. Previous research supports that intensive training regimes are characteristic of team sports, necessitating regular practice sessions, strategy development, and physical conditioning (Baker et al., 2003; Theisen et al., 2013). This finding is consistent with the view among coaches in the need for longer and more frequent training sessions in team sports to develop common skills and strategies (Li et al., 2025).

Limitations

Some potential limitations should be considered. First, the cross-sectional design did not allow for causal inferences regarding the relationships among sports specialization, training characteristics, and injury history. Longitudinal studies are needed to establish causality and to better understand how these factors influence each other over time. Second, our reliance on self-reported data, including injury history and training volumes, may be subject to recall bias and inaccuracies. Although we attempted to mitigate this by having researchers and parents/guardians assist with questionnaire completion, the potential for misreporting remains. Third, the study sample consisted of youth athletes from northern Poland, which may limit the generalizability of our findings to other regions and countries. Cultural, environmental, and socioeconomic differences could influence sports participation patterns and injury risks differently across diverse populations. However, it is worth noting that participants in our study came from both urban and rural areas. Fourth, we used a non-probability sampling method, specifically voluntary response sampling, which might introduce selection bias. Participants self-selected during educational meetings potentially skewed the sample towards more engaged or interested athletes. We did not assess resistance training practices among participants, which might have provided additional insights into the role of strength and conditioning in influencing sports participation patterns (Loturco et al., 2024). This limits the generalizability of our findings to the broader population of youth athletes. However, the voluntary nature of participation allowed us to gather detailed and motivated responses, enhancing the depth and quality of the data collected.

Practical Implications

Clinicians, coaches, and parents should recognize that both individual and team sports may have unique patterns, i.e., injury risks and training demands, emphasising the need for tailored injury prevention strategies. Understanding the patterns influencing sports participation, such as training volume and specialization trends, can help guide youth athletes in making informed decisions, potentially reducing burnout and overuse injuries.

Conclusions

Team sport athletes, who were predominantly male and older, trained more hours per week and exhibited higher overall sports specialization. They were also more likely to exceed the weekly hours-to-age training rule. Weekly training volume devoted to the main sport was a key feature indicating whether a participant was involved in an individual or a team sport. Coaches, clinicians, and parents should consider these distinctions when developing training programs and managing the athletic development of youth participants.

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Author Contributions: Conceptualization: B.W. and K.Z.; methodology: B.W., J.B., R.B., M.G. (Michał Grochowski) and B.P.; software: J.B., R.B., M.G. (Michał Grochowski) and B.P.; validation: B.W., R.R.-C. and M.G. (Michał Grochowski); formal analysis: J.B., R.B., M.G. (Michał Grochowski) and B.P.; investigation: B.W.; resources: B.W. and K.Z.; data curation: J.B., R.B., M.G. (Michał Grochowski) and B.P.; writing—original draft preparation: B.W.; writing—review & editing: J.B., R.B., M.G. (Michał Grochowski), R.R.-C., M.G. (Mariola Gepfert) and K.Z.; visualization: J.B., R.B., M.G. (Michał Grochowski) and B.P.; supervision: R.R.-C. and K.Z.; project administration: B.W.; funding acquisition: B.W. and K.Z. All authors have read and agreed to the published version of the manuscript.

ORCID iD:

Bartosz Wilczyński: https://orcid.org/0000-0002-8663-3698

Jakub Buler: https://orcid.org/0009-0008-6684-7446

Rafał Buler: https://orcid.org/0009-0000-5654-9754

Michał Grochowski: https://orcid.org/0000-0002-2453-2410

Bartosz Puchalski: https://orcid.org/0000-0001-9834-6250

Rodrigo Ramirez-Campillo: https://orcid.org/0000-0003-2035-3279

Mariola Gepfert: https://orcid.org/0000-0002-9749-5278

Katarzyna Zorena: https://orcid.org/0000-0003-2640-3791

Funding Information: This research was supported and co-funded by the Polish Minister of Education and Science (project no. SONP/SP/549693/2022).

Institutional Review Board Statement: This study was conducted following the principles of the Declaration of Helsinki, and approved by the Bioethics Committee for Scientific Research of the Medical University of Gdansk, Gdansk, Poland (protocol code: NKBBN/241/2023; approval date: 26 April 2023).

Informed Consent: Informed consent was obtained from all participants included in the study.

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

Acknowledgements: The authors would like to thank all parents, guardians, and coaches for their cooperation and support during the study.

Data Availability Statement: Supplementary materials are available at https://osf.io/5zb8y, including Figures S1–S4 (training duration, specialization age, and SHAP-based feature importance), Table S1 (demographics, specialization, training, and injury data), and Files S1–S2 (STROBE and CHAMP checklists).

Received: 18 February 2025

Accepted: 23 December 2025

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