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ORIGINAL RESEARCH

Variations of explosive strength for the students of the faculty of physical education and sports depending on the type of sports activities

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Abstract

Explosive strength has a decisive role in the rapid execution of movements and in achieving sports performance. The purpose of the study is to identify the differences in the level of explosive force for the upper and lower body, depending on the involvement in curricular physical activities, leisure physical activities or physical efforts in various sports disciplines. The participants are students of the Faculty of Physical Education and Sport/bachelor's degree: 147 men (age = 20.82 years old). The study was based on a transversal research, with the division of students into 3 distinct investigation groups (as an independent variable), according to sports majors: IS (individual sports), TSG (team sports games) and NA (non-athletes). 7 lower body explosive force evaluation tests and 6 upper body explosive force evaluation tests were applied. The use of ANOVA/Analysis of variance and the comparison on pairs of sports specializations indicate statistically significant differences for most of the tests, between the TSG and NA, respectively IS and NA groups, with the superiority of the athletes. No significant differences are reported between the TSG and IS groups, with 2 exceptions: in the 30s-Plyometric Push-Ups the IS group has significantly better values, respectively in the 30s-lateral hop for the TSG group ($p \leq 0.05$). The results of our study are in line with the average performance values provided by other research in the field (although they are weaker than those of elite athletes). The superiority of the individual values of volleyball players and sprinters/Track and field for the power of the lower body, respectively of combat sports practitioners and practitioners of sports games—which use the muscle groups of the trunk and arms in training—for the power of the upper body is confirmed, so the specificity of the effort also influences the explosive force values.

Keywords

Explosive force; Rapid contractions; University students; Individual sports; Team sports games; Specific effort

1. Introduction

1.1 Factors influencing the value of explosive force and its importance in sports activities

Explosive strength (equivalent to similar terms as muscular power, explosive power or explosive force) is important in achieving sports performance in most sports events and disciplines [1–5]. Muscle strength values are influenced by a complex of variables: gender, age stages, somatotype, nutritional and hormonal factors, body mass and percentage of muscle mass, dynamic balance, neural factors (intermuscular and intramuscular coordination), *etc.* [6–8]. Explosive strength and the force generated by the actions of the stretch-shortening cycle are independent elements of the motor function [9]. Efforts that involve the manifestation of explosive force generate specific adaptation mechanisms, related to the superior activation of motor units that facilitate fast contractions (fast-twitch—type II b), with a major role in supporting efforts that require the release of a large amount of energy in a short amount of time [10, 11].

Explosive force values for team sports practitioners are dependent on the quality of the warm-up before the competitive effort and on maintaining an optimal muscle temperature during the breaks between rounds [12]. Analysis of muscle group demands and participation in vertical and horizontal jumps for Saudi performance athletes (Track & field, Karate, Tennis, Soccer, Basketball) indicates (by Electromyography Activity/EMG) an essential contribution of femoral muscles for horizontal jumps and of lower leg muscles for vertical jumps, except tibialis anterior, according to [13]. For Irish national level shot putters, the stress on the rectus femoris and biceps femoris muscles is important for an optimal gliding technique, according to [14]. The integrity of the neuromyoarthrokinetic system is decisive in the performance of movements, aging affecting the quality of tendons and joints, with negative effects on explosive actions [15].

Decreased percentage of adipose tissue is decisive in increasing explosive force performance for young handball players (Qatar handball first league). With the exception of the medicine ball overhead throw (forwards) test, in all tests for assessing muscle power and agility (vertical jumps, 10 m sprint, *t*-test) normal-weight players have significantly better results than obese players [16]. A study conducted on Indonesian medical university students (21.76 years old) indicated that increased muscle mass is positively and significantly correlated with VJT (Vertical Jump Test) performance, and increased BMI (body index mass) is negatively and insignificantly correlated with explosive leg strength [17].

A decrease in performance in explosive strength tests is found when aerobic and strength-oriented workouts are planned in the same training session [18]. Performance on the VJT is influenced by sleep duration, latency and quality. A survey of elite mixed martial arts (MMA) athletes (27.2 years) reports strong negative associations between vertical jump value and sleep latency [19]. Biorhythm (physical cycle) influences performance related to muscle power. Research on young Iranian volleyball players indicates a significant correlation and better results in VJT and medicine ball throwing, for physical testing performed in the charged version of the physical cycle [20].

Muscular strength, throwing velocity and maximal force are dominantly demanded in the game of handball at the elite level, where players perform repetitive explosive actions based on jumps, accelerations and changes of direction, quick and varied throws, turns, *etc.* [21]. For handball players, the acute effect of HIIT (High Intensity Interval Training) does not negatively influence arm muscle strength and throwing velocity. However, performance decreases for the explosive force of the lower body are observed [22]. The explosive characteristics of the volleyball game indicate the usefulness of plyometric training, with performance-enhancing effects in vertical, horizontal jumps, agility and speed being highlighted [23]. Strength, speed and agility are necessary skills in the game of rugby, plyometric training and line sprinting being variants that ensure progress in these directions [24]. Combining plyometric training with short sprints and changes of direction in groups of young Tunisian (elite) soccer players generated significant increases in vertical jump, horizontal jump and short-distance acceleration performances [25, 26]. Also other studies support the importance of plyometric training in increasing explosive strength values [27–29]. The transition period can affect the physical performance of soccer players, with obvious decreases in results in the agility and acceleration tests, where muscle power is required [30].

In martial arts involving upper limb striking techniques, explosion and speed of movement is important, but contact areas and pressure (fist, palm or elbow) are different and require technique adapted for efficiency and reduced risk of injury [31]. For young karate practitioners/Kata (Indonesia), the role of explosive strength in the rapid execution of movements based on jumps, arm strikes, changes of direction/sudden actions are highlighted by [32]. Muscular strength is important in combat sports, where the technique of the movements involves various strikes with different segments, joints and jumps, the techniques aimed at the explosion of executions being integrated into the specifics of the training [33].

1.2 Variations of explosive strength depending on the level and specificity of sports activities

The demands specific to the value tier in which the athletes are active generate differences in the manifestation of muscle power. Analysis by age, gender, playing position and competitive level of vertical jump (CMJ) performance for soccer players provides interesting information. No significant differences are identified between the positions on the field, although Fullbacks have the best values, followed by Midfielders, Central Def., Goalkeepers and Strikers. Players in the national league have superior explosive strength to those in the regional or local leagues, at all age groups, so the higher competitive level also requires a higher level of fitness [34]. Another study on Zimbabwean rugby players shows significant improvement in arm and leg muscle strength values with the progression from U16 to U19 [35].

Research on various groups of performance athletes (Athletic sprints, Team sports and Combat sports) identify much higher values of muscle power, regardless of the sport practiced, compared to the values of non-athletic but physically active subjects, as an effect of specialized training [36]. The technical procedures in volleyball are conditioned by the execution technique and the level of the muscle strength value for different age stages, the quality of the service being influenced by the value of the players (men and women) who are active at the performance level [37, 38].

Assessments of lower body explosive strength in young Brazilian athletes (sprint running, judo and futsal) indicate medium and strong associations of vertical jump and muscle power values with physical performance in sport-specific tests, so explosive strength is a parameter that signals and influences sports performance. The highest values for vertical jumps are achieved by sprinters, then futsal players and judo athletes [39]. Variations in muscle strength and power are identified between male judo and Brazilian jiu-jitsu practitioners (19–26 years old). Judoka have higher values of back strength, and the jiu-jitsu group better scores of the explosive strength of the legs (standing long jump), as an effect of the specific demands of this sport, according to [40]. The comparison between the performance of the strength tests of the Brazilian adolescents practicing Judo and Wrestling, respectively, revealed better scores of the judoka for VJT, SLJ and 3 kg medicine ball chest throw, so the specifics of the sports activity influence the performance of muscle power [41].

Other studies carried out on national team athletes, from different sports disciplines, indicate the superiority in jumping tests for horizontally oriented sports (Athletic sprinting, long jump/triple jump, speed skating sprint), followed by vertically oriented sports (beach volleyball, ski jumping, weightlifting). The worst results are achieved by athletes involved in activities that require endurance and precision, with men having results approximately 33% higher than women [42]. Values of muscle strength and power at the level of the upper limbs are compared between groups of Turkish university student athletes (21.16 years old), with higher results of those who practice handball and boxing (as an effect of specific demands), compared to those who practice soccer and taekwondo (where the power of the lower train is requested as a priority), but at the level of the lower limbs no significant differences are found between the 4 sports specializations [43]. Studies of sprinters and high jumpers (elite level) report no significant differences between these categories in vertical jump value, even though sprinters have a slightly better average score [44]. Comparisons of the 10 m sprint value between U17 groups of different sports games show the superiority of volleyball players, followed by handball players, basketball players and soccer players [45].

Following the data provided by these researches, our study aims to compare the possible variations of the explosive force at the lower and upper body level between university students practicing team sports games (TSG), individual sports (IS) and the non-athletes category (NA), the results being then compared to the values provided by other studies on the same age categories and similar sports specializations.

Hypothesis 1: We estimate that we will obtain significant differences for the average explosive strength performances between the NA, TSG and IS categories.

Hypothesis 2: We will check if the top individual results (for lower body muscle strength tests) are achieved by volleyball and track and field players, as it results from consulting the majority of analyzed sources.

2. Materials and methods

2.1 Participants

All students of the Faculty of Physical Education and Sport in Galați-Lower University in Galați, 1st and 2nd year of study/degree (Physical Education and Sports specialization) were invited to participate in this research. Initially, a number of 152 students responded favorably, but 5 cases were removed from the study, as they did not participate in all explosive force evaluation sessions, and the data collected from these cases were not used in the statistical analysis of the results. The tested batch has the following characteristics: 147 men (age = 20.82 ± 2.24 years, weight = 72.84 ± 11.58 kg, height = 178.75 ± 6.59 cm). The batch was divided into 3 distinct groups, depending on the involvement in sports activities and their typology. The Non-athletes/NA group (48 students) consists of those who are involved only in curricular sports and leisure activities. The Team sports games/TSG group (52 students) has the distribution: soccer 38 (25.85%), handball 3 (2.04%), volleyball 4 (2.72%), basketball 5 (3.40%), rugby 2 (1.36%). The Individual sports/IS group (47 cases) has the distribution: fitness variants + body building 17 (11.56%), athletics/track and field 9 (6.12%), martial arts 8 (5.44%), sports dance 2 (1.36%), boxing 4 (2.72%), tennis 2 (1.36%), table tennis 2 (1.36%), rowing 2 (1.36%), swimming 1 (0.62%). We note that most of the evaluated athletes are not part of the national teams or teams belonging to the first league, being placed at the level of the lower leagues (second, third and fourth). Table 1 summarizes this distribution, with their numerical and percentage, as well as the anthropometric and age data of each group:

At the level of the team sports games practitioners (TSG) there is an imbalance between soccer practitioners (majority) and the other sports games (volleyball, handball, basketball, *etc.*), with a much lower numerical and percentage representation.

2.2 Procedure

Our research falls under the category of cross-sectional investigations. The application of the set of tests was preceded by the anthropometric measurements, these actions being planned at the end of May 2019, before the summer exam session. The criteria for inclusion in the study were the presentation of a favorable medical opinion for involvement in physical effort, the absence of injuries and participation in all 13 explosive strength assessment tests. All batches were tested at the Research Center for Human Performance at the Faculty of Physical Education and Sports in Galați. The subjects were assessed through 7 tests to evaluate the explosive strength of the lower body (Vertical Jump Test, Standing Long Jump Test, 3-Hop Test, The multiple 5 bounds test, 30s-lateral hop test, Speed Test 10 m, 30s-Continuous vertical jumps test), respectively of 6 tests related to the explosive force of the upper body (Overhand ball throw, Shot put, Standing Overhead Medicine Ball Throw-forward, Standing Overhead Medicine Ball Throw-backward, Standing medicine ball chest throw, 30s-Plyometric Push-Ups). Their description is presented in the Appendix, to allocate more space to the presentation of results and discussions. Additional information related to the tests applied in order to assess muscle strength is provided by the sources [46–50]. The large number of tests required assessment in two separate sessions/days (one for lower body strength, one for upper body strength), in groups of 15–20 students. In both sessions, the endurance strength tests (30s-Lateral hop test, 30s-Continuous vertical jumps test and 30s-Plyometric Push-Ups) were performed at the end, so that the induced fatigue does not affect the performance in the other assessment tests. The students were instructed to avoid physical demands of high volumes and intensities prior to the assessment, in order to prevent the manifestation of muscle fatigue, an aspect that would have reduced the performance values in the applied tests. Taking the tests was preceded by a 10-minute warm-up, which included running in an aerobic regime, dynamic exercises for stretching the muscles and mobilizing the requested joints. The dosage of warm-up exercises (distances, sets, number of repetitions, amplitude of stretching movements) was individualized, according to the particularities of each student. All applied tests were described, demonstrated and the way of measuring/quantifying performance was explained, most of which were already known to the students. With the exception of the 3 strength evaluation tests in endurance mode, two consecutive attempts were allowed for the other tests, with the best result obtained being recorded. The students were informed about the purpose of the study, being respected the ethical criteria related to the protection

TABLE 1. The number of cases and the percentages resulting from the division of the batch by sports activities.

Groups	Number/percent	Age	Height	Weight	BMI
Non-athletes	48 (32.65%)	20.22 ± 1.22	178.53 ± 7.05	72.35 ± 13.50	22.66 ± 4.05
Team sports games	52 (35.37%)	21.53 ± 3.04	177.89 ± 7.71	71.58 ± 10.33	22.63 ± 2.78
Individual sports	47 (31.97%)	20.63 ± 1.81	179.93 ± 4.36	74.74 ± 10.75	23.05 ± 2.95

BMI: Body Mass Index.

of personal data [51]. The agreement to publish the data processed in this study was released by the ethics committee of the university (the decision of the Ethics Commission of 06 January 2023).

2.3 The statistical analysis of data

SPSS software (Statistical Package for the Social Sciences/IBM Vers.24 Chicago, IL, USA) was used for the statistical processing of the obtained results. In order to assess the normality of the data distribution, at the level of each test for the three tested groups, the Shapiro-Wilk test was used. MANOVA (Multivariate tests and ANOVA) parametric techniques were applied. Levene's Test of Equality of Error Variances, F values and related significance thresholds for multivariate and univariate tests, Partial eta squared/$\eta^2{}_p$ (as an expression of size effect), differences between the 3 pairs of resulting data and their significance thresholds were calculated, with the use of Bonferroni *Post Hoc* Tests. The confidence interval was set at 95% ($p \leq 0.05$) [52–56].

3. Results

The data Statistically processed data are summarized in tables (T2 multivariate tests, T3–T4 univariate tests, T5–T6 comparison of pairwise average differences, T7–T8 presentation of superior individual values in the tests).

The multivariate analysis (Multivariate Tests/Table 2) indicates the global effect of the independent variable Sport activity on the results of the lower and upper body strength assessment tests. A statistically significant influence is observed ($p \leq 0.05$), with very strong values of the size effect/$\eta^2{}_p$ (28.4% of the variance of the results in the power tests is explained by the Sport activity variable).

The interpretation of the data provided by the Univariate test (Table 3) indicates in most cases statistically significant influences of the independent variable Sport activity on the results of the power tests of the lower body ($p \leq 0.05$). The only exception is for men in the Vertical Jumps test with object touch—30 s ($p > 0.05$). The size effect values are average in most situations (for example, only 12.7% of the performance variance in Acceleration 10 m and 12.1% of the performance variance in Lateral Jumps—30 s are generated by the Sport activity variable), but also weak (only 2.1% from the variance of results in Vertical jumps with object touch—30 s is explained by the independent variable).

For the Univariate test at the level of the upper body (Table 4), significant influences of the independent variable Sport activity on the level of strength results for the studied independent variables are also noted ($p \leq 0.05$). The only case where we report a statistically insignificant threshold ($p > 0.05$) is when throwing the medicine ball forwards overhead. For the 30 s plyometric push-ups test, higher values of the size effect are noted (25.2% of the variance is explained by the independent variable). In the other cases, we report only medium and weak effects for the men's group (for example, 7.7% of the variance of the performances in overhand ball throw, respectively only 5.8% of the variance in weight throw are explained by the Sport activity variable.

The comparison of the average values on the 3 defined group categories (Table 5) indicates the significant superiority ($p \leq 0.05$) of the TSG and IS groups for almost all tests compared to the NA group (normal appearance and what we expected). Exceptions are the tests of 3 successive jumps between the NA and TSG groups, Lateral jumps—30 s between the NA and IS groups, respectively Vertical jumps with object touch—30 s, where all comparisons between pairs generate only insignificant differences ($p > 0.05$). This last test generated the greatest difficulties in the evaluation at the level of the lower body for both genders, even at the level of performance athletes often noting the inability to optimally dose the effort, in many cases observing a high frequency of jumps in the first seconds, with the rapid onset of fatigue, which no longer allowed the repetition of actions throughout the 30-second interval. Between the TSG and IS groups there is only one significant difference noted, for Lateral Jumps—30 s, in favor of the TSG group, a possible explanation being the dominant presence of soccer players, for whom sudden changes of direction in different planes (agility movements) are frequently encountered, as for most team sports games ($p \leq 0.05$). We also highlight the better short-distance acceleration capacity of the TSG group, as an effect of adaptation to specific efforts, but statistically insignificant ($p > 0.05$).

At the level of upper body strength evaluation tests, we no longer find as many significant differences between groups in the case of men as in the case of lower body strength (Table 6). The only significant difference ($p \leq 0.05$) between the groups of athletes is for Plyometric Push-ups 30 s, where the presence of those involved in combat sports and fitness practitioners explains the higher average of the IS group, being familiar with these type of demands. It is interesting that only 2 cases of significant differences are identified between the NA and TSG group, in the Overhead Ball Throw and the Overhead Medicine Ball Throw Backward, while the IS group still shows 4 cases where the differences are significant compared to the NA group: Weight Throw, Overhead Medicine Ball Throw Backward, Chest Forward Medicine Ball Throw and Plyometric Push-ups 30 s. Overhead Medicine Ball Throw-forward is the only test where we did not even signal a significant

TABLE 2. The results of the multivariate tests (MANOVA[a]).

Gender	Effect	λ	F textit	Hypothesis df	Error df	Sig.	η^2_p	Observed Power
Male	Sport activity	0.512	4.037[b]	26.000	264.000	0.000	0.284	1.000

[a]: Design: Sport activity; [b]: Exact statistic; λ: Wilk's lambda; F: Fisher test; df: degrees of freedom; Sig.: level of probability; η^2_p: partial eta squared.

TABLE 3. Univariate test results (ANOVA)—the influence of the sport activity variable on the results of the lower body strength tests.

Dependent Variable	Sum of Squares	Mean Square	F_m (2, 144)	Sig.	Partial Eta Squared	Observed Power
Vertical Jump Test/VJT	705.383	352.692	10.569	0.000	0.128	0.988
Standing Long Jump Test/SLJ	4767.307	2383.653	8.057	0.000	0.101	0.954
3-Hop Test	45,701.080	22,850.540	6.733	0.002	0.086	0.912
The multiple 5 bounds test/MB5	136,602.846	68,301.423	7.328	0.001	0.092	0.934
30 s lateral double leg hop test	1025.291	512.645	9.873	0.000	0.121	0.982
Speed Test 10 m	0.199	0.100	10.431	0.000	0.127	0.987
30 s Continuous vertical jumps	35.040	17.520	1.528	0.220	0.021	0.321

F_m (F: Fisher test male).

TABLE 4. Univariate test results (ANOVA)—the influence/effect of the variable sport activity on the results of strength tests at the level of the upper body.

Dependent Variable	Sum of Squares	Mean Square	F_m (2, 144)	Sig.	Partial Eta Squared	Observed Power
Overhand ball throw (OBT)	570.779	285.390	6.006	0.003	0.077	0.877
Shot put-track and field	98,998.167	49,499.084	4.402	0.014	0.058	0.752
Overhead Medicine Ball Throw-forward 3 kg	126,372.809	63,186.405	2.243	0.110	0.030	0.451
Overhead Medicine Ball Throw-backward 3 kg	434,923.884	217,461.942	6.816	0.001	0.086	0.916
Medicine ball chest throw 3 kg	105,492.453	52,746.226	4.524	0.012	0.059	0.764
30 s Plyometric Push-Ups/clap push ups	1857.988	928.994	24.232	0.000	0.252	1.000

F_m (F: Fisher test male).

difference between the compared pairs ($p > 0.05$). The very poor results in the Shot Put (Athletics) are due to both poor execution technique and unfamiliarity with the test and the type of shot put, this athletic event being less popular and accessible, and the best results from both groups of athletes are recorded by overweight students.

Regarding the superior results for the strength of the lower body, we identify a balanced distribution of them, without being able to confirm the definite superiority of the TSG or IS groups, but we note the dominated presence of volleyball practitioners and those with specializations in athletic events (especially sprint) for this top (Table 7). Male soccer players obtain very good results for the 10 m acceleration test, respectively for the endurance strength tests (repeated lateral and vertical jumps), as an adaptation effect to the intense and repeated efforts specific to this sport. Those specializing in combat sports are not found in this ranking. We also noticed that basketball players are not even represented in this ranking.

The balanced distribution of the best performances between the TSG and IS groups is also true in the evaluation tests for the upper body strength (Table 8). The lack of performance athletes specialized in Shot put leads to the occupation of the podium by other sports specializations. For 30 s plyometric push-ups we note that the first 3 men's positions are occupied only by practitioners specializing in IS. Combat sports practitioners can also be found in this ranking, due to the specificity of the efforts, which were missing from the top of the lower body strength evaluation results. At the TSG level we observe the absence of soccer players, who were well positioned in the previously analyzed table, but a good representation of handball, volleyball and even basketball and rugby players, who have obvious demands on the strength of the upper body in training and competitions.

4. Discussion

4.1 Performance reporting to other lower body strength research

A comparative study of the fitness level of Russian male university students (17–18 years old) revealed better performance values of the 2008 generation compared to that of 2017, with the declines being more evident for the hypersthenic category.

TABLE 5. Analysis of the significance of differences between average scores by categories of sports activities in strength tests for the lower body/men (NA = 48, TSG = 52, IS = 47).

Test Group	Mean	Std. deviation	Std. error	a−b	Sig.^{b}	a−c	Sig.^{b}	b−c	Sig.^{b}
Vertical Jump Test/VJT									
a. NA	40.072	5.666	0.834						
b. TSG	44.976	5.748	0.801	−4.904*	0.000	−4.363*	0.001	0.541	1.000
c. IS	44.436	5.918	0.843						
Standing Long Jump Test/SLJ									
a. NA	217.437	18.483	2.483						
b. TSG	229.038	17.177	2.385	−11.601*	0.003	−12.669*	0.001	−1.068	1.000
c. IS	230.106	15.810	2.509						
3-Hop Test									
a. NA	669.687	60.320	8.409						
b. TSG	695.826	61.258	8.079	−26.139	0.080	−43.525*	0.001	−17.386	0.421
c. IS	713.212	52.403	8.498						
The multiple 5 bounds test/MB5									
a. NA	1081.437	88.653	13.935						
b. TSG	1151.057	102.163	13.389	−69.620*	0.001	−58.307*	0.011	11.313	1.000
c. IS	1139.744	97.861	14.083						
30 s lateral double leg hop test									
a. NA	29.020	7.206	1.040						
b. TSG	35.192	6.523	0.999	−6.171*	0.000	−1.681	0.772	4.490*	0.007
c. IS	30.702	7.893	1.051						
Speed Test 10 m									
a. NA	1.940	0.095	0.014						
b. TSG	1.851	0.089	0.014	0.089*	0.000	0.051*	0.037	−0.038	0.159
c. IS	1.889	0.107	0.014						
30 s Continuous vertical jumps									
a. NA	20.312	2.940	0.489						
b. TSG	21.346	3.371	0.470	−1.034	0.388	−1.049	0.400	−0.016	1.000
c. IS	21.361	3.801	0.494						

**: The mean difference is significant at the 0.05 level; ^{b}: Adjustment for multiple comparisons: Bonferroni; a−b = average difference NA/TSG; a−c = average difference NA/IS; b−c = average difference TSG/IS; NA: non-athletes; TSG: team sports games; IS: individual sports.*

For SLJ, hypersthenics from 2008 achieve 233.5 cm, compared to 225.7 cm in 2017, normosthenics 236 cm *vs.* 232.1 cm, and asthenics have the best performances: 241.4 *vs.* 237.7, according to [57]. Our athlete batches only outperform the 2017 hypersthenics.

The application of 8-Week Rope Skipping Intervention to Chinese university students in Physical Education and Sport (19.07-year-old males) generates an improvement in SLJ performance, from 234 cm to 251 cm, an increase in the velocity of the center of gravity at take-off and landing [58]. The assessment of leg muscle strength for National Collegiate Athletic Association (NCAA) Division I athletes from the USA (20.3 years old male and 19.7 years old female) majoring in football, gymnastics, soccer and volleyball indicates very good values for VJT (72.8 cm male and 51.1 cm female), respectively 10-yard Sprint (1.79 s male and 1.95 s female), according to [59]. Parkour training provides conditions for the adaptation of the musculo-skeletal structures to the high eccentric loads during jumping. Practitioners of this sport (19.4 years old) achieve superior performance in tests of explosive power of the lower limbs, compared to other investigated athletes: in SLJ (282.7 cm) *vs.* gymnasts (273.8 cm) and power athletes (261.3 cm) [60]. Comparing to all these results our students have much poorer values.

Testing of Iranian elite athletes (national team) practicing karate (kumite field) shows results of 56.6 cm for VJT according to [61]. High muscle strength values positively influence vertical and horizontal jump performance for Turkish martial

TABLE 6. Analysis of the significance of differences between average scores by sports activity category in upper body strength tests/men (NA = 48, TSG = 52, IS = 47).

Test	Group	Mean	Std. deviation	Std. error	a−b	Sig.[b]	a−c	Sig.[b]	b−c	Sig.[b]
Overhand ball throw (OBT)										
	a. NA	38.741	6.714	0.995						
	b. TSG	43.521	6.330	0.956	−4.779*	0.002	−2.348	0.297	2.432	0.245
	c. IS	41.089	7.631	1.005						
Shot put-track and field										
	a. NA	623.145	88.937	15.306						
	b. TSG	653.384	109.512	14.705	−30.239	0.469	−64.535*	0.011	−34.296	0.331
	c. IS	687.680	117.570	15.468						
Overhead Medicine Ball Throw-forward 3 kg										
	a. NA	861.458	161.722	24.227						
	b. TSG	890.192	161.044	23.277	−28.734	1.000	−72.457	0.111	−43.723	0.593
	c. IS	933.914	180.886	24.484						
Overhead Medicine Ball Throw-backward 3 kg										
	a. NA	1101.729	184.700	25.782						
	b. TSG	1227.884	160.533	24.771	−126.155*	0.002	−99.930*	0.022	26.225	1.000
	c. IS	1201.659	190.924	26.055						
Medicine ball chest throw 3 kg										
	a. NA	790.854	108.660	15.586						
	b. TSG	828.346	107.364	14.974	−37.492	0.255	−66.422*	0.010	−28.930	0.556
	c. IS	857.276	107.967	15.751						
30 s Plyometric Push-Ups/clap push ups										
	a. NA	12.520	5.565	0.894						
	b. TSG	15.442	5.278	0.859	−2.921	0.059	−8.692*	0.000	−5.770*	0.000
	c. IS	21.212	7.581	0.903						

**: The mean difference is significant at the 0.05 level; [b]: Adjustment for multiple comparisons: Bonferroni; a−b = average difference NA/TSG; a−c = average difference NA/IS; b−c = average difference TSG/IS; NA: non-athletes; TSG: team sports games; IS: individual sports.*

TABLE 7. The values of the best 3 individual results for each strength test at the lower body level (according to the practiced sport).

Test	Performance 1 (sport)	Performance 2 (sport)	Performance 3 (sport)
Vertical Jump Test/VJT	59.50 (volleyball)	58 (Track and field)	57 (soccer)
Standing Long Jump Test/SLJ	274 (Track and field)	265 (volleyball)	264 (Track and field)
3-Hop Test	849 (Track and field)	822 (Track and field)	814 (volleyball)
The multiple 5 bounds test/MB5	1413 (volleyball)	1400 (Track and field)	1362 (Track and field)
30 s lateral double leg hop test	48 (fitness)	48 (soccer)	47 (soccer)
Speed Test 10 m	1.66 (Track and field)	1.68 (soccer)	1.69 (volleyball)
30 s Continuous vertical jumps	31 (sports dance)	28 (soccer)	28 (rowing)

TABLE 8. The values of the best 3 individual results for each strength test at the upper body level (according to the practiced sport).

Test	Performance 1 (sport)	Performance 2 (sport)	Performance 3 (sport)
Overhand ball throw	68.10 (Track and field)	56.70 (handball)	56.60 (basketball)
Shot put-track and field	1124 (rugby)	986 (fitness)	910 (box)
Overhead Medicine Ball Throw-forward 3 kg	1568 (Track and field)	1350 (rowing)	1343 (volleyball)
Overhead Medicine Ball Throw-backward 3 kg	1730 (fitness)	1582 (fitness)	1582 (basketball)
Medicine ball chest throw 3 kg	1090 (fitness)	1088 (rugby)	1058 (fitness)
30 s Plyometric Push-Ups/clap push ups	37 (karate)	36 (fitness)	36 (K1)

arts practitioners (21.6 years). Average results of 56.07 cm (with a maximum of 70 cm) are obtained for the VJT, 242.46 cm (with a maximum of 270 cm) for the SLJ, and for the 10 m sprint, 1.61 s is obtained (with a best performance of 1.52 s), according to [62]. For Egyptian boxers (22.6 years old), the effects of specific training applied 8 weeks × 3 sessions per week are effective regarding general and specific physical condition. The tested batch increases its performance in short distance sprints and SLJ (255 cm in final tests) [63]. This research also reports much better values on explosive leg strength tests compared to our student groups.

Lower body explosive strength performance for Greek Mixed Martial Arts (MMA) fighters is enhanced by the application of the Specific Training Group (STG), based on high intensities and low volumes. Average values for 10 m sprint of 1.88 s are obtained [64]. This result is similar to that obtained by the IS group in our study (1.889 s). The application of CrossFit training methods for Polish Kickboxing practitioners (20.07 years old) generates progress in the fitness level, including for SLJ, with an average value of 204.83 cm [65]. The obtained value is lower than the averages of the 3 groups investigated by us. The comparison between Karate and Taekwondo practitioners (ages = 21 years) regarding lower body explosive strength values indicates significantly better values for athletes involved in Taekwondo (as an effect of the dominant use of jumps and foot techniques), and the average values of both batches exceed the average performance of the batches studied by us using VJT: (60.3 cm for Karate and 75.9 cm for Taekwondo. Weaker values than those of our batches are obtained at SLJ: 206.7 cm for Karate and 212.2 cm for Taekwondo, according to [66]. For Indonesian karate practitioners, average values of 45 cm are obtained for VJT (close to the average of our IS group), with a maximum of 61 cm, and for SLJ an average of 209 cm is obtained (much lower than the average of all our groups), but with a maximum of 275 cm [32].

The average results of Indonesian national team sprinters (25 years old) for lower limb strength are high: 286 cm for SLJ and 67.1 cm for VJT. Strong associations between acceleration capacity and maximum sprint speed with SLJ and moderate with VJT are also identified [67]. Analysis of explosive strength performances of elite Brazilian sprinters (23 years old) revealed strong correlations between these results and times obtained in short distance sprints, which are important in the assessment and monitoring of skills associated with sprint performance. For SLJ men have an average of 284 cm and women 237 cm [68]. Very good values of muscle strength performance for lower limbs are obtained by Turkish male sprinters (20.4 years): 274 cm in SLJ, 789 cm in 3-Hop Test and 1435 cm in the multiple 5 bounds test (MB5), according to [69]. Lower body strength values for a group of elite male sprinters (24.9 years old) indicate average performance of 290 cm in the Standing Long Jump Test [70]. All these studies highlight and confirm the superiority of explosive leg strength for sprinters, with average results that are much better than our batches.

The competition level requirements for male tennis players/Turkish university students in division 1 (22 years) and division 2 (22.3 years) generate significant differences in physical performance between groups, including for the manifestation of explosive strength of arms and legs. Those in division 1 achieve a VJT of 46.6 cm (slightly better than our batch of IS), and those in division 2 have a weaker average of 44.2 cm (similar to those from our batches) [71]. The application of combined aerobic-anaerobic technical training at the level of Turkish university students specializing in tennis (22.2 years old) leads to the optimization of anaerobic strength performance. Values of 60.9 cm are obtained at VJT (top results, far above those obtained by us), 220 cm at SLJ (values lower than those of our groups of athletes) and 2.0 s at 10 m sprint (values still lower than of both groups of athletes investigated by us), according to [72].

The values of the muscle strength of the lower limbs (for the Tunisian football players—national team U23) are 12.99 m for the multiple 5 bounds test (MB5)/five jump test, respectively 62.42 cm for the vertical jump/Arm-CMJ, between the 2 tests strong associations being reported [73]. The use of exercises aimed at optimizing the explosive force of deficient muscle groups (during a macrocycle) of university basketball players in Kazakhstan ensures the optimization of performance related to muscle strength. Average final values of 250 cm at SLJ and 53 cm at VJT are obtained, according to [74]. The implementation of plyometric training in the training process of Thai male university basketball students (19.60 years old) generates a significant improvement in the performances related to agility, short distance sprint and vertical jump. At VJT, 59.20 cm are obtained during the initial tests, and 64.20 cm at the end of the training program [75]. A study of professional volleyball players (24.5 years old) identified mean values of 1.71 s for the 10 m acceleration test, according to [76]. All these results shown are more valuable than those obtained by our TSG group.

The comparative analysis of the strength of the lower limbs for professional Serbian handball and basketball players indicates significant differences, explained by the specificity of the technique of the procedures and efforts in each sports game. For horizontal jumps, handball players achieve better results: 238.53 cm, compared to 203.40 cm for basketball players at SLJ, respectively 728.93 cm, compared to 630.47 cm at 3 Hop Test [77]. Our TSG group scores better than the basketball average on both tests, but worse than the handball average.

The type of stress in plyometric training (horizontal *vs.* vertical jumps) influences the value of muscle strength. For elite handball players (23.4 years), training based on horizontal jumps (10 weeks × 2 sessions) optimized agility and 10 m sprint performance (1.92 s *vs.* 1.99 s for those who used vertical jumps) [78]. A program to optimize muscle strength and speed, applied for 8 weeks to young Romanian national league handball players (19.94 years old) showed a final result of 1.93 s for the 10 m speed test, better than the initial result of 1.97 s [79]. However, our batch of TSG records better values in the 10 m sprint compared to these analyzed studies.

A study of male professional basketball players in the first league/Turkey identifies average values of 1.86 s for the 10 m sprint according to [80]. The values are similar to those obtained by us for the TSG group.

When testing South African rugby players (18–25 years), average values for SLJ were 224.63 cm for the sprint-trained group and 209.27 cm for the plyometric-trained group, with no significant differences between the results [24]. Both values are lower than those recorded by our TSG group.

4.2 Performance reporting to other upper body strength research

Turkish university students practicing tennis/division 1 achieve 1236 cm in Standing Overhead Medicine Ball Throw 3 kg/forwards, and those in division 2 only 1157 cm [71]. Research on handball players from Qatar/First National League (25.6 years old) indicates the superiority of normal weight in arm muscle strength tests (981 cm for normal weight at 3 kg Overhead Medicine Ball Throw/forwards *vs.* 961 cm for overweight) [81]. Both studies report superior results to those found by us for the investigated groups.

At the level of Polish university students, the following performances are obtained in the medicine ball throw variants: For Medicine ball backward throw the order is Bodybuilding/fitness (1122.3 cm), volleyball (1046.28 cm), martial arts (1038.67 cm), Jogging followed by sauna (998.24 cm), golf (997.99 cm). In the Medicine ball forward throw variant, the order of performance is Bodybuilding/fitness (928.02 cm), Golf (875.69 cm), Jogging followed by sauna (861.08 cm), martial arts (854.46 cm), volleyball (836.97 cm), according [82]. However, our TSG and IS groups achieve average results above these values for Medicine ball backward throw. Medicine ball forward throw results are close to those of our study for the TSG group. The better results of the TSG group for Overhead Ball Throw backward (in our study) can be explained by the familiarity with the thrust type of throws encountered in sports games, but with no significant differences from the IS group. However, we are surprised by the lower average score in Overhead throwing the medicine ball forward of the TSG group compared to the IS group, a procedure with which the footballers (with dominant representation in the group) are familiar from the out throws, but their contribution is not enough to ensure to a superior average of the team sports game practitioners.

Standing Overhead Medicine Ball Throw (forwards) values for water polo practitioners (17.1 years), after combined training (medicine ball + polo ball) or based only on medicine ball throws (3 kg) are 798 cm for the medicine ball version, respectively of 750 cm for the combined version [83]. The results are weaker than those obtained by us for all 3 groups of men, but it must be taken into account that the compared group has a lower average age. Training planning based on medicine ball exercises (8 weeks) has a positive effect on physical performance and specific skills in basketball players (21.25 years old) in Malaysia. In the final tests, 936 cm is obtained for the Standing Overhead Medicine Ball Throw (forward) [84]. This value is similar to the one we obtained for the TSG group (933 cm). For Indian cricket players (18–25 years old), average values of 980cm are recorded for the Standing Overhead Medicine Ball Throw (backward), and significant associations were also identified between upper body muscle strength values and force values, but also the lack of significant associations between body balance and muscle strength values [85]. The values are lower than all the averages obtained by our male groups.

Studies on high school students in Romania revealed values of overhand ball throw of 26.93 m for girls and 40.21 m for boys. The use of basketball structures in physical education lessons does not improve performance, with lower scores being recorded: 24.56 m for girls and 37.50 m for boys [86]. The values shown are weaker than those of our TSG and IS groups, but similar and slightly better than the NA group.

Maximizing performance in the case of Shot Put involves the application of occasional programs/sequences, in which for the initial phases, strength accumulations are highlighted, and then emphasis is placed on strength training and explosive efforts. The values for this test in American university students (18–21 years old), with 1–6 years of weight throwing experience have an average value of 12.97 m [87]. For the junior shot-putters, higher values/personal best = 1357 cm are obtained, the performances in this test being correlated with several factors: the volume of the muscles of the upper and lower body, peak power output (PPO) of the arms and legs, work of hand action force (WHAF) and release velocity parameter [88]. For the throwers in the athletic events (20.6 years, Division I collegiate throwers—hammer/discus/javelin) after 12 weeks of training, average performances are recorded in the shot put variant (overhead throw) a performance of 12.43 m is obtained [89]. The use of different post-activation exercises for the upper and lower body (plyometric push-ups, isometric push-ups and countermovement jumps/CMJ) in a group of moderately experienced Shot Put athletes (19.9 years) ensures the improvement of performance in this athletic throwing test. Peak performance of 1320 cm is achieved for men [90]. Our results are far below the values of the previously analyzed studies, but it must be taken into account that within the tested batches there is not even one student specializing in this throwing test.

The individualization of efforts, plyometrics and strength training should be used in the training of amateur boxers (22.7 years), to increase the speed of movements and strength-endurance indices. For Plyometric Push-Ups)/clap push-ups (60 s) an average value of 42 repetitions is obtained at the end of the training stages [91]. This score is higher than what we obtained for all groups, but the comparison is irrelevant, because our testing involved doing push-ups only for 30 s.

5. Conclusions

Our investigation has identified significant differences in muscle strength only between IS and NA groups, respectively TSG and NA, so working hypothesis 1 is only partially confirmed. The comparison between IS and TSG groups average values identifies for most tests a balance of results, with similar and non-significant values, so we cannot state that either of the two groups of athletes is superior in terms of lower and upper body muscle strength. However, the differentiated demands related to the specificity of the effort lead in two cases to significant differences between the groups of athletes: 30 s Lateral Jump test (with better TSG values, as an effect of the changes of direction specific to sports games) and 30 s plyometric push-ups (where the presence of martial arts athletes raises the average value in favor of the IS group).

The practical utility of the study results from the fact that the research highlights the differences that appear in terms of explosive strength between the 3 analyzed groups, and which are due to the level of involvement in different physical activities for training and competitions. This aspect allows the identification of strengths and weaknesses in explosive strength training for each individual group. The consistent presence in the top of individual lower body strength performances of volleyball players, soccer players and Track and field athletes, respectively fitness practitioners, track and field and combat sports for upper body strength indicates the importance of explosive strength for these sports specializations in determining sport performances and the need to find the best methods to optimize its values. Individual and group results can be provided to teachers who teach sports subjects within the faculty, as a reference point regarding the level of physical fitness of the students.

Limits of the study and future directions of investigation:

Our research has obvious limitations. The lack of strength platforms and electronic devices (Vertec, Optojump, *etc.*) imposed the exclusive use of field tests and did not allow the evaluation of subjects through other tests, frequently used in specialized studies (CMJ/Countermovement Jump, Squat jump, Abalakov test, Drop Jump). This aspect did not facilitate the comparison of our results with those of similar studies, especially for the 30 s repeated jump tests, where the muscle strength performances are expressed in W/Watts. The imbalance between the assessed sports specializations (with a good representation of soccer players and weaker representation of the other sports tests and disciplines), as well as the lack of representatives from other disciplines (for example gymnastics or athletic throwing tests) are factors that determine us not to be able to generalize the results, which are only a characteristic of the studied batches. However, the large number of tests used we believe can compensate for these shortcomings and provide a fairly clear overview of explosive strength performance for the tested university students. The large volume of resulting data did not allow the presentation of performances related to other independent variables (variations according to anthropometric indicators or BMI steps), which will be exploited in other scientific papers. Research is needed on larger groups of athletes according to specializations, age categories and above all performance level, in the group investigated by us, there are predominantly athletes who are active in the lower leagues. This aspect also explains the poorer performances resulting from the comparison with other similar studies, but in which elite athletes were evaluated.

AVAILABILITY OF DATA AND MATERIALS

The data are contained within this article.

AUTHOR CONTRIBUTIONS

GDM and GM—perform the conceptualization, perform the visualization; GDM—performs the methodology, performs the data curation; GB—performs the validation, performs the project administration.; GDM, GM and GB—perform the formal analysis; GM—performs the investigation, performs the writing-review and editing, performs the supervision; GDM and GB—perform the writing-original draft preparation. All authors have read and agreed to the published version of the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

All participants were informed of the purpose of the research and the procedures. The study was conducted with the free consent of the students, who participated voluntarily in this research. The standards for investigating human subjects were met, according to the Helsinki Declaration (2013). There is an Ethics Approval and Consent to Participate—no. 01/HCEU/06.01.2023—document emitted by the Ethics Committee of the University Dunarea de Jos of Galati.

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CONFLICT OF INTEREST

The authors declare no conflict of interest. Georgian Badicu is serving as one of the Editorial Board members of this journal. We declare that Georgian Badicu had no involvement in the peer review of this article and has no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to DAM.

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