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COMPARATIVE ANALYSIS OF THE EFFORTS OF HIGHLY QUALIFIED ELITE ARMWRESTLERS WITH DIFFERENT STRENGTH ABILITIES

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Abstract

Study purpose. Determination of the peculiarities of the manifestation of strength in competitive exercises of highly qualified armwrestlers with different strength abilities.

Materials and methods. The study involved the 4 best armwrestlers in the world weighing from 80 to 100 kg (m = 87.50 ± 2.47 kg) in 2017-2020. Four power test exercises have been identified that ensure the performance of a competitive action in armwrestling: flexion of the fingers, stretch with a hammer, hook and bending the hand. Strength indicators in all test exercises were measured with an FL1K 0.5N, 1000N electric strain gauge dynamometer, Kern & Sohn GmbH (China), fixed on the armwrestling table using an author's block device.

Results. The results of the correlation analysis of the relationships between the studied indicators confirm the presence of a difference in the direction and strength of the relationships between the strength and time characteristics of the efforts of athletes with different strength and speed-strength abilities. Thus, out of 36 correlation indicators, the data of armwrestlers 1 and 2 have 11 modules with very high connection strength (r = 0.926-0.999), of which 7 modules are with time and 4 modules are with force characteristics of efforts. Athletes 3 and 4 also have 3 modules with very strong connections (r = 0.916-0.948) and 8 modules with strong connections (r = 0.739-0.886), of which 7 modules are with strength indicators and 4 modules are related to time characteristics. But the other correlation indicators have very weak (r < 0.29) and weak (r = 0.3-0.5) levels of relationships.

Conclusions. Analysis of the time and force characteristics of the manifestation of force in the process of achieving boundary resistance allows us to clearly establish the genetically determined speed and strength abilities of the explosive, fast and slow force of armwrestlers.

Keywords: armsport, armwrestling, armwrestlers, explosive power, strength indicators.

Introduction

The preparation of highly qualified athletes is the main object of research in modern science and sports, which solves the problem of developing the foundations for the rational organization of the training process. The most important element of such an organization can be a system of comprehensive monitoring of athletes' preparedness levels, taking into account all formative factors. In this regard, there is a need to accurately determine the indicators of the level of sportsmanship of an arm wrestler, especially at the stage of preparation for the main start, that is, at the stage of pre-competition specialized training. Since the technical and tactical training of highly qualified athletes is at approximately the same level, special attention must be paid to control over strength and speed-strength indicators (Mazurenko, 2019).

Studying the experience of preparing and performing in competitions of world armwrestling leaders provides unique information that concentrates the positive experience of the athlete (Podrihalo et al., 2021; Bezkorovainyi et al., 2022). However, to date, the methodological aspects of constructing individual training processes of the world's leading armwrestlers have not yet become the object of close

attention of researchers. Such works are rare (Bezkorovainyi et al., 2019; 2023), although their significance from both theoretical and practical points of view is beyond doubt.

An analysis of the practice of competitive activity of armwrestlers shows that the duration of a fight in this sport can range from a few tenths of seconds to tens of minutes in some cases (Ahamed et al., 2013). At the beginning of the fight, both opponents show explosive power. Subsequently, the athlete who seized the initiative shows fast and slow force (Akpina et al., 2013). The effectiveness of the manifestation of these traits depends on the level of strength endurance (Burdukiewicz et al., 2018).

During the fight, the arm muscles in most cases perform work in the aucontontonic (combined) mode, when all three modes of muscle work are alternated or summed up – myometric (concentric), plyometric (eccentric) and isometric. This combined mode manifests itself when fighting from a few tenths of a second to tens of minutes. With such duration of the fight, strength endurance will be of great importance, and vice versa, when victory is quickly achieved (in a few seconds), the muscles perform work in a biometric mode, overcoming the efforts of the opponent due to high of explosive force (Ogawa et al., 2022; Hirai, 2021).

Based on the results of our previous studies (Bezkorovainyi et al., 2019; 2022; 2023), it was established that the explosive force of highly skilled armwrestlers is formed by the starting and accelerating force. The starting force manifests itself in the first 200 ms, which is accompanied by a rapid increase in force that does not reach the limit values, as well as a maximum increase in the speed-force index, which obviously makes it possible to develop maximum acceleration during of this time. Subsequently, fast force appears, characterized by an increase in the force to overcome resistance, which has not yet reached the limit value, as well as a decrease in the speed-force index and, accordingly, a decrease in acceleration. As the fight continues, overcoming the opponent's resistance reaches a limiting value, and the acceleration is relatively stabilized. The strength displayed at this stage of the fight is characterized by slow strength. The duration and magnitude of the manifestation of fast and especially slow force depend on the level of strength endurance of the arm wrestler (Kamayev et al., 2020, 2021; Zixiang Tong, 2021).

In connection with such features of armwrestling, in order to determine an effective methodology of the training process that corresponds to the volume and intensity of the loads and their direction, it is especially important to establish the natural strength abilities of the athlete and their significance in achieving successful competitive activity.

In connection with the above, the purpose of this study was to determine the characteristics of the manifestation of strength in competitive exercises by highly qualified armwrestlers with different strength abilities.

Material and Methods

Participants

The study involved 4 leading arm wrestlers in the world weighing from 80 to 100 kg (average weight 87.50±2.47 kg). Athlete 1 (age 38) – multiple world champion weighing 90 kg (Ukraine), athlete 2 (age 32) – multiple medalist of international competitions weighing 85 kg (USA), athlete 3 (age 28) – multiple world champion weighing 82 kg (Ukraine), athlete 4 (age 33) – multiple world champion weighing 93 kg (Ukraine). All athletes consented to the study.

Research Design

Strength and speed capabilities in test exercises were determined by an electrical tenzodynamometer of the FL1K 0.5N, 1000N series, Kern & Sohn GmbH (China) with an accuracy class of up to 50 g, fixed on a specialized table for armwrestling using an author's specially made block device – "ARM2 device". The strength and speed capabilities of armwrestlers were determined based on the results of four test exercises covering the main muscle groups that ensure the performance of a competitive action, namely: flexion of fingers, stretch with a hammer, hook and bending the hand (Kamayev et al, 2021). All exercises were performed with both left and right hands.

Measurements of strength and speed-strength indicators of each of the athletes were carried out three times within three years (2017-2020), after the end of the main competition of the year (armwrestling championship or world cup). They made three attempts in each movement on the left and right hands, after measurements the best results were selected.

When measuring the strength of the muscles of the hands and speed-strength indicators, the subject stood facing the table, grabbed the special handles of the device with a brush and squeezed them with maximum force, trying to show maximum force as soon as possible. Flexion of fingers was performed with a special eccentric 3D handle, which the athlete grabbed and pressed with his fingers into the platform, the pressure vector was directed to the chest. Stretch with a hammer was performed with a fabric loop, the pressing vector was directed to the forehead. The hook was performed with a rotating handle with a diameter of 30 mm, which the athlete grabbed and tried to pull up to the chest, simulating a hook fight. The block was located on the left or right sides of the table, respectively. Bending the hand was performed with a rotating handle with a diameter of 45 mm, which the athlete grabbed and tried to bend the hand towards the chest. The distance and angle between the handles of the device was easily changed and selected for each exercise.

The special computer program AFH-FASTFD made it possible to process the measurement data in real time (on-line) and the previously collected data from the memory of the electrical tenzodynamometer (off-line). AFH-FASTFD is compatible with the operating systems Windows.

Statistical Analysis

Statistical analysis of the obtained data was carried out using the licensed program STATISTICA 10. The following parameters were determined and calculated: maximum (F) and relative ($F_1 = \Sigma F/m$) strength, kg; total strength index in four strength exercises ($\Sigma F = F_1 + F_2 + F_3 + F_4$), kg; time to reach maximum strength ($\Sigma t = t_1 + t_2 + t_3 + t_4$), s; speed-strength index ($J = \Sigma F/\Sigma t$), kg/ms; average strength, index of four exercises ($\overline{F} = \Sigma F/4$), kg; total strength gradient of four

exercises ($\Sigma t_{0,5F}$), ms; speed-strength index in the first 500 ms ($J_{500} = \Sigma F_{500}/\Sigma t_{500}$), kg/ms; time to reach 1 kg force ($t_1 = \Sigma t_{0.5F}/(0.5 \times F)$), ms/kg; Wilcoxon-White test; the coefficient of variation; Spearman correlation analysis.

Results

According to our latest research (Bezkorovainyi et al., 2019, 2022, 2023), it has been established that among highly qualified arm wrestlers, multiple winners and prize-winners of world and European championships, national championships (USA, Poland, Ukraine), each athlete has purely individual natural abilities and a correspondingly high level of special preparedness. The main thing where they differ is in the indicators of maximum strength and speed-strength capabilities.

From a number of strong armwrestlers weighing from 80 to 100 kg, four of the most titled athletes were singled out, who are especially different from other athletes. These are two armwrestlers with high levels of explosive power and two athletes with pronounced maximum strength and strength endurance.

Analysis of the overall results of achieving maximum performance in four test exercises (flexion of fingers, stretch with a hammer, hook and bending the hand) indicates that armwrestlers of the strength group (athletes 1 and 2) differ

Table 1. Features of the strength and time characteristics of the manifestation of strength by armwrestlers with different strength abilities

Indicator	Athlete	Left arm	Right arm	Hand sum	Group sum	X±m	t-test	V, %
ΣF, kg	1	233.80	260.50	494.30	886.50	221.62±15.89	t=0.74; P>0.05; (t_{fact} 16 > t_{table} 11)	14.34
	2	190.00	202.20	392.20				
	3	326.50	173.50	500.00	990.20	249.55±31.48		25.43
	4	236.10	254.10	490.20				
$\bar{F}$, kg	1	58.45	65.12	123.57	221.92	55.48±3.92	t=0.73; P>0.05; (t_{fact} 16 > t_{table} 11)	14.15
	2	47.80	50.55	98.35				
	3	81.62	43.87	125.49	248.03	61.88±7.87		25.44
	4	59.02	63.52	122.54				
Σt, s	1	5.3	5.5	10.8	19.9	4.97±0.32	t=2.79; P<0.05; (t_{fact} 10 < t_{table} 11)	14.08
	2	3.9	5.2	9.1				
	3	6.6	5.9	12.5	28.5	7.12±0.70		20.00
	4	6.8	9.2	16				
J, kg/s	1	44.11	47.36	91.47	178.72	44.77±3.12	t=1.62; P>0.05; (t_{fact} 14 > t_{table} 11)	13.96
	2	48.37	38.88	87.25				
	3	49.47	35.41	84.88	147.22	35.30±4.95		28.07
	4	34.72	27.62	62.34				
F1, kg/kg	1	2.59	2.89	5.48	10.1	2.52±0.14	t=0.75; P>0.05; (t_{fact} 17 > t_{table} 11)	16.50
	2	2.24	2.38	4.62				
	3	3.98	2.12	6.1	11.37	2.84±0.40		28.16
	4	2.54	2.73	5.27				
Σt0,5F, ms	1	910	1410	2320	3895	948.74±161.40	t=3.69; P<0.05; (t_{fact} 10 < t_{table} 11)	34.02
	2	670	905	1575				
	3	2046	1935	3981	8231	2058.75±258.25		25.07
	4	1500	2750	4250				
ΣF500, kg	1	195.9	204.9	400.8	712.8	178.2±12.94	t=1.84; P>0.05; (t_{fact} 13 > t_{table} 11)	14.50
	2	156	156	312				
	3	202.8	106.7	309.5	496.3	124.07±26.43		42.60
	4	93	93.8	186.8				
J500, g/ms	1	97.95	102.45	200.4	356.4	89.1±6.47	t=1.83; P>0.05; (t_{fact} 13 > t_{table} 11)	14.50
	2	78	78	156				
	3	101.4	53.35	154.75	248.15	62.04±13.21		42.60
	4	46.5	46.9	93.4				
t_1, ms/kg	1	7.73	10.82	18.55	33.56	8.39±0.83	t=3.14; P<0.05; (t_{fact} 10 < t_{table} 11)	19.8
	2	7.05	7.96	15.01				
	3	12.53	22.31	34.84	69.19	17.30±2.70		31.30
	4	12.71	21.64	34.35				
J_{finish}, kg/s	1	10.82	12.36	23.18	55.51	13.88±1.22	t=5.45; P<0.05; (t_{fact} 10 < t_{table} 11)	17.65
	2	17.89	14.44	32.33				
	3	26.89	23.03	49.92	101.99	25.50±1.75		3.92
	4	29.81	22.26	52.07				

from fast athletes (athletes 3 and 4) by 11.7 % strength data (990.2 kg versus 886.5 kg). This difference remains in the average strength indicators (247.55±31.48 kg versus 221.62 ± 15.89 kg), but this difference turned out to be unreliable (Table 1). This is explained by the high coefficient of variation of 25.43 % and 14.34 %, respectively.

A similar difference between the strength capabilities of these athletes according to the average test indicators is completely preserved.

In terms of the time to reach maximum strength, the first two athletes showed a significantly better result compared to the other two athletes – 4.97 ± 0.32 s versus 7.12 ± 0.70 s. The difference between these indicators of 43.2 % provided significant differences between them – $t = 2.79$; $P < 0.05$ (Table 1).

In connection with such temporary characteristics of the efforts of armwrestlers, athletes 1 and 2 demonstrated 26.8 % higher speed-strength index values, respectively, 44.77 ± 3.12 kg/s versus 35.30 ± 4.95 kg/s than athletes 3 and 4. Moreover, the difference between such data is unreliable – $t = 1.62$; $P > 0.05$. The high result of achieving maximum strength with the left arm (326.5 kg) and the relatively small body weight (82 kg) of athlete 3 allowed the second pair to demonstrate higher relative strength – 2.84 kg versus 2.54 kg the first two athletes. Considering the increased coefficient of variation (28.16 % and 16.50 %), the difference between these data also turned out to be unreliable – $t = 0.75$; $P > 0.05$.

Determining the force gradient (the time to reach half the maximum force) made it possible to establish high speed-strength capabilities of the first pair. Thus, athletes 1 and 2 demonstrated better results by 2.17 times compared to athletes 3 and 4 – 948.75 ± 161.40 ms versus 2057.75 ± 259.25 ms. Thanks to this difference, despite the rather high coefficients of variation (34.02 % and 25.17 %), these data are significantly different ($t = 3.69$; $P < 0.05$; $t_{fact}\ 10 < t_{table}\ 11$).

Analysis of strength achievements for 500 ms indicates the highest strength capabilities of athletes 1 and 2. Thus, during this time they reached a level of 178.20 ± 12.94 kg, and arm wrestlers 3 and 4 showed 124.07 ± 26.13 kg. But the difference between these results is insignificant ($t = 1.84$; $P > 0.05$), since in this case the variability of the statistical aggregates is also large (14.5 % and 42.6 %). Due to the same test execution time, the speed-strength indicator in this test completely repeats the strength capabilities data for this time.

Calculation of the time athletes reach a force of 1 kg also confirms the high speed-strength abilities of armwrestlers 1 and 2. The data obtained allows us to establish that these athletes demonstrated better results by 2.06 times than arm wrestlers 3 and 4 – 8.39 ± 0.83 ms versus 17.30 ± 2.70 ms. This is supported by the reliability of the difference in indicators – $t = 3.14$; $P<0.05$.

According to the results of determining the speed-strength indicator at the last second of the test, armwrestlers 3 and 4 showed a significantly higher result, which was 1.84 times (83.7 %) higher than the achievement of athletes 1 and 2 (25.50 ± 1.75 kg/s versus 13.88 ± 1.22 kg/s). such data differ significantly from each other – $t = 5.45$; $P < 0.01$; $t_{fact}\ 10 < t_{table}\ 11$).

In this study, the significance of differences between the achievements of armwrestlers was tested using the nonparametric Wilcoxon-White test for independent samples. The Student's t-test data are fully confirmed by the Wilcoxon-White test.

Analyzing the results of the study, we can summarize that all strength indicators, which were determined without taking into account the time characteristics of efforts, were better in athletes 3 and 4. It is especially noticeable that armwrestler 3 demonstrated very high results in strength tests with his left hand. In this regard, obviously, he won all significant victories in competitions with his left hand. His right arm is the weakest in all strength tests.

Armwrestler 2 demonstrated small strength data, but was the fastest in all indicators of time characteristics of efforts.

Armwrestler 1 has equally high performance in both strength and time characteristics of efforts. His results are the most harmonious, therefore, of all four athletes, he is the most titled.

Athlete 4 also has relatively high strength data, but the time characteristics of performing efforts are noticeably weaker, and his sporting achievements are less effective.

The results of the correlation analysis of the relationships between the studied indicators confirm the presence of a difference in the direction and strength of the relationships between the strength and time characteristics of the efforts of athletes with different strength and speed-strength abilities. Thus, out of 36 correlation indicators, the data of armwrestlers 1 and 2 have 11 modules with very high connection strength ($r = 0.926$-0.999), of which 7 modules are with time and 4 are with force characteristics of efforts. Athletes 3 and 4 also have 3 modules with very strong connections ($r = 0.916$-0.948) and 8 with strong connections ($r = 0.739$-0.886), of which 7 modules are with strength indicators and 4 modules are related to time characteristics. But other correlation indicators have very weak ($r<0.29$) and weak ($r=0.3$-0.5) levels of relationships.

Considering that the main differences in the reaction of arm wrestlers to test exercises are related to the temporal characteristics of efforts and the peculiarities of conducting a fight in competitions, it was especially important to analyze the dynamics of the studied characteristics at the beginning of strength exercises.

Thus, at the beginning of a strength exercise within 100 ms, not all athletes have time to engage in the exercise. Athletes 2 and 3 showed zero reaction with their right hands. At the same time, athlete 2 with his left hand reached a level of 106.2 kg (Table 2), and in a total of 100 ms, armwrestlers 1 and 2, according to average statistical data, showed 2.45 times greater strength compared to the results of athletes 3 and 4 (48.97 kg vs. 20.00 kg). Despite this discrepancy, the difference between these results is unreliable, since the coefficients of variation are very large (68.12 % and 64.00 %).

Accordingly, with such dynamics of growth in strength indicators, the indicators of the speed-strength index change (Table 3).

Between 100 ms and 200 ms of the testing process, strength indicators increase significantly, namely for athletes 1 and 2 by 2.26 times (from 48.97 kg to 125.5 kg), for armwrestlers 3 and 4 – by 3.3 times (from 20.00 to 66.15 kg). The difference between the achievements of both pairs of athletes was 89.7 %. Such a difference in this case indicates significant differences ($t = 3.93$; $P < 0.05$) between strength indicators at this stage of the study (Table 2). The rate of increase in the speed-strength index between 100 ms and 200 ms is much lower compared to strength indicators. Thus,

Table 2. Dynamics of power characteristics of arm efforts in competitive exercises when testing armwrestlers (kg)

Indicator	Athlete	Left arm	Right arm	Hand sum	Group sum	X±m	t-test	V, %
F_{100}, kg	1	53.7	36.0	89.7	195.9	48.94±16.6	t=1.63; P>0.05	68.12
	2	106.2	0	106.2				
	3	19.8	0	19.8	80	20.00±6.4		64.00
	4	42.1	18.1	60.2				
F_{200}, kg	1	125.4	119.7	245.1	502.2	125.50±4.19	t=3.92; P<0.05	6.61
	2	119.6	137.5	257.1				
	3	109.7	54.8	164.5	264.6	66.15±14.55		44
	4	51.7	48.4	100.1				
F_{300}, kg	1	161.9	174.3	336.2	627.1	156.77±7.43	t=3.86; P<0.05	9.59
	2	139.5	151.4	290.9				
	3	153.6	81.2	234.8	381.3	95.32±19.64		41.21
	4	78.7	67.8	146.5				
F_{500}, kg	1	195.9	204.9	400.8	712.8	178.20±12.94	t=1.96; P>0.05	14.54
	2	156	156	312				
	3	202.8	106.7	309.5	496.3	124.10±24.42		42.68
	4	93	93.8	186.8				
F, kg	1	233.8	260.5	494.3	886.8	221.62±25.89	t=0.74; P>0.05	14.34
	2	190	202.5	392.5				
	3	326.5	173.5	500	990.2	247.55±31.48		25.43
	4	236.1	254.1	490.2				
Ff_{inish}, kg	1	37.9	55.6	93.5	174.0	43.50±4.80	t=3.53; P<0.05	22.10
	2	34.0	46.5	80.5				
	3	123.7	66.8	190.5	493.9	123.50±22.2		35.90
	4	143.1	160.3	303.4				

in athletes 1 and 2 the increase was 28.2 % (from 0.489 kg/ms to 0.627 kg/ms), and in athletes 3 and 4 – 65.0 % (from 0.200 kg/ms to 0.330 kg/ms). The difference between the achievements of armwrestlers during this time, as well as in the strength data, is significant (t = 4.18; P < 0.05) (Table 3).

In the subsequent period of time from 200 ms to 300 ms, strength indicators gradually increase. For athletes 1 and 2 the increase was 24.9 % (from 125.50 kg to 156.77 kg), and for athletes 3 and 4 this figure increased from 66.25 kg to 95.32 kg (43.88 %). The difference between these indicators of both pairs of arm wrestlers (156.77 kg and 95.32 kg) was significant (t = 3.86; P < 0.05) (Table 2).

During this time period, the speed-strength index begins to decline. Thus, in athletes 1 and 2 it decreased from 0.627 kg/ms to 0.523 kg/ms (by 19.9 %), and in athletes 3 and 4 the rate of decrease was only 4.1 % (from 0.330 kg/ms to 0.317 kg/ms). Despite such rates of decline, the data of the first pair are significantly better than the results of the second pair – t = 2.98; P < 0.05 (Table 3).

In the next 200 ms (from 300 ms to 500 ms), naturally, the influence of force continues to grow in both pairs of athletes. The growth rate of strength indicators in athletes 3 and 4 is still significantly higher. Thus, for these armwrestlers the magnitude of the force impact increased from 95.23 kg to 124.1 kg (by 32.2 %), and for athletes 1 and 2 – by 13.4 % (from 156.77 kg to 178.20 kg). The difference between these results turned out to be unreliable – t = 1.96; P > 0.05. And the speed-strength index decreases more rapidly in athletes 1 and 2 – by 76.9 % (from 0.523 kg/ms to 0.356 kg/ms), in the second pair of armwrestlers the rate of decrease was 27.3 % (from 0.356 kg/ms to 0.249 kg/ms). The difference between such data also turned out to be insignificant (t = 1.84; P > 0.05) (Table 2, 3).

Subsequently, a gradual increase in strength continues until maximum strength is achieved in both pairs of athletes. The time to reach maximum strength, as noted earlier, varies significantly. So, for the first pair this time was 4.97 s, and for the second – 7.12 s. Armwrestlers 1 and 2 reached 221.62 kg during this time, and athletes 3 and 4 reached 247.55 kg over a longer period of time. The difference between these indicators is insignificant – t = 0.74; P > 0.05.

When maximum strength was achieved, the speed-strength index indicators were: for the first pair – 0.045 kg/ms, and for the second – 0.035 kg/ms. The difference between these data was 25.57 %, but due to large coefficients of variation (23.91 % and 27.70 %), the discrepancy turned out to be unreliable (t = 1.47; P > 0.05) (Table 3).

During the time remaining before reaching the maximum strength of 2.97 s (4.97 – 0.5 * 4 s), the strength indicator of the first pair of athletes 5.12 s (7.12 – 0.5 * 4 s) increases by 24. 4 % (from 178.20 kg to 221.62 kg), and for the second – by 99.5 % (from 124.10 kg to 247.55 kg).

Thus, the dynamics of power characteristics of effort observed during the specified period allows us to assert that athletes 3 and 4 have high power endurance. Armwrestlers 1 and 2 have significantly higher power characteristics in the first 200 ms and 300 ms of effort, which provides them with quick victories. According to the results of our research, such dynamics of power characteristics are achieved due to a high speed-strength indicator, starting from 100 ms of the beginning of the effort.

Analyzing the data obtained on the discrepancy between strength indicators, time characteristics and the level of strength endurance depending on the genetically determined abilities of highly qualified arm wrestlers, it is necessary to

Table 3. Dynamics of speed-strength index characteristics during testing of armwrestlers

Indicator	Athlete	Left arm	Right arm	Hand sum	Group sum	X±m	t-test	V. %
J_{100}, kg/ms	1	0.537	0.36	0.897	1.959	0.489±0.170	t=1.59; P>0.05	77.50
	2	1.062	0	1.062				
	3	0.198	0	0.198	0.8	0.200±0.064		64.00
	4	0.421	0.181	0.602				
J_{200}, kg/ms	1	0.627	0.598	1.225	2.51	0.627±0.021	t=4.18; P<0.05	6.63
	2	0.598	0.687	1.285				
	3	0.548	0.274	0.822	1.322	0.330±0.072		43.90
	4	0.258	0.242	0.5				
J_{300}, kg/ms	1	0.54	0.581	1.121	2.091	0.523±0.024	t=2.98; P<0.05	9.35
	2	0.465	0.505	0.97				
	3	0.512	0.27	0.782	1.27	0.317±0.065		41.00
	4	0.262	0.226	0.488				
J_{500}, kg/ms	1	0.392	0.409	0.801	1.425	0.356±0.025	t=1.84; P>0.05	14.30
	2	0.312	0.312	0.624				
	3	0.41	0.213	0.623	0.997	0.243±0.053		43.00
	4	0.186	0.188	0.374				
J, kg/ms	1	0.044	0.047	0.091	0.179	0.045±0.021	t=1.47; P>0.05	23.91
	2	0.049	0.039	0.088				
	3	0.049	0.029	0.078	0.141	0.035±0.048		27.70
	4	0.035	0.028	0.063				

compare the features of the formation of explosive, fast and slow strength in these athletes. Since our previous studies (Bezkorovainyi & Kamayev, 2023) noted that explosive force is formed by starting and accelerating forces, it was found that explosive force in arm wrestlers manifests itself in the first 300 ms, and starting force manifests itself within 200 ms of effort. Within 100 ms, cases of zero reaction at the beginning of the effort are observed in both pairs of athletes under study (Table 2). But during this time, athletes 1 and 2 had a strength indicator and speed-strength index that was 2.45 times higher than that of arm wrestlers 3 and 4 (48.97 kg versus 20.00 kg) (Fig. 1).

Over 200 ms, the growth rates of both indicators in the second pair of athletes are higher, so the strength is 3.33 times higher, and the speed-strength index is 1.65 times higher (Fig. 1). But despite this difference in increase, the strength indicator and speed-strength index of athletes 1 and 2 are significantly higher than those of armwrestlers 3 and 4 (125.5 kg versus 66.15 kg) – t = 4.18; P < 0.05 (Table 2, 3). The high starting strength of the first pair is supported by a significantly higher speed-strength index.

Between 200 ms and 300 ms, under the conditions of the onset of muscle contraction, the process of increasing acceleration and increasing working force occurs, which

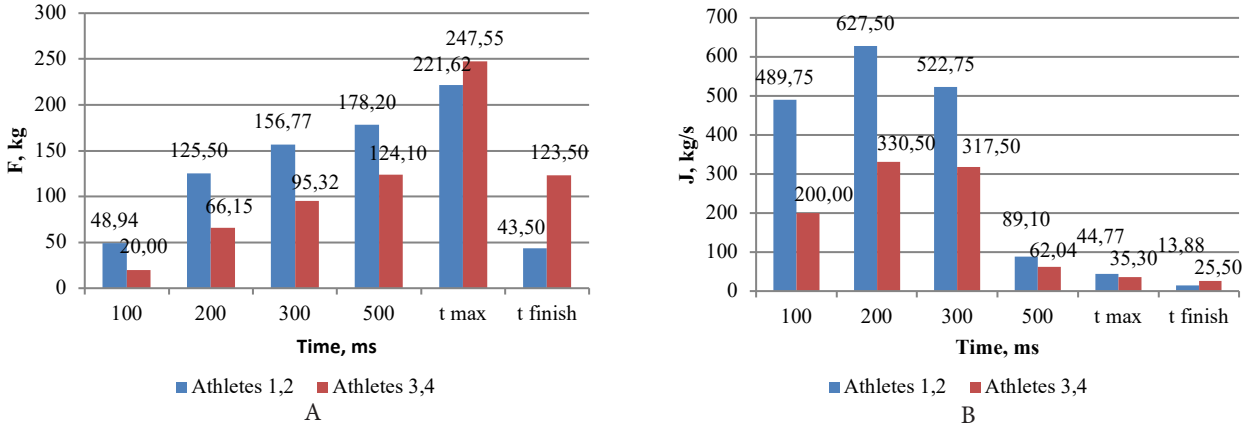

Fig. 1. Dynamics of strength indicators (A) and speed-strength index (B) of armwrestlers in different time periods of testing

corresponds to the accelerating force. During this time period, the formation of explosive force is completed and the beginning of a decrease in the speed-strength index in both pairs is noted, respectively, by 16.7 % in the first and by 3.9 % in the second (Fig. 1). During this period of time, athletes 1 and 2 have significantly higher levels of strength and speed-strength index compared to the data of arm wrestlers 3 and 4 ($t = 3.86$; $P < 0.05$ – in strength; $t = 2.89$; $P < 0.05$ – speed-strength index).

In the next period of time (from 300 ms to 500 ms), the speed-strength index decreases with great intensity: in athletes 1 and 2 – by 5.86 times, and in athletes 3 and 4 – by 5.12 times. From this we can state that the acceleration becomes significantly less than the maximum, and the strength indicator continues to increase in the first pair by 13.67 %, in the second – by 30.00 %, but the strength has not yet reached the limit values. The difference between strength indicators and speed-strength indices is unreliable, respectively – $t = 1.96$; $P > 0.05$ and $t = 1.84$; $P > 0.05$. This creates fast force.

During the time that remains until the limit strength indicators are reached (for the first pair of athletes – 2.97 s, for the second – 5.12 s), the strength of armwrestlers 1 and 2 increases by 24.4 % (from 178.20 kg to 221. 62 kg), and athletes 3 and 4 – by 99.5 % (from 124.10 kg to 247.55 kg). The difference between these indicators is not significant ($t = 0.74$; $P > 0.05$). During this period of time, the speed-strength index continues to decrease, but with less intensity. So, for the first couple the decrease was 49.75 %, and for the second – 43.1 %.

When the maximum strength values were reached in athletes 1 and 2, the speed-strength indicator decreased to 44.77 kg/s, and in athletes 3 and 4 – to the level of 35.30 kg/s. This difference between the strength and speed-strength characteristics of the effort is explained by the large difference (52.6 %) in the time to achieve maximum strength between athletes. The manifestation of slow strength corresponds to a significant decrease in the speed-strength indicator and a slowdown in its pace when the maximum strength values are reached. The amount and time of application of this force until maximum force is achieved depends on the level of strength endurance. Proof of this statement in this study is the calculation of the strength index (123.50 kg vs. 43.5 kg; $t = 3.52$; $P < 0.05$) and speed-strength index (25.50 kg/s vs. 13.88 kg/s; $t = 5.45$; $P < 0.01$) at the last second in the second pair was significantly higher compared to the indicators of the first pair.

A comparative analysis of the strength and speed-strength indicators of the left and right hands allows us to state that the difference between them in both pairs is unreliable, however, in the second pair of athletes the discrepancy between the left and right hands fluctuates within 33.5 % to 88.2 %, and in the first – from 4.6 % to 47.6 %.

Discussion

In arm wrestling there are many examples when arm wrestlers weighing from 80 to 100 kg take part in competitions for absolute superiority at national championships, as well as European and world championships, and international competitions (Min Kyung-hyun et al., 2018). I would also like to note that these athletes often defeated super-heavyweights who weighed 20-50 kg or more. This is what attracts special attention from spectators, fans, athletes, coaches and, of course, researchers (Diffrient, 2019; Silva et al., 2009), when lighter athletes, inferior to anthropometric data, win due to strength and speed-strength indicators. All of these individuals are interested in determining the strongest athlete of the tournament, country, continent and even the world. Therefore, it is this weight category that is given special attention, and it became the object of our research. Taking into account the peculiarities of the external characteristics of the physique of such athletes, their techniques and tactics of conducting a fight, it is especially important to determine the most effective and influential characteristics of the manifestation of force that ensure the success in armwrestling.

The study was carried out over three years, since, as noted above, athletes weighing from 80 to 100 kg took part in competitions for absolute championship and received prizes. The four athletes selected for the study had the best indicators of both strength and speed-strength indicators, which was also confirmed by the results of participation in competitions.

However, despite the higher qualifications of the athletes who participated in the study, it must be recognized that the number of arm wrestlers who won world-class competitions is limited by the small size of the specialized sample. To date, a study has been conducted of winners of world and European level competitions weighing 60-80 kg (Bezkorovainyi et al., 2019; 2021; Mazurenko, 2019) and athletes weighing more than 100 kg (Bezkorovainyi, 2023). It should also be noted that the small sample is due to the small number of highly qualified athletes of this level of preparedness who agreed to conduct research with them.

But, in our opinion, the value of the results obtained lies in the fact that they coincide with the data obtained in the study of highly qualified athletes in the weight categories of 60-80 kg and more than 100 kg (Bezkorovainyi, 2023).

To conduct the study, the author's device was used to measure both strength and time indicators of the development of dynamic strength. This device differed from others (Vlasko & Dzhym, 2023) used in research in that it was highly mobile, easy to transport and assemble, and also accurately measured forces up to 50 g and time up to 100-110 ms. Other researchers have determined absolute strength as well as static endurance, which is measured using conventional dynamometers and stopwatches (Harčarik et al., 2020). The author's device allows you to automate measurements, as well as create a database about the strength and speed-strength capabilities of armwrestlers.

According to preliminary studies (Podrigalo et al., 2021; Rovnaya et al., 2019), it was found that arm wrestlers, based on genetic attachment, can be divided into those who have a tendency to quickly perform competitive exercises, and those who have the ability to perform strength endurance. Based on this, the four athletes under study were divided into two pairs with different strength and speed-strength abilities.

Considering that the listed factors have a direct impact on the result of competitive activity, it was important to determine the degree of their influence on the strength abilities of athletes and the characteristics of muscle efforts that most influence the sporting achievements of armwrestlers of the specified weight.

Hypothetically, it was assumed that this may not be a large indicator of maximum strength, but other strength and speed-strength capabilities, such as explosive strength and strength endurance; in addition, it was important to establish the degree of influence of these qualities on the ability to demonstrate greater rapid strength and strength endurance.

There is very little research in this direction in speed-strength sports. Also, the listed problems are not sufficiently covered in the available sources of information (Coletta et al., 2022; Mao J-T et al., 2022); therefore the search for an answer regarding the determination of the characteristics of the manifestation of various characteristics of the manifestation of dynamic efforts of arm wrestlers is of particular importance for the theory and practice of sports.

It was also assumed that the absolute strength indicators of armwrestlers are not decisive in the effectiveness of a competitive match. Thus, in the works of Mazurenko (2019), it was noted that athletes with weaker strength indicators won the competition. Therefore, our research was aimed at studying both strength and speed-strength indicators, that is, the gradual development of different types of strength over time. The hypothesis turned out to be correct, which is confirmed by the results of the correlation analysis. Thus, out of 36 correlation indicators, the data of armwrestlers 1 and 2 have 11 modules with very high connection strength ($r = 0.926–0.999$), of which 7 modules are with time and 4 are with force characteristics of efforts. Athletes 3 and 4 also have 3 modules with very strong connections ($r = 0.916–0.948$) and 8 with strong connections ($r = 0.739–0.886$), of which 7 modules are with strength indicators and 4 modules are related to time characteristics. That is, the first pair wins due to explosive strength, and the other two athletes due to strength endurance.

According to publications and the results of our research, dynamic force in the process of overcoming resistance is manifested through explosive, fast and slow force (Harčarik et al, 2020; Podrigalo et al., 2017). It has also been established that explosive force is characterized by two components: starting and accelerating force (Chang-Yk Lee et al., 2022). The starting force manifests itself from 100 to 200 ms and provides the speed of development of the working force at the initial moment of muscle tension (Coletta et al., 2022), which confirms our data. Thus, in all the athletes we studied, the speed-strength index appears at 200 ms of effort, regardless of the level of genetically determined abilities.

Armwrestlers 1 and 2 with high speed-strength characteristics demonstrated significantly high results of starting and accelerating force, respectively, $t = 3.92$; $P < 0.05$ and $t=3.86$; $P < 0.05$ at 200 ms and 300 ms force. The time to achieve maximum strength in these athletes is significantly less ($t = 2.79$; $P < 0.05$), and they also have a significantly better indicator of the force gradient ($t = 3.69$; $P < 0.05$) and the time to achieve strength in 1 kg ($t = 3.14$; $P < 0.05$). This pair of athletes is characterized by a harmonious ratio of strength and speed-strength characteristics of the effort between the left and right hands.

Armwrestlers with predominant indicators of strength endurance are characterized by a higher indicator of maximum and relative strength, a significantly longer time to achieve maximum strength, as well as significantly higher indicators of strength and speed-strength index in the last second of effort, respectively: $t = 3.52$; $P < 0.05$ and $t = 5.45$; $P < 0.01$.

Separately, it can be noted that athletes with high speed-strength characteristics of effort are more titled and have more harmonious results with both left and right hands.

However, it should be noted that, due to the small size of the specialized sample, there is a risk of overinterpretation of the study results. It is important to note that while the results are relevant and have potential value for understanding the performance of elite armwrestlers, they may not be generalize to broader population or armwrestlers of varying fitness levels.

Conclusions

The conducted research made it possible to reliably establish the degree of difference in the manifestation of efforts of armwrestlers with high rates of speed-strength characteristics of effort and athletes with high capabilities of strength endurance. Based on the results of the study, the features of the dynamics of the time and power characteristics of the efforts of highly qualified arm wrestlers weighing from 80 to 100 kg before achieving boundary efforts in competitive exercises were determined, as well as the significance of various characteristics of the manifestation of efforts on the success of results in competitive activities. Thus, analysis of the time and force characteristics of the manifestation of force in the process of achieving boundary resistance (maximum force) allows us to clearly establish the genetically determined speed and strength abilities for the manifestation of explosive, fast and slow strength of armwrestlers.

Further research will be aimed at experimentally substantiating the methodology for developing speed-strength capabilities (starting, explosive, fast, slow strength) for training from groups of initial training to groups of maximum capabilities, to which it is planned to attract a larger number of participants by age, weight and level of preparedness.

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Conflict of interest

The authors declare no conflict of interest.

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АНАЛІЗ Й ОЦІНКА ОСОБЛИВОСТЕЙ ПРОЯВУ ДИНАМІЧНОЇ СИЛИ У ПРОВІДНИХ АРМРЕСТЛЕРІВ СВІТУ

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 10 с., 3 табл., 1 рис., 24 джерел

Мета. Визначення особливості прояву сили у змагальних вправах армрестлерів високої кваліфікації з різними силовими здібностями.

Матеріал і методи. У дослідженні взяли участь 4 кращих армрестлера світу вагою від 80 до 100 кг (m = 87,50 ± 2,47 кг) у 2017-2020 роках. Визначено чотири силові тестові вправи, що забезпечують виконання змагальної дії в армрестлінгу: згинання пальців, розгинання молотком, гак і згинання кисті. Силові показники у всіх тестових вправах вимірювали електротензодинамометром серії FL 1K 0,5N, 1000N, Kern & Sohn GmbH (Китай), закріпленим на столі для армрестлінгу за допомогою авторського блокового приладу.

Результати. Результати кореляційного аналізу взаємозв'язків між досліджуваними показниками підтверджують наявність різниці у спрямованості та силі взаємозв'язків між силовими та часовими характеристиками зусиль спортсменів із різними силовими та швидкісно-силовими здібностями. Так, з 36 показників кореляційного зв'язку дані армрестлерів 1 і 2 мають 11 модулів із дуже великою силою зв'язку (r = 0,926-0,999), з яких 7 модулів із часовими та 4 з силовими характеристиками зусиль. У спортсменів 3 і 4 також є 3 модулі з дуже великою силою (r = 0,916-0,948) і 8 – із сильними зв'язками (r = 0,739-0,886), з яких 7 модулів із силовими показниками та 4 модулі пов'язані з часовими характеристиками. Але інші показники кореляційного зв'язку мають дуже слабкі (r < 0,29) та слабкі (r = 0,3-0,5) рівні взаємозв'язків.

Висновки. Аналіз часових і силових характеристик прояву сили у процесі досягнення межового опору (максимальної сили) дозволяє чітко встановити генетично обумовлені швидкісні та силові здібності до прояву вибухової, швидкої та повільної сили армрестлерів.

Ключові слова: армспорт, армрестлінг, армрестлери, вибухова сила, силові показники.

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