



AIMING POINT TRAJECTORY AS AN ASSESSMENT PARAMETER OF SHOOTING PERFORMANCE

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ABSTRACT

Purpose. The purpose of this study was to elaborate on the scientific methodology for providing an assessment of air-pistol shooters' aiming stability by (i) substantiating the parameters of aiming stability, (ii) specifying the quantitative evaluation methods in using an optoelectronic target, (iii) evaluating the reliability of tests determining aiming stability, and (iv) developing a methodology for creating individual and group parameters of aiming stability. **Methods.** The aiming trajectories of 95 air-pistol shooters, each of whom fired 60 shots using a SCATT optoelectronic simulator, were calculated to develop individual and group aiming stability parameters. Research methods included an optoelectronic registration of movement, research on top air-pistol shooters' sports results, mathematical modelling, variation statistics, cluster analysis, two-way ANOVA with data correlation and reliability theory tests. **Results.** It was found that an average aiming point trajectory on the SCATT optoelectronic target measured one second before a shot could be accepted as an assessment parameter of aiming stability, as it is one of the basic parameters of technical preparation and its position is not influenced by the ballistic characteristics of the pistol and pellets ($\eta = 0.944$). **Conclusions.** The parameters of aiming stability in air-pistol shooting were developed using a modification of the clustering method. This allows for the identification of weak points in the structure and organization of shooters' training and for adjustment of the training process.

Key words: air-pistol shooting, aiming stability, optoelectronic training system

Introduction

Contemporary air-pistol shooting technique consists of three elements: aiming, weapon retention and firing (pulling the trigger). Weapon retention is synonymous with stability, where controlling hand vibrations is an important factor when aiming and when the trigger is pulled [1]. The quantitative technical parameters of shot performance can be obtained by using optoelectronic shooting simulators such as the SCATT Professional Training Systems [2], Home Trainer [3] and the Sport Shooter Training System [4]. It has been found that if aiming stability is disturbed 0.1–0.2 s before firing (simple reaction time), the aiming point trajectory moves rapidly away from the point of aim. It occurs due to the difficulty in simultaneously controlling all the three processes (aiming, weapon retention and firing) and by muscle non-coordination. It is evident that an attempt to counteract this instability by firing earlier (during simple reaction time) would be an incorrect approach as this cannot eliminate the effects of muscle non-coordination [5].

Individual and group competitive techniques are developed to optimize shooters' training. Training programmes should consider long-term planning in order

to avoid physical overstrain. A number of parameters of shooting technique should be cultivated to help shooters break bad habits and achieve better sport results [6]. For the effective management of the training process, especially when planning a training schedule, one should not only consider the individual features of shooting technique, but also study the informative characteristics of top competitors. This allows for the identification of weak points in both the structure and organization of training and to appropriately adjust the training process [7]. This is particularly true in competitive shooting technique. That is why the further development of aiming stability parameters is one of the key elements in improving shooting technique and is the main theoretical and practical task of shooters' training in a shooting sport.

Theoretical and practical training with optoelectronic simulators is gaining more importance as they are more widely used. Many practical recommendations are provided by the developers of these simulators [2–4] on aiming, weapon retention and firing in order to improve shooting technique [8–10]. In spite of this, little research has been conducted to analyse the algorithms and models of these simulators that can help compare virtual shots with real ones. Our previous research has revealed statistically significant differences between the SCATT simulator's virtual shots (as the location of the "holes" marked at the moment when the trigger is pulled) and real shots, which were

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found to begin from a zero value of the simulator’s ballistics coefficient, i.e., without any artificial dispersion. This difference increases as the simulator’s ballistics coefficient grows. This indicates a large discrepancy between the SCATT model and the real lateral component of bullet (pellet) movement. As a result, a digitization method of the aiming point trajectory coordinates on SCATT interface graphs, based on accessible Microsoft Office programmes, was developed. It is a simple, accurate and acceptable way to quantitatively estimate the optoelectronic peculiarities in an air-pistol shooters’ training [5].

As far as the problem of assessing aiming stability is concerned, the only study that analysed this issue was one on the aiming technique of an 11-year-old air-pistol shooter; no other publications were found on this subject [11].

Therefore, the aim of this study was to elaborate on the scientific methodology for providing an assessment of air-pistol aiming stability by analysing the following issues: (i) substantiating the parameters of aiming stability, (ii) specifying a quantitative evaluation method by use of an optoelectronic target, (iii) evaluating the reliability of the test for determining aiming stability, and (iv) developing a methodology for creating individual and group parameters that determine aiming stability.

Material and methods

The study analysed top air-pistol shooters’ results that were recorded on a SCATT optoelectronic simula-

tor [2] as well as data available on the internet on their results [12]. The aiming trajectories of 95 air-pistol shooters, each of whom took 60 shots in accordance to International Official Statutes, Rules and Regulations [13], were calculated to develop individual and group parameters of aiming stability. An average aim point trajectory (on the SCATT optoelectronic target) taking place one second before a shot was considered as a parameter of the weapon retention process (see Fig. 1). This parameter of technical preparedness does not depend on the ballistic characteristics of a pistol and pellets [14].

For this study, the data from the SCATT target coordinate system of all 60 trajectory centres (aiming points) was averaged in order to eliminate systematic aiming error. The coordinates of the aiming trajectories were recalculated into this coordinate system. The distances from the average of these 60 aiming trajectories to the average of each aiming trajectory were then calculated. The horizontal (x) and vertical (y) coordinates of the average aiming points were extracted into a spread sheet file showing all shot data.

Parametric statistical methods were used to analyse the results as the number of experimental samples was quite large (60 shots in each series). Variation statistics (arithmetic mean and standard deviation), Student’s t -test, Snedecor’s F -test [15], and cluster analysis [16] were used to substantiate the parameters of aiming stability and to further quantitatively evaluate the research method. Two-way ANOVA with data correlation and reliability theory tests [17] were used to evaluate the test reliability of the selected parameters of aiming stability. Significance level was fixed

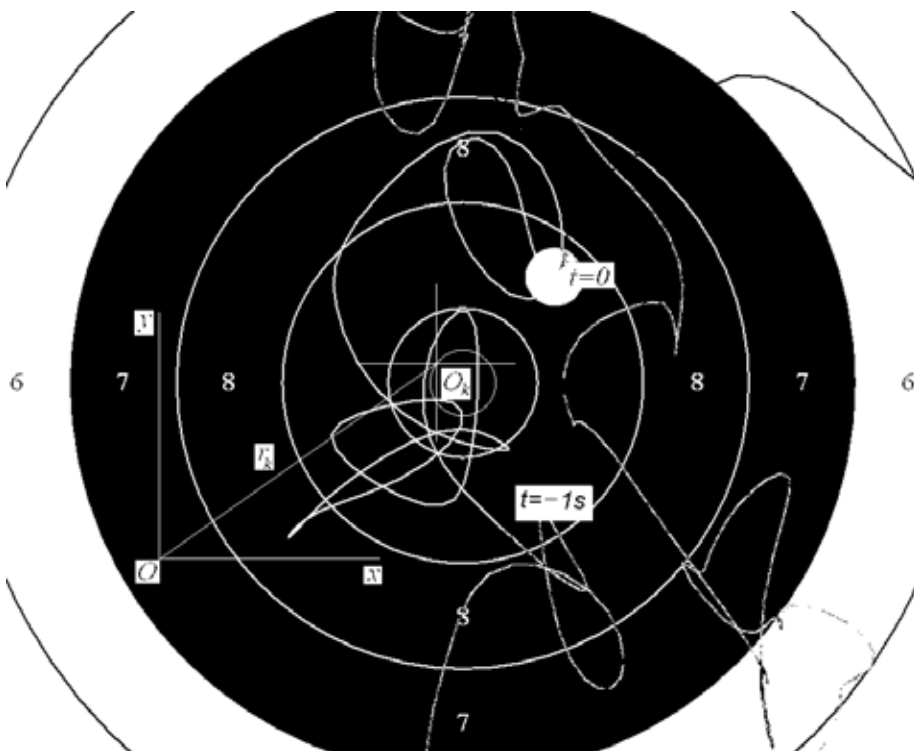


Figure 1. A sample target showing the aiming parameters: $t = -1$ s is the beginning of the aiming trajectory 1 s before pulling the trigger; $t = 0$ is the moment when the shot is taken; O_k is the trajectory centre of one shot; O is the total average point of all aiming trajectories (60 shots)

at 0.05. An inter-group correlation coefficient was used to calculate a test reliability coefficient:

$$\eta = \frac{MS_t - MS_e}{MS_t}, \quad (1)$$

where MS_t is the inter-group variance that estimates the difference between the shooters' results; MS_e is the variance of errors that estimates the sum of the dispersion of the shot results in the series as well as among them.

Variation statistics and a clusterization method were used to develop the group parameters of aiming stability. The basic idea of this approach was based on the fundamentals of cluster analysis, which is used to divide the object sample into clusters that do not overlap one another. Each cluster consists of similar objects, but the objects of different clusters are very dissimilar. Each object was characterized by a number of object factors. A matrix of distances was developed using these factors, and each object was described in relation to its distance from other objects in the system. The quantitative parameter of the cluster process is mathematical criterion. The limits between the cluster groups of the objects were defined with the help of this criterion.

The system of parameters measuring aiming stability consisted of samples of the average distance away from the total average of the aiming point trajectories (60) to the average point of each aiming trajectory one second before the shot. Each sample characterizes the shooter by the average distance and its variation:

$$M = \frac{\sum_{k=1}^N I_k}{N}; SE = \sqrt{\frac{\sum_{k=1}^N (I_k - M)^2}{N(N-1)}}, \quad (2)$$

where M is the arithmetic mean, I_k is the average distance taken from the total average aiming point (from 60 trajectories) to the average point of each aiming trajectory one second before the k -shot, N is the number of shots, i.e. 60, and SE is the standard error of arithmetic mean.

The confidence level, on which the null hypothesis could be rejected based on the samples of two shooters from one parent population, was used as a mathematical criterion to define the borders between the clusters. As such, a distance matrix between the average results of the shooters was developed from the estimated value of the confidence level on which the null hypothesis (3) could be rejected:

$$H_0: M_i = M_j, \quad (3)$$

where $i, j = 1.2...n$.

Student's t -test, independent of the variables, was used to test this hypothesis. Corresponding confidence levels for the null hypothesis on the dispersion of the

experimental samples (4) were obtained using Snedecor's F -distribution:

$$H_0: MS_i = MS_j. \quad (4)$$

These levels were taken into consideration when the Student's t -test formula was defined.

The shooters' groups were clustered by three confidence levels (0.95, 0.99 and 0.999) using the results of statistical hypothesis testing on arithmetic means. The clusters' borders were defined using the following algorithm: the results of the first shooter were compared to the other 94 shooters at the confidence level of 0.999. In the second clusterization attempt, the comparison process started from the last (n^{th}) shooter, and in the third clusterization attempt, from the middle $\left(\frac{n+1}{2}\right)^{\text{th}}$ shooter. The borders between the clusters at 0.99 and 0.95 confidence levels were defined by the three attempts mentioned above.

A critical value of the confidence level was chosen according to the optimal interval number, which was defined by Sturges' formula [18]:

$$K = 3.32 \lg(n). \quad (5)$$

The interval range (h) was defined by the following equation:

$$h = \frac{M_{max} - M_{min}}{K}, \quad (6)$$

where M_{max} and M_{min} are the extreme arithmetic means.

Fisher's chi-square distribution for attributive characters was used to develop a methodology for creating individual and group models of aiming stability as well as to test them. The influence of the grouping method (the interval or the cluster) on shooters' distribution results in the qualification groups was examined with:

$$\chi^2 = \sum \frac{(O - E)^2}{E}, \quad (7)$$

where O is the number of intervals and clusters and E is the average number of corresponding pairs of intervals and clusters. The calculations were performed using Microsoft Excel and Statistica (StatSoft, USA).

Results and discussion

The results of two-way ANOVA with data correlation, which was used to evaluate the reliability of the weapon retention test, are presented in Table 1. No statistically significant differences were found between the shot results in series ($p = 0.107$). Therefore, the test reliability coefficient was estimated as an inter-group correlation coefficient (1): $\eta = 0.944$; test reliability was sufficient as $\eta > 0.900$. Consequently, if a shooter is

Table 1. Two-way ANOVA results of the average aiming point distance of 95 shooters in a 60-shot series: *SS* is a sum of squared deviation; *df* is the number of degrees of freedom; *MS* is variance; *F* is Snedecor's criteria; *p* value; *Q* is a part of the total dispersion

Cause of dispersion	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p</i>	<i>Q</i> , %
Series	835	59	14.15	1.236*	0.107	1.0
Shooters	19177	94	204.01	17.818†	0.000	23.0
Interaction	63500	5546	11.45			76.0
Errors	64335	5605	11.48			77.0
Total	83512	5699	14.65			100

* $F_{0.05; 59; 5546} = 1.323$; † $F_{0.05; 94; 5546} = 1.254$

well-qualified, the value of this parameter would be small (the highest level was found to be 2.5 mm; the lowest level, 11.4 mm) and vice versa.

As no statistically significant differences were found between the locations of the aiming trajectory centres, the dispersion of the distances of these points was used as an individual model characteristic of aiming performance. The stability of the parameters of individual aiming technique was evaluated with a rather small part ($Q = 1.0\%$) of total dispersion (see Tab. 1).

The individual characteristics of aiming stability were developed using the parameters of the aiming trajectory coordinates (see Fig. 2). The confidence levels of the first 10 shooters (from a total of $n = 95$), on which the null hypotheses (3) and (4) from the sample origin of one parent population could be rejected, are presented in Table 2. The average of the shooters' results, starting with the smallest (the best) results, are shown in Figure 2.

When comparing the results of the first shooter with the remaining 94 at a confidence level of 0.999, one can see that the values of the confidence levels starting with the 2nd and up to 8th columns of the first row in the right upper part of Table 2 (0.0945÷0.0029) are more than the critical value of 0.001, thereby im-

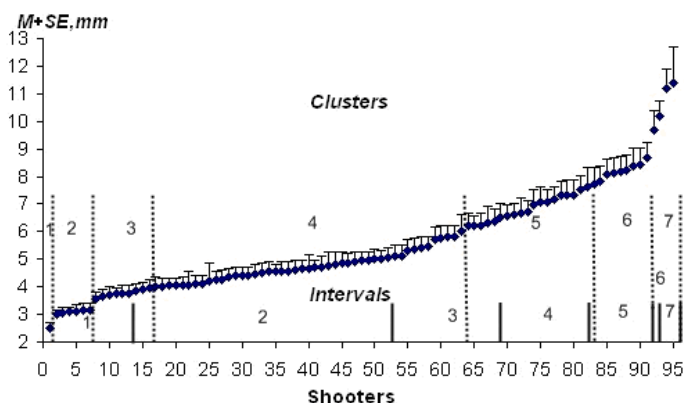


Figure 2. Parameters of shooters' aiming stability ($M + SE$)

plying that these results belong to the first cluster (see Tab. 3). Other shooters (9÷95) belong to the other clusters due to their confidence level values being smaller than the critical value of 0.999. The right border of the second cluster was defined starting with the 9th row of Table 2. Thus, the 95 competitors were divided into five clusters as model "a" (see Tab. 3).

For the second clusterization attempt, the comparison began from the last (95th) shooter (model "b"). For the third clusterization attempt, the comparison started from the middle (48th) shooter (model "c"). The same algorithm was used to define the locations of the clusters' borders at the confidence levels of 0.99 and 0.95 (models "d" ÷ "i", respectively).

The number of clusters in each clusterization attempt varied between four and eight. The optimal number of intervals defined by Sturges' formula (5) was seven. In such cases, some specialists recommend to choose a value of seven or eight intervals [18]. That is why the clusterization results are not used if the number of clusters equalled four÷six (models "a" ÷ "f").

The number of clusters that equalled eight were found when the clustering process began from the objects located at the extreme ends (i.e. the results of the

Table 2. The value of a significance level (the first 10 out of $n = 95$ shooters), which the null hypotheses on the sample origin from one parent population can be rejected: $p(t) \setminus p(F)$

No	1	2	3	4	5	6	7	8	9	10
1		0.0945	0.0416	0.0425	0.0639	0.0416	0.0272	0.0029	0.0002	0.0006
2	0.9982		0.7297	0.7130	0.7037	0.5900	0.5206	0.0995	0.0235	0.0321
3	0.8027	0.8010		0.9770	0.9355	0.8137	0.7442	0.1651	0.0465	0.0583
4	0.9749	0.9767	0.7785		0.9564	0.8363	0.7686	0.1775	0.0528	0.0645
5	0.0888	0.0892	0.0514	0.0947		0.8916	0.8328	0.2326	0.0891	0.0978
6	0.1476	0.1482	0.0900	0.1565	0.7975		0.9434	0.2780	0.1113	0.1201
7	0.4089	0.4102	0.2825	0.4269	0.3781	0.5317		0.2907	0.1127	0.1231
8	0.0087	0.0088	0.0042	0.0095	0.3482	0.2327	0.0698		0.7069	0.6563
9	0.1796	0.1803	0.1119	0.1900	0.7162	0.9148	0.6041	0.1937		0.9155
10	0.0078	0.0078	0.0037	0.0085	0.3283	0.2176	0.0640	0.9684	0.1805	

first or last shooter), where the confidence level was 0.95. However, the borders of these clusters were located at random and labelled as models “h” and “i”. It is possible that the differences with these border locations are the result of the influence of extreme effects. In addition, the recommended number of qualifying groups in sport competition is seven: the highest, high, upper-intermediate, intermediate, lower-intermediate, low and

the lowest [18]. This method of division is suitable for model “i”. So, the highest sports skill level was equated with the first cluster (the results of the record-holders). The other six clusters were equated with the six official rankings based on the Unified Sports Classification System used in the former USSR [19]: Master of Sports at the International Level (high level), Master of Sports (upper-intermediate level), Master of Sports Candidate

Table 3. The division variants of air-pistol shooters by clusters and intervals ($n = 95$)

Ranks	Clusters									Intervals
	a	b	c	d	e	f	g	h	i	
	The object from which the clusterization began									
	1	95	48	1	95	48	1	95	48	
	$p = 0.001$			$p = 0.01$			$p = 0.05$			j
1.	1 ÷ 8	1	1 ÷ 7	1 ÷ 7	1 ÷ 7	1	1 ÷ 2	1	1	1 ÷ 13
2.	9 ÷ 48	2 ÷ 9	8 ÷ 72	8 ÷ 34	8 ÷ 31	2 ÷ 11	3 ÷ 8	2 ÷ 4	2 ÷ 7	14 ÷ 52
3.	49 ÷ 72	10 ÷ 49	73 ÷ 91	35 ÷ 63	32 ÷ 62	12 ÷ 64	9 ÷ 32	5 ÷ 13	8 ÷ 21	53 ÷ 67
4.	73 ÷ 91	50 ÷ 73	92 ÷ 95	64 ÷ 84	63 ÷ 83	65 ÷ 84	33 ÷ 58	14 ÷ 35	22 ÷ 63	68 ÷ 81
5.	92 ÷ 95	74 ÷ 95	–	85 ÷ 92	84 ÷ 95	85 ÷ 92	59 ÷ 75	36 ÷ 58	64 ÷ 82	82 ÷ 91
6.	–	–	–	93 ÷ 95	–	93 ÷ 95	76 ÷ 90	59 ÷ 73	83 ÷ 91	92
7.	–	–	–	–	–	–	91 ÷ 93	74 ÷ 90	92 ÷ 95	93 ÷ 95
8.	–	–	–	–	–	–	94 ÷ 95	91 ÷ 95	–	–

Table 4. The test results of the null hypothesis on the frequency similarities in the qualification groups based on intervals and clusters

Parameter	Number of intervals or clusters							Sum
	1.	2.	3.	4.	5.	6.	7.	
O_{in}	13	39	15	14	10	1	3	95
O_{cl}	1	6	9	47	19	9	4	95
Sum	14	45	24	61	29	10	7	190
E	7	22.5	12	30.5	14.5	5	3.5	95
$2(O-E)^2/E$	10.27	24.20	1.50	17.85	2.79	6.40	0.14	63.17

Table 5. The test results of the null hypothesis on the similarity of the results distribution in the qualification groups based on intervals and clusters

Statistics	1.	2.	3.	4.	5.	6.	7.
M_{in}	3.33	4.47	5.73	6.95	8.13	9.66	10.92
SD_{in}	1.86	2.70	3.39	3.80	4.56	5.59	6.95
M_{cl}	2.52	3.09	3.76	4.76	6.83	8.18	10.61
SD_{cl}	1.50	1.64	2.05	2.90	3.91	4.42	6.65
F -test	1.529	2.718	2.734	1.722	1.358	1.600	1.093
ν_{in}	779	2339	899	839	599	59	179
ν_{cl}	59	359	539	2819	1139	539	239
$F(0.05; \nu_{in}; \nu_{cl})$	1.406	1.145	1.137	1.094	1.123	1.346	1.256
$p(F)$	0.021	0.000	0.000	0.000	0.000	0.004	0.260
t -test	3.287	9.440	12.173	17.786	6.188	2.388	0.472
ν	838	2698	1438	3658	1738	598	418
$t(0.05; \nu)$	1.963	1.961	1.962	1.961	1.961	1.964	1.966
$p(t)$	0.001	0.000	0.000	0.000	0.000	0.017	0.637

(intermediate level), First-Class Shooter (low intermediate level), Second-Class Shooter (low level) and Third-Class Shooter (the lowest level). That is why a modification of the clustering process proposed here for model 'i', starting from the middle object at a confidence level of 0.95, was taken as the basis for characterizing the entire group into corresponding qualification groups.

The division of the variation series into intervals was considered as an elemental method for developing subgroups. The width of the intervals ($h = 1.27$) was defined by using equation (6) for all the 95 shooters, with the extreme arithmetic means of $M_{max} = 11.41$ mm and $M_{min} = 2.52$ mm. The initial borders of the intervals are as follows: 3.79, 5.06, 6.33, 7.60, 8.87 and 10.14 mm (see Fig. 2). The number of shooters in each variation series interval is shown in model "j" (see Tab. 3).

The characteristics of the groups' fullness, its ability to be divided and the interval and cluster similarities (or differences) in the variation parameters and in overall tendency were used to compare the characteristics of the variation series and the cluster analysis methods. A comparison revealed an influence of the grouping method on the distribution of the shooters' results among the qualification groups. The calculated values by chi-square distribution (7) is higher ($\chi^2 = 63.17$) than its critical value ($\chi^2_{0.05; 6} = 12.59$). Thus, the division into clusters is statistically significantly different ($p = 0.05$) from the division into intervals, i.e. the null hypothesis on similarity was rejected (see Tab. 4).

The most informative indicator as a comparative characteristic of both of the methods mentioned above is the interval and cluster similarities of the variation parameters and of central tendency (see Tab. 5). The test results of the null hypotheses on the similarity of the results distributed into qualifying groups, based on the variation series intervals and on the clusters, indicate a similarity of dispersions ($p = 0.260$) and arithmetic means ($p = 0.637$) only in the seventh pair of intervals and clusters. In 12 out of 14 possible comparative analysis options, a statistically significant difference of scattering was detected ($p = 0.05$).

Therefore, the location of the interval borders differs from the location of the cluster borders. This is probably because of the difference in the grouping principles of both methods. The proposed variant of the clustering method is based on Student's parametric test, which takes into account the central tendency and the variation of the samples when the null statistical hypothesis is tested. The variation series method of grouping is based on the location of extreme objects (the amplitude is the least informative characteristic of variation). Thus, it is believed that such a proposed modification of the clustering method should be used in an assessment of an air-pistol shooter's aiming stability. The results of the variation series method can be used for defining the clusters number by the number of variation series intervals (see Fig. 3).

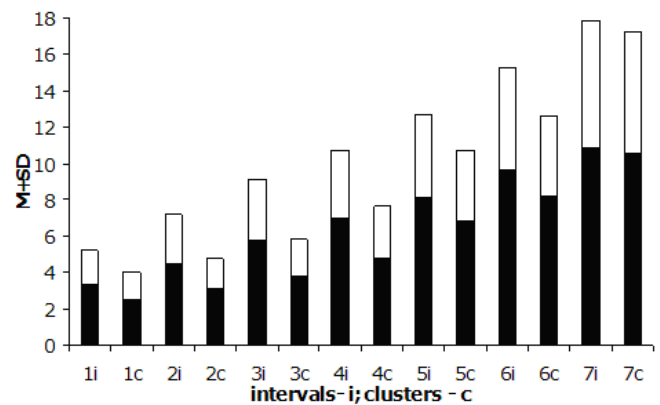


Figure 3. The quantitative parameters of the shooters' aiming stability developed with intervals (i) and clusters (c)

Conclusions

1. An average aiming point trajectory taken one second before taking a shot on the SCATT optoelectronic target should be accepted as an assessment parameter of aiming stability, as it is one of the basic parameters of technical preparedness and does not depend on the ballistic characteristics of a pistol and pellets. This test has shown high reliability in the assessment of sports technique ($\eta = 0.944$). If a shooter is well-qualified, the value of this parameter is small, and vice versa (the highest level – 2.5 mm; the lowest level – 11.4 mm). Nonetheless, statistically significant differences between the locations of the aiming trajectory centres ($p = 0.107$) in a competition series provided us an opportunity to take the parameters of the scattering of these points as a quantitative characteristic of the individual manner of aiming stability.

2. The outlined clustering method could be useful and suitable for defining the limits between shooters' qualification groups (as a parameter of aiming stability). A confidence level (where the null hypothesis could be rejected, based on the samples of two shooters' results from the same general population) can be used as a quantitative criterion to define the borders between the clusters of aiming stability. Clustering the group results of about 95 shooters has to be performed at a significance level of 0.05 in order to create an optimal number of qualifying groups.

3. The clustering process should start with a comparative analysis of the central objects in the matrix, i.e. shooters ranked in the middle of the series. If the clustering process starts with the first or last shooter, it will change the position of the limits between clusters due to the influence of extreme effects. The limits formed by variation series intervals differ significantly from the cluster limits because of the difference in the principles of grouping in these two methods. The proposed variant of the clustering method is based on the Student's parametric test, which takes into account the central

tendency and variation of the samples when the null statistical hypothesis is tested.

4. Variation series and cluster methods have a high level of separating power of the grouping processes ($p < 0.0001$). The test results of the null hypothesis on the frequency similarity of the qualifying groups, based on the clusters and variation series intervals, show a total dissimilarity of the corresponding pairs of intervals and clusters ($p = 0.05$).

5. The proposed modification of the clustering method should be used in an assessment of an air-pistol shooter's aiming stability. The results of the variation series method can be used for defining the cluster numbers based on the number of variation series intervals.

6. Parameters of aiming stability in air-pistol shooting were developed using the proposed modification of the clustering method. This allows for the identification of weak points in the structure and organization of shooters' training and allows for adjustment of the training process.

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