Acta of Bioengineering and Biomechanics
Vol. 11, No. 4, 2009

Original Paper

Specificity of shooting training with the optoelectronic target

IHOR ZANEVSKYY[1,*], YULIYA KOROSTYLOVA[2], VOLODYMYR MYKHAYLOV[2]

[1] Pułaski Technical University, Department of Physical and Health Education, Radom, Poland.
[2] Lviv State University of Physical Culture, Department of Kinesiology, Lviv, Ukraine.

Our aim was to estimate quantitatively the specificity of training with the SCATT optoelectronic training simulator in comparison with a real shot with pellets, exemplified by the air-pistol shooting. The research was conducted using the methods of optoelectronic registration of movements, the Shapiro–Wilk method, one-way ANOVA, statistical tests based on Student's *t*-test and Snedecor's *F*-distribution, and office computer technologies. The method of point coordinate digitization on trace graphs and the trajectory of SCATT interface is developed. The differences in the position of virtual holes at three types of training shots arise in a vertical coordinate ($p < 0.02$) but no significant differences in a horizontal coordinate ($p > 0.3$) are found. SCATT simulator menu option of shot result forecast in a given shot moment seems to be incorrect, because it does not take into account fundamental changes in weapon movement during triggering.

Key words: *air-pistol, SCATT system shooting, training*

1. Introduction

Athletes and coaches have to find new efficient methods for sports quality improvement due to sports shooting competition at a high level. First of all, this concerns the technique of shooting. The control of postural and weapon stability is a distinctive feature in this sport [5]. That is why optoelectronic training simulators such as Noptel [9], RIKA [8], and SCATT [7] are quite popular nowadays. Optoelectronic training systems are widely used in different shooting sports events for checking and improving weapon stability, aiming accuracy, correctness of a cock lowering [1], [2], [4] or releasing bowstring in the sport of archery [3]. Besides, the systems fix an aiming time, shot intervals and other parameters. Polish and Ukrainian shooters make use of SCATT systems because they are considered to be available and suitable for training. Optoelectronic simulator training specificity in comparison with real shooting is not ascertained yet. Besides, SCATT system virtual holes and real cartridge (or pellet) holes are to be digitally compared.

According to SCATT operation manual the absence of weapon's recoil and shot sound are those two factors that cause training peculiarities in comparison with real shot with cartridge. However, SCATT developers are of the opinion that training without cartridges is also useful. After 2–3 months of training with optoelectronic systems, 3–5 training lessons with cartridges are enough for athletes to adapt to recoil. Based on long experience gained by athletes and coaches of Russia and Soviet Union shooting teams, SCATT developers recommended high-level shooters to train with SCATT in the following manner: 70–80% of their time in the preparatory training period and 30–50% during the competition period. Those shooters that do not find it convenient to train with SCATT should use the system only to find mistakes and to develop new postures [7].

The experts' opinion is that unspecific SCATT training has a positive effect on beginners because

* Corresponding author: Ihor Zanevskyy, Department of Physical and Health Education, Pułaski Technical University, ul. Malczewskiego 22, Radom 26-600, Poland. E-mail:izanevsky@onet.eu
Received: August 8th, 2009
Accepted for publication: January 21st, 2010

recoil and sound of real shooting are believed to slow education by the factor of two or three. From this point of view the later the beginner gets cartridges, the better it is. Nevertheless, high-level results could not be achieved only by using SCATT training system without cartridges due to the considerable influence of close grouping of shots on them.

The aim of the research was to evaluate the specificity of training with SCATT optoelectronic system in comparison with real pellet shot in air-pistol example.

The problems that should be solved are as follows:

1. The coordinate systems of aiming points and SCATT virtual holes are to be elaborated. 2. The method of coordinate point digitizing on trajectory graph ("Trace") and coordinate graph ("Distance") of SCATT interface is to be developed. 3. Coordinate mean value and dispersion of virtual holes location in different types of training shots (pellet shot, compressed air shot, and dry firing) are to be compared.

2. Material and methods

In accordance with the official air-pistol rules [6] highly-qualified sportswoman took 90 shots: 30 pellet shots, 30 compressed air shots, and 30 dry firings. Air-pistol Steyr LP-10 and Finale Match pellets 4.49 mm were used in the experiment. In experimental shooting, in order to level the anticipated reaction to pistol holding character directly before triggering, the shooter did not know whether the pistol had been loaded with pellets or with compressed air (cocking lever «F»), or dry firings (cocking lever «T»). The air-pistol was loaded by an assistant who hid cocking lever by special shield (figure 1). Besides the sequence of shots with the pellets, shot imitation with compressed air or dry firings was defined at random.

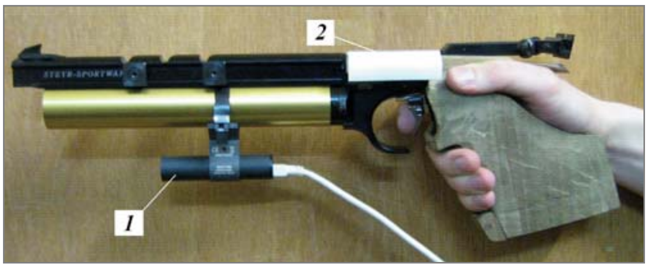

Fig. 1. The air-pistol during an experimental shot:
1 – SCATT system sensor; 2 – a special shield to hide cocking lever

Orthogonal coordinate system of SCATT target image with sighting trajectory and hole (the point S) begins (the point O) in upper left angle of Paint workspace (figure 2). Horizontal axis (ξ) has positive direction to the right, and vertical (η) downwards. The scale of SCATT target image was defined by 7–7 circle diameter: $\mu = l/\lambda = 0.0891$, where l = 59.5 mm is the target circle diameter 7–7 [6]; λ = 672 is the corresponding dimension on computer screen in pixels. Calculations were made in MS Excel.

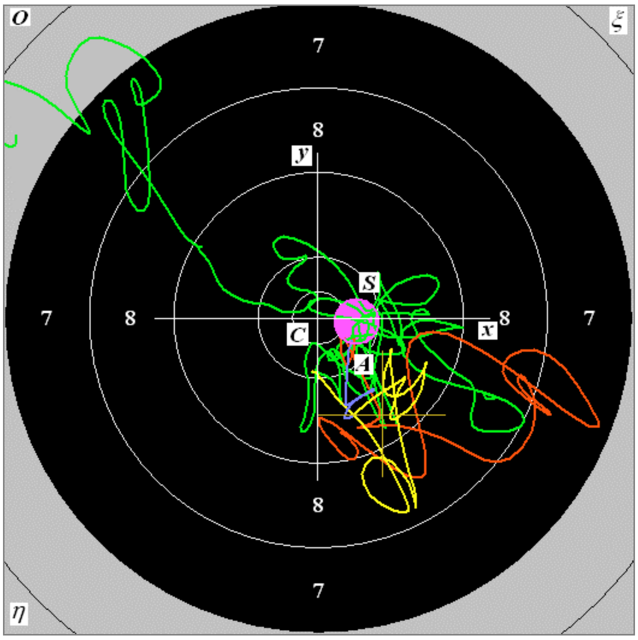

Fig. 2. SCATT virtual target: A – aiming point in triggering moment; S – centre of virtual hole

Coordinates of the hole centre on the target were defined by the equations:

$$x_S = \mu(\xi_S - \xi_C)\,;\; y_S = \mu(\eta_C - \eta_S)\,.$$

The point C is the centre of the target.

Thus the method of digitizing point coordinates on trajectory graph ("Trace") and of moving-away-from-axes graph ("Distance") of SCATT interface based on office computer technologies (MS Excel, Paint) was found. This method is simple, accurate (the digitized limit of error is close to 0.01 mm) and suitable for numerical estimation of unspecific optoelectronic training in air-pistol shooting. System developers mention that SCATT computer program uses the algorithm to calculate correction of weapon lateral movement when a pellet leaves a muzzle. Aerodynamic coefficient measures this correction. Besides, when a pellet leaves a muzzle it continues diametrical movement in the same direction as a muzzle in shot moment. It is mentioned that SCATT shows a hole aside a trajectory if a shooter has bad stability. Because SCATT system documentation does not describe the coordinate system location of aiming points and virtual holes but several coordinate systems are used, we have to examine this problem in detail. For example, aiming point and virtual hole (see figure 2) have the following target coordinates: x_A = 3.16 mm, y_A = –2.06 mm, x_S = 3.48 mm, and y_S = –0.24 mm in shot moment. It is recommended that the users of this system choose experimentally the optimum coefficient of pellet lateral movement that corresponds to 'shot distance and pellet velocity' [7].

Another coordinate system is used for the graph 'Aiming point coordinates relative to target centre depending on time' (figure 3). The positive directions of a horizontal moving (the displacement along the *X*-axis) from the left to the right and vertical (the displacement along the *Y*-axis) downright are taken there.

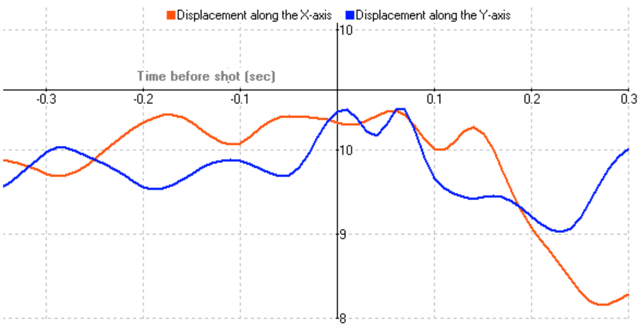

Fig. 3. The graph of aiming point coordinates (the point *A* in figure 2) relative to target centre depending on time (8, 9, and 10 are the numbers of target circle): *X* is horizontal coordinate, which has upwards positive direction; *Y* is vertical coordinate, which has downwards positive direction

Table 1. Aiming point coordinates (the point *A* in figure 2) relative to the target centre depending on time before and after a shot

t (sec)	*X* (mm)*	*Y* (mm)*
–1.00	–0.71	4.98
–0.90	6.37	13.40
–0.80	4.10	14.67
–0.70	9.23	17.89
–0.60	6.75	3.52
–0.50	6.46	7.19
–0.40	9.63	6.83
–0.30	7.98	5.96
–0.20	3.08	9.23
–0.10	5.07	6.78
0.00**	**3.14**	**2.06**
0.10	5.61	8.40
0.20	13.12	12.02
0.30	19.42	5.61

* *X* is horizontal coordinate (positive direction is to the right); *Y* is vertical coordinate (positive direction is to the down).
** Triggering moment.

Aiming point coordinates are taken from SCATT file using "samples.vbs" program (Copyright © 2002 ZAO Scatt). They are represented in text format and have opposite coordinate axes positive direction to graph of horizontal moving (figure 3) from the left to the right and to graph of vertical moving from upwards to downwards (table 1).

Shot final characteristics in MS Excel file was constructed from scatt file using "scattexp.vbs" program (Copyright © 2001 ZAO Scatt). In this MS Excel file, the virtual hole coordinates have common positive directions of axes (*X* grows to the right and *Y* grows upwards) with the correction of muzzle lateral velocity. This correction is fixed by the coefficient of pellet lateral movement (table 2). The research was conducted using the methods of optoelectronic registration of movements, the Shapiro–Wilk method, one-way ANOVA, statistical tests based on Student's *t*-test and Snedecor's *F*-distribution, and office computer technologies (MS Excel and MS Paint).

Table 2. Final characteristics of the shot imitation

Parameters	Values
Shot number	107
The moment of shot	November 04, 2008; 19:27
Shot result	10.5
Aiming time	0:00:06.5
Hole coordinate *X* (mm)*	3.48
Hole coordinate *Y* (mm)*	–0.24
Average aiming point *X* (mm)	5.99
Average aiming point *Y* (mm)	–9.06
Steadiness in 10.0 (%)	18
Steadiness in 10a0 (%)	84
Trace length (mm)	88.3
Distance between hole and AAP**	9.2

* Pellet lateral movement coefficient equals 15.
** Average aiming point (mm).

3. Results

A comparative analysis of the coordinates of holes calculated from a Paint SCATT virtual target (see figure 2) made it possible to determine the positive directions of data file coordinates and coordinate graphs (see figure 3). An opposite positive direction of horizontal coordinate of Aiming Point graph (from top to bottom) that regards the corresponding numeric coordinate in a text file (see tables 1, 2) and the scene of SCATT virtual target on computer screen has been found. An opposite positive direction of vertical coordinate in a text file (from top to bottom) is registered.

Experimental shot results are shown in table 3. The sequence of shots was defined at random: 1, 3, 10, 13, 22, 26, 29, 31, 33, 37, 44, 49, 51, 54, 56, 58,

Table 3. Coordinates of virtual holes for three types of shooting and the distances from the holes to the target centre (mm)

Pellet shot *			Compressed air shot			Dry firing		
x_S	y_S	r_S	x_S	y_S	r_S	x_S	y_S	r_S
0.24	3.48	3.49	10.22	0.98	10.27	5.91	–8.52	10.37
19.26	15.20	24.54	–0.03	–0.09	0.09	1.34	–0.63	1.48
15.92	–1.70	16.01	15.60	–4.17	16.15	11.82	–4.40	12.61
6.30	5.58	8.42	5.14	–11.34	12.45	10.74	8.73	13.84
6.34	–0.94	6.41	12.56	2.13	12.74	10.72	2.59	11.03
14.53	–5.88	15.67	6.90	–6.94	9.79	6.97	11.54	13.48
–0.86	–2.14	2.31	5.79	–1.87	6.08	1.76	–6.61	6.84
11.25	3.79	11.87	8.89	–0.98	8.95	11.86	4.41	12.66
–4.41	2.89	5.27	7.68	0.55	7.70	5.84	3.71	6.92
3.76	1.37	4.00	3.32	4.13	5.30	7.78	–1.07	7.86
5.62	3.67	6.71	3.67	4.07	5.48	8.82	–0.95	8.87
6.54	–1.28	6.66	2.97	12.12	12.48	8.64	6.38	10.75
11.74	17.75	21.28	3.71	–0.43	3.74	3.03	–7.36	7.96
–3.85	1.20	4.03	1.46	–7.83	7.97	–2.65	1.25	2.93
–2.46	–0.23	2.47	2.94	1.98	3.55	4.37	5.76	7.23
3.62	1.66	3.98	–0.38	1.15	1.21	6.41	3.04	7.09
10.27	–7.14	12.51	9.97	8.12	12.86	3.20	–5.37	6.25
–2.22	11.49	11.70	2.67	–8.14	8.57	2.00	–4.64	5.06
1.55	3.40	3.74	7.87	–5.30	9.49	11.93	3.12	12.34
13.94	5.68	15.05	1.32	–5.84	5.99	8.64	–1.06	8.70
11.66	–0.44	11.67	7.33	–10.99	13.21	10.84	–1.19	10.90
15.73	8.51	17.89	–0.65	–0.99	1.18	4.49	–0.90	4.58
15.59	–7.66	17.37	4.10	0.37	4.12	13.28	0.62	13.29
8.24	–5.04	9.66	5.55	–3.18	6.40	4.98	–5.00	7.06
–0.67	2.63	2.72	–3.99	–8.07	9.00	9.97	–5.51	11.39
11.93	–3.18	12.35	4.78	–9.06	10.24	2.17	–4.94	5.40
10.44	12.27	16.12	7.12	–23.16	24.23	1.88	–2.30	2.97
0.73	–9.15	9.18	–1.91	–9.38	9.57	–3.05	–9.77	10.23
9.38	–8.62	12.73	3.45	–15.70	16.08	–0.35	0.36	0.50
1.66	–6.95	7.15	6.38	–8.97	11.01	13.62	–1.03	13.66

* The virtual hole coordinates on SCATT target but not the real shot hole coordinates are shown here.

60, 61, 65, 66, 68, 71, 73, 74, 79, 81, 82, 87, 88, 90 are pellet shots; 2, 4, 9, 11, 12, 15, 16, 17, 18, 20, 23, 32, 34, 36, 39, 41, 42, 45, 46, 52, 53, 55, 63, 69, 76, 80, 83, 85, 86, 89 are compressed air shots, and 5, 6, 7, 8, 14, 19, 21, 24, 25, 27, 28, 30, 35, 38, 40, 43, 47, 48, 50, 57, 59, 62, 64, 67, 70, 72, 75, 77, 78, 84 are dry firings.

The coordinates of virtual holes were recalculated to eliminate systematic aiming error. The origin of SCATT target coordinate system was transferred to the centre of mass of all 90 holes. The coordinates of virtual holes in new coordinate system shown in Appendix were calculated as follows:

$$x_{Sc} = x_S - \bar{x}_S\,;\; y_{Sc} = y_S - \bar{y}_S\,;\; r_{Sc} = \sqrt{x_{Sc}^2 + y_{Sc}^2}\,,$$

where

$$\bar{x}_S = \frac{\sum_{i=1}^{90} x_S}{90} = 5.92 \text{ mm},\quad \bar{y}_S = \frac{\sum_{i=1}^{90} y_S}{90} = -0.96 \text{ mm}$$

are the arithmetic means of virtual holes coordinates on SCATT target.

Table 4. Processing of statistic results representing coordinates of virtual holes and the distances from virtual holes to the SCATT target centre: *M* is arithmetic mean; *m* is standard deviation of arithmetic mean; *SW–W* is Shapiro–Wilk criteria; *p* is the level of confidence

Shot	Parameter	*M* (mm)	*m* (mm)	*SW–W*	*p*
Pellet	x_{Sc}	0.80	1.23	0.960	0.303
	y_{Sc}	2.30	1.26	0.957	0.257
	r_{Sc}	8.61	0.86	0.946	0.137
Compressed air	x_{Sc}	–1.11	0.78	0.989	0.983
	y_{Sc}	–2.60	1.31	0.974	0.664
	r_{Sc}	7.48	0.82	0.957	0.261
Dry firing	x_{Sc}	0.31	0.85	0.963	0.370
	y_{Sc}	0.30	0.93	0.978	0.771
	r_{Sc}	6.28	0.49	0.956	0.237

The Shapiro–Wilk test was used to prove normal distribution in three experimental samples of a general totality. That is why parametric mathematical statistics method can be used. Zero statistical hypothesis is possible when distribution is normal. The Shapiro–Wilk criteria (*SW–W*) measured range from 0.946 to 0.989 at the *p*-level of confidence from 0.137 to 0.983

(table 4). Therefore, zero statistical hypothesis about normal distribution law was accepted in all nine samples.

One-way ANOVA for coordinates and the distances from virtual holes to the SCATT target centre was used to evaluate the influence of the training method on a result. Shot performing method was specified by a dispersion analysis factor. Three zero statistical hypotheses about the equality of arithmetic means' coordinates and virtual holes' distances to the SCATT target centre were accepted.

Table 5. Results of one-way ANOVA depending on virtual holes' location using different SCATT training methods ($n = 30$; $\nu = 2$)

Parameters	F*	p	Q, %
x_{Sc} as horizontal	1.041	0.357	2.3
y_{Sc} as vertical	4.362	**0.016**	9.1
r_{Sc} as distance	2.457	0.091	5.3

* $F_{p=0.05; n=30; \nu=2} = 3.101$ is Snedecor criteria critical value; Q is the contribution of training method factor to the general variation of results.

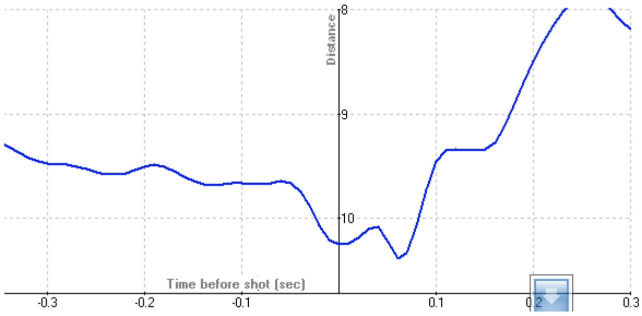

Fig. 4. The graph of aiming point distance (the point A in figure 2) from target centre depending on time (the point C in picture 2): 8, 9, and 10 are the numbers of target circle; circle diameter 10–10 is 11.5 mm; 9–9 is 27.5 mm, and 8–8 is 43.5 mm (*Official Statutes Rules and Regulations* [6])

Statistically significant difference in the vertical coordinates of virtual holes ($p = 0.016$) was defined using one-way ANOVA (table 5). Training method factor contribution to the general variation value of this coordinate is 9.1%. Training method factor contribution to the variation of horizontal coordinate and the distances from virtual holes to the centre of the SCATT target is comparatively insignificant (2.3% and 5.3% at the level of confidence of 0.356 and 0.092, respectively). Thus, the differences in the positions of virtual holes at three types of training shots are shown in a vertical coordinate but no significant difference in a horizontal coordinate is noticed.

Statistically insignificant difference in the distances from virtual holes to the SCATT target centre is set ($p > 0.05$). Shooting sport result is estimated only by the distance between the hole and the target centre. Angular coordinate (hole "clock") is insignificant and not taken into consideration [6]. Two coordinates are necessary to define a hole location. In a polar coordinate system, they are a distance from a pole (a coordinate origin) and the axis of radius-vector location. In a rectangular coordinate system, they are two hole centre projections on the coordinate axes (figure 5). Several different holes could be at equal distances from the target centre ($r_1 = r_2 = r_3 = r_4$) but could have different coordinates ($x_1 \neq x_2 \neq x_3 \neq x_4$, and $y_1 \neq y_2 \neq y_3 \neq y_4$). That is why the hypothesis on point coordinates is more informative than that on points' distance from coordinate origin.

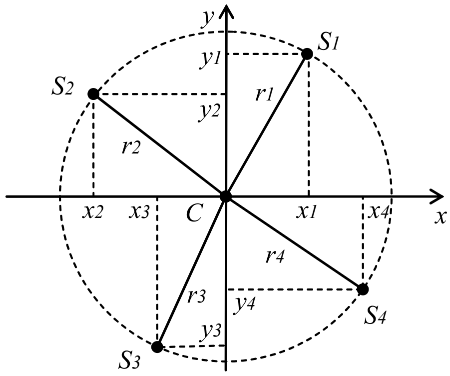

Fig. 5. Target diagram for several different holes whose distances from the target centre are equal

Let us discuss the differences in pairwise comparison of arithmetic means and variances of horizontal and vertical coordinates of virtual holes in different training methods. One-way ANOVA method showed a significant difference between arithmetic means in the vertical coordinates of holes ($p < 0.02$) common for all three training methods. Firstly, it is necessary to determine which pairs of training methods are more similar or unsimilar if arithmetic mean in the vertical coordinate is taken into consideration. Secondly, it is necessary to determine the same regarding dispersion in the vertical and horizontal directions. In the sport shooting, concentration of holes is a very important parameter that depends on the shooter's skill [2].

Student's t-test is used to compare arithmetic means, and Snedecor's F-distribution allows us to compare variances. Zero statistical hypothesis was rejected ($p < 0.01$) for vertical coordinate in pellet shots (2.30 ± 1.26 mm) and compressed air shots (–2.60 ± 1.31 mm). Statistically significant differences in other five arithmetic mean pairs were not found (table 6).

Table 6. Level of confidence on which zero hypothesis about equal arithmetic mean parameters of virtual holes location can be rejected according to Student's *t*-test

Kind of shots	Pellet shot	Dry firing	Compressed air
Pellet shot	$x_{Sc} \setminus y_{Sc}$*	0.208	**0.009**
Dry firing	0.742	$x_{Sc} \setminus y_{Sc}$	0.077
Compressed air	0.195	0.225	$x_{Sc} \setminus y_{Sc}$

* These are the values of confidence level for the vertical coordinate in the cells based up and right from diagonal cells, as well as for the horizontal coordinate – left and down.

Taking into account the recoil of weapon, it is reasonable to suppose that the position of virtual holes at a dry firing must significantly differ from the position of holes at a shot with a pellet and compressed air. But we really noticed significant differences between pellet shots and compressed air shots and no significant differences between them and a dry firing shots.

Zero statistical hypothesis about dispersion of virtual hole positions was rejected ($p < 0.01$) for horizontal coordinates in pellet shots (the corresponding variance is 45.2 mm^2) compared with compressed air shots (18.3 mm^2) and dry firing shots (21.7 mm^2, $p < 0.03$). Statistically significant difference ($p < 0.04$) in the vertical dispersion of compressed air shots (51.6 mm^2) in comparison with dry firing (26.2 mm^2) is also noticed (table 7). Thus, like in the mean coordinates, there is no definite difference in virtual hole dispersions between pellet and compressed air shots compared with dry firing.

Table 7. Level of confidence on which zero hypothesis about equal dispersion of virtual holes location can be rejected according to Snedecor *F*-test

Kind of shots	Pellet shot	Dry firing	Compressed air
Pellet shot	$x_{Sc} \setminus y_{Sc}$*	0.057	0.414
Dry firing	0.027	$x_{Sc} \setminus y_{Sc}$	**0.036**
Compressed air	**0.009**	0.326	$x_{Sc} \setminus y_{Sc}$

* These are the values of confidence level for the vertical coordinate in the cells based up and right from diagonal cells, as well as for the horizontal coordinate – left and down.

Insignificant differences ($p > 0.3$) in the centres of virtual holes to target centre between pellet (8.61 ± 0.86 mm) and compressed air firing (7.48 ± 0.82 mm) and between compressed air and dry firing (6.28 ± 0.49 mm, $p > 0.2$) were fixed (table 8). The dispersions of these distances were much more significant. Statistically significant difference between the variance in dry firing (7.3 mm^2) with pellet shots (22.2 mm^2) and compressed air (20.3 mm^2) was found ($p < 0.01$).

Table 8. Level of confidence on which zero hypothesis about equal arithmetic mean parameters and equal dispersion of virtual holes location can be rejected according to Student's *t*- and Snedecor's *F*-tests

$t \setminus F$*	Pellet shot	Dry firing	Compressed air
Pellet shot	r_{Sc}	**0.002**	0.406
Dry firing	**0.023**	r_{Sc}	**0.004**
Compressed air	0.347	0.216	r_{Sc}

* These are the values of confidence level for Snedecor's *F*-test in the cells based up and right from diagonal cells, as well as for Student's *t*-test – left and down.

4. Discussion

The method of the digitization of coordinate points on trace graphs ("Trace") and of moving-away from axes graph ("Distance") based on such programs as MS Paint and Excel is simple and acceptable for quantitative estimation of optoelectronic way of training specificity in air-pistol shooting.

It is interesting to notice that the differences between pellet and compressed air shots compared with dry firing are significant in three pairs, but several different holes could be at equal distances from the target centre but could have different coordinates. That is why the hypothesis about the point coordinates is more informative than the hypothesis about the points' distance from coordinate origin. There are no significant differences between pellet and compressed air shots.

The option of shot moment change is provided for SCATT computer program. It is noted that this allows us to predict the result if a shot is taken earlier or later than actual triggering moment. However, we are doubtful about this opinion. Let us consider the aiming point trajectory (see figure 2). Triggering moment is represented by a principled change of trajectory characteristics. Static equilibrium balance of hand muscle antagonists, which provides weapons stability during the aiming, is disturbed during triggering. In addition, before triggering a muscle activation occurs because of shot anticipation reaction.

The changes of hole coordinate because of sooner or later triggering are forecasted based on the aiming point coordinates at zero shot moment. When the aiming point coordinates change formally in the triggering moment, any fundamental changes in weapon movement are not taken into account. Therefore, the forecast of a result change that is based on shot moment change seems to us incorrect.

5. Concluding remarks

The opposite positive direction of horizontal coordinate of Aiming Point graph (from top to bottom) with regard to corresponding numeric coordinate in a text file and to the scene of SCATT virtual target on computer screen is set. In addition, opposite positive direction of vertical coordinate in a text file (from top to bottom) is registered.

The differences in the positions of virtual holes at three types of training shots arise in a vertical coordinate ($p < 0.02$) but there is no significant difference in a horizontal coordinate ($p > 0.3$). Taking into account the recoil of the weapon, it seems reasonable to suppose that the position of virtual holes at a dry firing must significantly differ from the position of holes at a shot with a pellet and compressed air. But we really noticed the significant differences between shot with a pellet and compressed air ($p < 0.01$) and no significant in differences between them with a dry firing. As in the case of mean coordinates, there is no definite difference in virtual hole dispersions between pellet and compressed air shots compared with dry firing.

The forecast of the results based on SCATT system for the change of a given shot moment seems to us incorrect, because it does not take into account fundamental changes in weapons movement due to triggering.

Acknowledgements

1. The idea of the research appeared during our scientific cooperation with Dr. Hans J. Gros (1954–2006) at the Institute of Sports Science, Stuttgart University (Collaborative Linkage Grant LST.CLG.977859 funded by NATO Science Programme).

2. The authors thank Anonymous Referee for fruitful remarks.

References

[1] Ball K.A., Best R.J., Wright T.V., *Body sway, aim point fluctuation and performance in rifle shooters: inter- and intra-individual analysis*, Journal of Sports Sciences, 2003, 14, 559–566.

[2] Ball K.A., Best R.J., Wright T.V., *Inter- and intra-individual analysis in elite sport: pistol shooting*, Journal of Applied Biomechanics, 2003, 19, 28–38.

[3] Edelmann-Nusser J., Heller M., Hofmann M., Ganter N., *On-target trajectories and the final pull in archery*, European Journal of Sport Science, 2006, 6, 213–222.

[4] Mononen K., Viitasalo J.T., Era P., Konttinen N., *Optoelectronic measures in the analysis of running target shooting*, Scandinavian Journal of Medicine and Science of Sports, 2003, 13, 200–207.

[5] Nowak S., *Controlling of upright position and its development in the process of physical education*, Politechnika Radomska, Radom, Poland, 2005.

[6] *Official Statutes Rules and Regulations*, International Shooting Sport Federation, München, Germany, 2009.

[7] *Professional training systems SCATT, ZAO NPP SCATT*, Moscow, Russia, 2006 (http://www.scatt.com).

[8] *RIKA Home Trainer*, RIKA Sport GmbH, Micheldorf, Austria, 2008 (http://www.rika1.com).

[9] *Technical shooting analysis*, Noptel Oy, Oulu, Finland, 2007 (http://www.noptel.fi/eng/sport/).

Appendix

Virtual hole coordinates and their distances
from the origin of coordinate system which is located
in the centre of mass of virtual holes

Pellets			Dry firing			Compressed air		
x_{Sc}	y_{Sc}	r_{Sc}	x_{Sc}	y_{Sc}	r_{Sc}	x_{Sc}	y_{Sc}	r_{Sc}
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
–5.68	4.44	7.21	4.30	1.94	4.71	–0.01	–7.56	7.56
13.34	16.16	20.95	–5.95	0.87	6.02	–4.58	0.33	4.60
10.00	–0.74	10.02	9.68	–3.21	10.19	5.90	–3.44	6.83
0.38	6.54	6.55	–0.78	–10.38	10.41	4.82	9.69	10.82
0.42	0.02	0.42	6.64	3.09	7.32	4.80	3.55	5.97
8.61	–4.92	9.91	0.98	–5.98	6.06	1.05	12.50	12.54
–6.78	–1.18	6.89	–0.13	–0.91	0.92	–4.16	–5.65	7.02
5.33	4.75	7.14	2.97	–0.02	2.97	5.94	5.37	8.00

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
–10.33	3.85	11.03	1.76	1.51	2.32	–0.08	4.67	4.67
–2.16	2.33	3.18	–2.60	5.09	5.72	1.86	–0.11	1.86
–0.30	4.63	4.64	–2.25	5.03	5.51	2.90	0.01	2.90
0.62	–0.32	0.69	–2.95	13.08	13.41	2.72	7.34	7.83
5.82	18.71	19.59	–2.21	0.53	2.28	–2.89	–6.40	7.02
–9.77	2.16	10.01	–4.46	–6.87	8.19	–8.57	2.21	8.85
–8.38	0.73	8.42	–2.98	2.94	4.19	–1.55	6.72	6.90
–2.30	2.62	3.49	–6.30	2.11	6.65	0.49	4.00	4.03
4.35	–6.18	7.56	4.05	9.08	9.94	–2.72	–4.41	5.18
–8.14	12.45	14.88	–3.25	–7.18	7.88	–3.92	–3.68	5.38
–4.37	4.36	6.18	1.95	–4.34	4.76	6.01	4.08	7.26
8.02	6.64	10.41	–4.60	–4.88	6.71	2.72	–0.10	2.72
5.74	0.52	5.76	1.41	–10.03	10.13	4.92	–0.23	4.92
9.81	9.47	13.63	–6.57	–0.03	6.57	–1.43	0.06	1.44
9.67	–6.70	11.76	–1.82	1.33	2.26	7.36	1.58	7.52
2.32	–4.08	4.69	–0.37	–2.22	2.25	–0.94	–4.04	4.15
–6.59	3.59	7.51	–9.91	–7.11	12.20	4.05	–4.55	6.09
6.01	–2.22	6.40	–1.14	–8.10	8.18	–3.75	–3.98	5.47
4.52	13.23	13.98	1.20	–22.20	22.23	–4.04	–1.34	4.26
–5.19	–8.19	9.70	–7.83	–8.42	11.50	–8.97	–8.81	12.58
3.46	–7.66	8.40	–2.47	–14.74	14.95	–6.27	1.32	6.41
–4.26	–5.99	7.35	0.46	–8.01	8.02	7.70	–0.07	7.70