Original Article

Connection between performance and body sway/morphology in juvenile Olympic shooters

DANIEL MON[1], MARIA S. ZAKYNTHINAKI[2], SANTIAGO CALERO[3]

[1]*Faculty of Teacher Training and Education. Autonomous University of Madrid, Spain*
[2]*University of Applied Sciences (TEI), Crete, Greece*
[3]*University of Armed Forces ESPE, Quito, Ecuador*

ABSTRACT

The objective of the study was to examine, via use of a simple specific test, the correlation between body sway and performance in Juvenile Olympic shooters, to compare the differences in body morphology between different shooting modalities and to know if the anthropometric profile of a shooter influences performance. 38 national level juvenile shooters (24 pistol and 14 rifle) who competed at a pistol and air rifle Young Promises Spanish Championship participated in the study. Body sway (measured in terms of movements of the Centre of Pressure (COP): maximum displacements, maximum and minimum average velocities, rotation angles and total areas) and anthropometric data (age, height and weight) were recorded under competition conditions during shooting simulations. Performance was measured in terms of average points per shot. The variables of stress and experience before competition were also considered. The study was observational and descriptive following a cross-sectional design. The results showed that, in the juvenile category, rifle shooters perform better than pistol shooters, but pistol shooters have less body sway. Performance was found to be statistically related to COP displacements, only in pistol shooters. Body weight was found to be related to body sway but not with performance. Body height was found to be related neither with body sway, nor with performance No anthropometric differences have been found to exist between the different modalities (pistol and rifle). **Keywords:** Pistol, Rifle, Balance, Weight, Height, Competition.

Cite this article as:
Mon, D., Zakynthinaki, M.S., & Calero, S. (2019). Connection between performance and body sway/morphology in juvenile Olympic shooters. *Journal of Human Sport and Exercise*, *14*(1), 75-85. doi:https://doi.org/10.14198/jhse.2019.141.06

Corresponding author. *Faculty of Teacher Training and Education. Autonomous University of Madrid, Spain.*
E-mail: daniel.mon@uam.es
Submitted for publication April 2018
Accepted for publication July 2018
Published *in press* July 2018
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202

doi:10.14198/jhse.2019.141.06

INTRODUCTION

Olympic shooting is a precision and accuracy sport. The margins of error are so small that any angular deviation greater than 0.016° can ruin the final score (Zatsiorsky andAktov, 1990). As scores very close to the maximum (total of 600 points for men and 400 for women) are usually achieved by high level shooters at competition, decimal points are used (RFEDETO, 2014) this way increasing the need for maximum precision control.

According to the scientific literature of Olympic shooting the factors that can affect performance are numerous. As it is widely confirmed by the coaches' experience, body sway seems to play an important role. The relation of body sway and performance, however, still remains a matter of scientific discussion. In addition, in some sports performance is related to a certain biotype. The influence, however, of body morphology on performance in Olympic shooting also remains unknown.

For high level shooters the relation between body sway and performance has been confirmed (Era et al., 1996; Mononen et al., 2003). It is also clear that the displacements of the centre of pressure (COP) are directly related to the movements of the gun (Ball et al., 2003a, 2003b; Mononen et al., 2007; Pellegrini andSchena, 2005). Some studies report a direct significant relation between body sway and performance in air pistol and running target (Gulbinskienė andSkarbalius, 2009; Viitasalo et al., 1999). Other authors found such direct influence only in elite level shooters (Mason et al., 1990), and others only in novice shooters (Era et al., 1996; Mononen et al., 2007). The authors in (Ball et al., 2003b) reported the relation between body sway and performance to be hardly significant. It is worth noticing here, however, that not all body sway tests seem to give similar results: according to Gulbinskienė and Skarbalius (2009) the more specific the test used (involving movements similar to the technical movements of the modality under study) the more information it can reveal regarding the role of body sway.

In general the body morphology of the athletes of different sports differs (Bayios et al., 2006). The study of Hegeman et al. (2007) have showed that body sway is affected by age as well as body height. It has been also reported that age, height and weight can affect the body sway of the athletes, and heavier athletes were found to have significantly less body sway (Hue et al., 2007). Other studies, however, found no direct relation between weight and movement of the COP in adolescents (King et al., 2011). Regarding body weight, Olympic shooters appear to be shorter and heavier than athletes of other sports (Belinchon, 2010). The same author reports that there are no specific biotypes that exist or influence performance in Olympic shooting.

It is worth noticing that the majority of the studies examine the way the above mentioned factors influence performance within a single modality (Mononen et al., 2007; Tang et al., 2008). The number of studies that compare such findings between different modalities still remains limited (Aalto, Pyykko, et al., 1990; Belinchon, 2010; Gulbinskienė andSkarbalius, 2009). It is also important to note that all existing studies are based on data recorded under laboratory or training conditions (Mononen et al., 2007; Mononen et al., 2003; Su et al., 2000). A number of studies were performed using Noptel optoelectronic (Hawkins, 2011; Mononen et al., 2007) or Scatt training systems (Ball et al., 2003a, 2003b), even though no consensus exists on the validity of such type of systems (Mononen et al., 2003; Zanevskyy et al., 2010). Very few studies exist that examine the factors that affect performance under real competition conditions (Simo Ihalainen et al., 2017).

The present study is based on a simple to carry out Olympic shooting specific test and focuses on the three following objectives: Examine the correlation between body sway and performance in Juvenile shooters, compare the differences in body morphology between different shooting modalities and know if the anthropometric profile of the shooter influences performance.

MATERIAL AND METHODS

Participants

The participants of the present study were 38 of the 41 juvenile shooters who competed at the pistol and air rifle Young Promises Spanish Championship that took place in Granada, Spain, (92,68% participation in the study of the total competition participants). 3 of the 41 shooters had been injured during the year before the competition. For this reason, these 3 previously injured participants were not included in the analysis.

The juvenile category is referred to the age of the shooters and included shooters between 17 and 18 years old at 31st of December of the competition year (RFEDETO, 2014). The participation to the study was voluntary and open to all competing shooters during the limited time of official training before competition. According to the regulations of the Spanish Federation of Olympic Shooting, eligibility to compete required a previously obtained (in other national competitions) minimum score of 450 points in boys and 260 points in girls in air pistol and 480 points in boys and 280 points in girls in air rifle. The maximum shooting score at the championship was 600 for boys and 400 for girls (RFEDETO, 2014).

Measures

Variables referring to the profile of the participants

For the purposes of the present study the following variables were analysed regarding the participants profile: weight, height, experience in months, training hours per week, time between testing time and competition, average points per shot (APS) – variable introduced in the present study in order to allow comparisons in performance between male and female shooters (it is worth reminding here that the maximum score at competition differs between the two sexes, please refer to the Participants subsection).

The participants' profile, as far as the above-mentioned variables are concerned, is presented in Table 1.

Table 1. Mean ± standard deviations of the variables referring to the participants' profile

	Pistol		Rifle	
	Male	Female	Male	Female
Weight (kg)	74,70±14,46	62,79±12,26	73,28±15,07	64,83±11,33
Height (m)	1,73±0,07	1,60±0,03	1,71±0,08	1,60±0,09
APS (points)	8,91±0,29	8,45±0,52	9,05±0,62	9,47±0,16
Experience (months)	50,00±25,50	33,58±23,27	46,75±20,92	52,00±24,79
Weekly training (hrs)	5,17±3,60	2,46±1,41	4,88±3,73	5,50±1,67
Time until competition (days)	1,42±0,79	0,92±0,79	1,00±0,76	0,83±0,98

Variables referring to the movement of the COP of the participants

In the literature of Olympic shooting a number of different variables are considered for the analysis of the movement of the COP. The majority of the studies make use of the COP velocity, both in average and maximum terms and in both the X and the Y axis, the total area of the displacement of the COP or the maximum displacements of the COP in the X and Y axes (Hawkins andSefton, 2011).

In the present study the movements of the COP of the participants during the tests was analysed by use of the following variables: maximum displacements of the COP in the X and Y axes, total area of the displacement of the COP, average both, minimum and maximum COP velocity on the force platform plane; minimum and maximum COP velocity in the X and Y axes, length of principal and secondary axis of the ellipse that best fits the COP data, angle of rotation of the COP ellipse in respect to the X and Y axis coordinate system.

The calculation of the displacements, velocities, areas and angles was done by use of the mathematical package Matlab R2009a. The average calculated values of the above-mentioned variables for all participants are presented in Table 2.

Table 2. Mean ± standard deviations of the variables referring to the movement of the COP of the participants

	Pistol			Rifle		
	Male	Female	Total	Male	Female	Total
Max. Displ. X	21,08±4,61	21,22±4,70	21,15±4,55	26,59±6,4	25,83±2,08	26,26±4,89
Max. Displ. Y	20,71±4,39	26,25±6,17	23,48±5,95	24,54±4,09	27,06±5,93	25,62±4,92
Principal axis	20,77±3,3	21,89±4,64	21,33±3,98	26,50±5,87	26,11±2,16	26,33±4,51
Secondary axis	21,35±4,27	26,75±6,19	24,05±5,89	25,56±4,33	27,83±5,91	26,54±4,99
Rotation angle	-1,33±8,14	1,21±6,13	-0,12±7,21	-3,40±8,11	2,39±5,18	-0,92±7,39
Total area	357,92±115,07	481,81±199,41	419,86±171,33	553,46±192,26	575,89±129,46	563,07±162,73
Aver. velocity X	0,10±0,03	0,12±0,04	0,11±0,03	0,12±0,03	0,13±0,02	0,12±0,03
Max. Velocity X	0,47±0,12	0,57±0,17	0,52±0,15	0,54±0,16	0,57±0,09	0,55±0,13
Aver. velocity Y	0,16±0,04	0,19±0,06	0,18±0,05	0,18±0,05	0,20±0,03	0,19±0,04
Max. Velocity Y	0,73±0,17	0,89±0,26	0,81±0,23	0,79±0,18	0,91±0,16	0,84±0,18
Aver. COP Velocity	0,21±0,06	0,25±0,07	0,23±0,07	0,24±0,06	0,26±0,04	0,25±0,05
Max. COP Velocity	0,74±0,17	0,91±0,27	0,82±0,23	0,81±0,19	0,92±0,16	0,86±0,18
Min. COP Velocity	0,004±0,001	0,004±0,001	0,004±0,001	0,004±0,002	0,005±0,003	0,005±0,002

*Units of COP measures are as follows: COP displacements: m*10-3; rotation angle: degrees (°); area: m*10-6; COP velocities: m/sec.*

A portable force platform (Kistler 9286AA) was used to record the movements of the COP on the X (anterior-posterior) and the Y (medium-lateral) axes. A sampling frequency of 100 Hz was selected consulting previous studies, where the frequency range to measure COP movements ranged between 50 Hz (Mononen et al., 2007) and 200 Hz (S Ihalainen et al., 2016) as well as previous studies which used a dumbbell to measure the body sway movements (Mon et al., 2016; Mon, Zakynthinaki, Cordente, Monroy Antón, et al., 2014).

Performance was measured by use of official paper targets, according to the International Shooting Sport Federation (ISSF) Rules and Regulations (Edition 2009) and as provided by the referees of the Spanish Olympic shooting federation after the competition.

Procedures

This study was observational and descriptive following a cross-sectional design. The protocol consisted of a single static bipodal balance test in which a1,5 kg dumbbell (same weight for every participant) was used to simulate the gun (this weight corresponds to the maximum official gun weight limit, as established by

RFEDETO (2009) and according to (Mon et al., 2016; Mon, Zakynthinaki, Cordente, Monroy Antón, et al., 2014) . The tests were repeated three times for each subject and took place before competition (during the official training time) at one of the official competition stands to assure competition conditions regarding the luminosity, the temperature, the floor type, or the distance to the target. To visually complete the simulation of a shot, the targets used were official paper targets. Care was taken so that the study (force platform and its corresponding hardware) did not interfere with the actual competition, so the testing time was one day before the actual competition day.

The participants were asked to stand barefoot on the force platform in a position that simulated the actual shooting position. Each test lasted 30 seconds, starting from the moment the shooter was ready and holding the weight ready to simulate shooting. A resting period of 60 seconds was allowed between test repetitions, to simulate the competition rhythm, i.e. a normal competition cycle of 30 seconds plus 60 seconds (mean time per shot in competition: one shot each 90 seconds).

The local ethics committee provided an approval for the present study and an informed consent was signed by all the participants before data collection. We confirm that our research meets the highest ethical standards for authors and co-authors. The study was performed following the guidelines of the Declaration of Helsinki, last modified in 2008.

The authors certify that the present research was carried out in the absence of any financial, personal or other relationships with other people or organizations that could inappropriately influence, or be perceived to influence, the presented work and lead to a potential conflict of interest.

Analysis

The statistical analysis of the variables was performed using SPSS PASW Statistics 17. ANCOVA tests were used; sex and category were the independent variables. The Kolmogorov-Smirnov was used to determine goodness of fit to the normal distribution of the variables. The Bonferroni test was used as post-hoc test.

To examine the relation between weight and total body sway of the shooters, Pearson product moment correlations and partial correlations were used to analyse the relation between performance and total body sway while having control of the effect of weight difference. The level of significance was set at .05.

RESULTS

Comparisons between groups

The groups refer to different sex (male-female) and modality (pistol-rifle).

Anthropometric and Olympic shooting related parameters

Male shooters were found heavier and taller than female shooters ($F(1,34) = 4,97$; $p<0,05$; $F(1,34) = 25,97$; $p<.001$ respectively). The average points obtained at competition were significantly higher in the rifle group ($F(1,34) = 14,69$; $p<.01$). A significant relation between sex and modality was found ($F(1,34) = 8,49$; $p<.01$). In the pistol group the male participants obtained higher scores ($p<.05$) while in the rifle group no significant differences were found between male and female shooters. The training hours were not significantly different between the groups ($p>.05$).

COP variables

The maximum displacements in the anterior-posterior (X) axis, as well as the lengths of the principal axes of the COP ellipses were found to be significantly smaller in the pistol group, (F (1,33) =8,43; p<0,01 and F (1,33) =10,55; p<.01 respectively. The total calculated areas of the COP ellipse were found to be significantly smaller in the pistol group (F (1,33) =5,68; p<.05). For the rest of the COP variables no significant differences were found p>.05.

Differences in sex were found to have no significant effect on any of the COP variables and no significant interaction between modality regarding the COP variables.

Correlations of the anthropometric parameters

No significant differences were found between weight and maximum displacement of the COP in X, nor between weight and length of the principal axis of the COP ellipse, nor between weight and the rotation angle of the coordinate system of the COP ellipse, for both sexes.

For the male juvenile shooters, no significant differences were found between weight and total area of the COP ellipse and for the female juvenile shooters, no significant differences were found between weight and minimum COP velocity. The rest of the variables were found to be significantly correlated.

Table 3. Pearson product-moment correlation coefficient between weight and COP variables

	Weight	
	Male (n=20)	Female (n=18)
Max. Displ. X	-0.09	-0.23
Max. Displ. Y	-0.62**	-0.61**
Principal axis	-0.08	-0.24
Secondary axis	-0.62**	-0.60**
Rotation angle (°)	0.24	0.04
Total area	-0.32	-0.49*
Aver. velocity X	-0.64**	-0.76***
Max. Velocity X	-0.63**	-0.72**
Aver. velocity Y	-0.64**	-0.71***
Max. Velocity Y	-0.68***	-0.69***
Aver. COP Velocity	-0.66***	-0.71***
Max. COP Velocity	-0.65***	-0.72***
Min. COP Velocity	-0.44*	-0.32

** p<0,05, ** p<0,01, *** p<0,001.*

Correlations regarding performance

Since the training was not homogeneous neither regarding pistol male and female shooters, nor regarding the two modalities (pistol and rifle) an analysis was performed for the correlations between the three different groups.

The experience of the shooters was found to be significantly related to performance (APS) only in the rifle group. The maximum displacements in the X axis as well as the lengths of the principal axis of the COP ellipse were found to be inversely correlated with performance (APS) in the pistol group, both for males and females.

In the female pistol group, inverse correlations were found between performance (APS) and maximum displacement in the Y axis, length of secondary axis of the COP ellipse, average COP velocity, total area of the COP ellipse, average, maximum and minimum COP velocity on both the X and the Y axes, maximum COP velocity and average COP velocity. In the rifle group no correlations between performance (APS) and COP movement was found.

Table 4. Pearson product-moment correlation coefficient between the average points per shot (APS) and anthropometric variables, training variables and COP variables

	Pistol		Rifle
	Male (n=12)	Female (n=12)	(n=14)
Weight	0.02	-0.17	-0.32
Height	-0.37	0.02	-0.38
Experience	0.28	0.41	0.57*
Weekly training	0.27	0.30	0.24
Time until competition	0.38	0.36	0.28
Max. displacement X	-0.66*	-0.78**	-0.01
Max. displacement Y	-0.14	-0.59*	-0.13
Principal axis	-0.62*	-0.80**	-0.06
Secondary axis	-0.19	-0.59*	-0.11
Rotation angle	0.11	0.19	-0.17
Total area	-0.51	-0.69*	-0.03
Average velocity X	-0.03	-0.70*	-0.10
Max. Velocity X	-0.02	-0.65*	-0.19
Average velocity Y	-0.07	-0.69*	-0.12
Max. Velocity Y	-0.20	-0.69*	-0.10
Average COP Velocity	-0.02	-0.67*	-0.10
Max. COP Velocity	-0.13	-0.67*	-0.10
Min. COP Velocity	-0.27	-0.51	-0.07

**p<.05; **p<.01.*

DISCUSSION

The present study is based on body sway data of Juvenile Olympic shooters recorded under competition conditions. This way the performance measured is clear of any influences of laboratory simulations. It is only at competition that all the factors that determine athletic performance are combined.

The tests used for the data recording simulated the shooting position. Similar, easy to carry out, Olympic shooting specific tests can be reproduced anywhere and without the need of a gun (pistol or rifle). This way the present study could be extended to also include other population groups. The results of the analysis of such data in combination with the conclusions of the present study could be very important for the selection of novice shooters.

Regarding the performance, male pistol shooters had higher scores than female pistol shooters; in contrast, in rifle modality no performance differences were found between male and female shooters. Our results are similar to Goldschmied and Kowalczyk (2016) who suggested the recently introduced (2018) change in shooting rules, to increase the number of shots in order to equalize the volume between men and women, something that could also be the object of future studies.

In male pistol shooters, performance is related to the amplitude of the COP displacement, on the X axis and on the principal axis of the COP ellipse. Performance was not found to be related to the COP velocity. In female pistol shooters, performance is related both to the amplitude of COP displacements and the maximum and average COP velocities. Therefore, the results are in concordance with Mon, Zakynthinaki, Cordente, Monroy Antón, et al. (2014) regarding the COP length X axis movements and velocity influence on the performance in males.

As was expected, rifle shooters perform better (in terms of average points per shot) confirming the previous references (Mon, Zakynthinaki, Cordente, Barriopedro, et al., 2014). This difference could be due to differences in the gun, or in technique (Reinkemeier, Buhlmann, et al., 2006; Reinkemeier, Bühlmann, et al., 2006), or even in the specific uniform (jackets, trousers and shoes) used by the shooters which can increase performance up to 20% (Aalto, Pyykkö, et al., 1990).

The pistol group was found to have statistically less total COP area, less displacement of the COP in the X axis and consequently shorted principal axis of the COP ellipse. No other differences regarding the COP variables were found between the two modalities. Our results therefore differ from (Mon, 2014) probably because in that study used a non-specific shooting position to measure the COP movements. Moreover, this result could be due to the nature of the test used for the measurement of body sway (Ball et al., 2003a), as the testing position was more similar to the shooting position of the pistol shooters.

The angle of rotation of the COP ellipse was not found to be significantly related to performance. This result could be explained because a range of degrees between the feet line and the shooting line can cause less movements of the COP (Hawkins, 2013).

Body weight was found to be inversely related to the COP displacements on the Y axis as well as the COP velocities. This could suggest that, in contrast to other sports (Hue et al., 2007; King et al., 2011), an increase in body weight could be technically beneficial to junior categories shooters. This results are in accordance with Mon (2016), suggesting that the weight have a strong relation with the COP movements but not with the performance. Finally, body height is related neither with body sway, nor with performance and there are no anthropometric differences between the different modalities of pistol and rifle.

Our results therefore suggest that neither body height nor body weight influence shooting performance; these two anthropometric measures can be therefore considered not determinant in shooting (Belinchon, 2010). It should be noted, however, that there is a number of other anthropometric values which have not been taken into in account in our study, such as widths, lengths, thicknesses and skinfolds, or other measures that calculate proportionality, such as body composition and somatotype indexes. So, no conclusion can be drown regarding the existence of a specific somatotype - future studies could shed more light into this question.

Taking into account the results of this study, the following practical applications arise: On one hand, pistol-shooting specific balance training should be followed, especially in female athletes, and coaches should be careful with all the variables which could influence a shooter's balance such as their weight, strength, coordination, etc. On the other hand, the coaches should test all juvenile boys and girls who want to practise shooting, in both pistol and rifle modalities, independently of their height or weight, as these variables are found to have no influence on shooting performance.

Finally, is important to recognize the limitations of the study. Although the participation in the study was the 92,68% of the competition participants, the statistical power is not very strong due the comparative analysis by modalities and sex, by which the sample was divided and smaller groups were created. Furthermore, the data collection for all the shooters was performed following a single shooting position similar to the pistol position (during 30 seconds and barefoot) in order to make a standard test for participant - this simplified test could be also being assumed to be a limitation.

CONCLUSIONS

Balance seems to play different roles in young shooting modalities. Body sway movements affect performance in pistol shooting but not in rifle, being the X axis and the principal axis COP movements the most important variables. In addition, balance is more important in female pistol shooters than in male pistol shooters. However, the weight seems to be an important factor for the COP displacements in Juvenile shooters.

Regarding the anthropometric profile, neither the height nor the weight seems to be related to performance in Juvenile precision shooters. Moreover, no differences were found between modalities in the anthropometric variables that were studied. These results suggest that some anthropometric variables play a similar role in both shooting precision modalities.

Finally, although our results do not suggest a tendency to have an anthropometric profile, future studies should be carried out examining more body measurements variables in order to determine the existence of an anthropometric profile and to confirm the results of the present study using bigger samples as well as different Olympic shooting categories or modalities.

ACKNOWLEDGMENTS

The present study was supported by the Faculty of Physical Activity and Sports Science (Madrid, Spain) and the University of Armed Forces ESPE (Quito, Ecuador).

REFERENCES

Aalto, H., Pyykko, I., Ilmarinen, R., Kahkonen, E., & Starck, J. (1990). Postural stability in shooters. ORL J. Otorhinolaryngol. Relat. Spec., 52(4), 232-238. https://doi.org/10.1159/000276141

Aalto, H., Pyykkö, I., Ilmarinen, R., Kähkönen, E., & Starck, J. (1990). Postural stability in shooters. ORL, 52(4), 232-238. https://doi.org/10.1159/000276141

Ball, K. A., Best, R. J., & Wrigley, T. V. (2003a). Body sway, aim point fluctuation and performance in rifle shooters: inter- and intra-individual analysis. J Sports Sci, 21(7), 559-566. https://doi.org/10.1080/0264041031000101881

Ball, K. A., Best, R. J., & Wrigley, T. V. (2003b). Inter- and intra-individual analysis in elite sport: Pistol shooting. J Appl Biomech, 19(1), 28-38. https://doi.org/10.1123/jab.19.1.28

Bayios, I., Bergeles, N., Apostolidis, N., Noutsos, K., & Koskolou, M. (2006). Anthropometric, body composition and somatotype differences of Greek elite female basketball, volleyball and handball players. J Sports Med Phys Fitness, 46(2), 271-280.

Belinchon, F. (2010). Estudio médico deportivo de las modalidades de tiro olímpico. Universidad Complutense de Madrid, Madrid.

Era, P., Konttinen, N., Mehto, P., Saarela, P., & Lyytinen, H. (1996). Postural stability and skilled performance--a study on top-level and naive rifle shooters. J Biomech, 29(3), 301-306. https://doi.org/10.1016/0021-9290(95)00066-6

Goldschmied, N., & Kowalczyk, J. (2016). Gender Performance in the NCAA Rifle Championships: Where is the Gap? Sex Roles, 74(7-8), 310-322. https://doi.org/10.1007/s11199-014-0436-y

Gulbinskienė, V., & Skarbalius, A. (2009). Peculiarities of investigated characteristics of lithuanian pistol and rifle shooters´ training and sport performance. Ugdymas Kuno Kultura, 21.

Hawkins, R. (2011). Identifying mechanic measures that best predict air-pistol shooting performance. Int J Perf Anal Spor, 11(3), 499-509. https://doi.org/10.1080/24748668.2011.11868568

Hawkins, R. (2013). Effects of stance angle on postural stability and performance with national-standard air pistol competitors. Eur J Sport Sc, 13(5), 483-489. https://doi.org/10.1080/17461391.2012.755569

Hawkins, R., & Sefton, J. (2011). Effects of stance width on performance and postural stability in national-standard pistol shooters. J Sports Sci, 29(13), 1381-1387. https://doi.org/10.1080/02640414.2011.593039

Hegeman, J., Shapkova, E. Y., Honegger, F., & Allum, J. H. J. (2007). Effect of age and height on trunk sway during stance and gait. J Vestib Res, 17(2), 75-87.

Hue, O., Simoneau, M., Marcotte, J., Berrigan, F., Doré, J., Marceau, P., . . . Teasdale, N. (2007). Body weight is a strong predictor of postural stability. Gait Posture, 26(1), 32-38. https://doi.org/10.1016/j.gaitpost.2006.07.005

Ihalainen, S., Kuitunen, S., Mononen, K., & Linnamo, V. (2016). Determinants of elite-level air rifle shooting performance. Scand J Med Sci Sports, 26(3), 266-274. https://doi.org/10.1111/sms.12440

Ihalainen, S., Mononen, K., Linnamo, V., & Kuitunen, S. (2017). Which technical factors explain competition performance in air rifle shooting? Int J Sports Sci Coa, 78-85.

King, A. C., Challis, J. H., Bartok, C., Costigan, F. A., & Newell, K. M. (2011). Obesity, mechanical and strength relationships to postural control in adolescence. Gait Posture.

Mason, B., Cowan, L., & Gonczol, T. (1990). Factors affecting accuracy in pistol shooting. Excel, 6, 2-6.

Mon, D. (2016). Estudio de las variables de equilibrio, fuerza y antropometría determinantes del rendimiento en tiro olímpico en la modalidad de pistola aire., Universidad Politécnica, Madrid.

Mon, D., Zakynthinaki, M. S., Cordente, C. A., Barriopedro, M. I., & Sampedro, J. (2014). Body sway and performance at competition in male pistol and rifle Olympic shooters. Bio Hum Kinetics, 6, 56-62. https://doi.org/10.2478/bhk-2014-0010

Mon, D., Zakynthinaki, M. S., Cordente, C. A., Barriopedro, M. I., & Sampedro, J. (2016). Prevalidación de un test de equilibrio en tiro olímpico sin armas. Rev Int Med Cienc Ac, 64, 775-787.

Mon, D., Zakynthinaki, M. S., Cordente, C. A., Monroy Antón, A., & López Jiménez, D. (2014). Validation of a Dumbbell Body Sway Test in Olympic Air Pistol Shooting. PLoS ONE, 9(4), e96106. https://doi.org/10.1371/journal.pone.0096106

Mononen, K., Konttinen, N., Viitasalo, J., & Era, P. (2007). Relationships between postural balance, rifle stability and shooting accuracy among novice rifle shooters. Scand J Med Sci Sports, 17(2), 180-185.

Mononen, K., Viitasalo, J. T., Era, P., & Konttinen, N. (2003). Optoelectronic measures in the analysis of running target shooting. Scand J Med Sci Sports, 13(3), 200-207. https://doi.org/10.1034/j.1600-0838.2003.00130.x

Pellegrini, B., & Schena, F. (2005). Characterization of arm-gun movement during air pistol aiming phase. J Sport Med Phys Fit, 45(4), 467-475.

Reinkemeier, H., Buhlmann, G., Eckhardt, M., Kulla, C., & Linn, U. (2006). Air rifle shooting: fitness - technique - 3-positions - supported - movement sequences - rifles - aiming paths - exercises - psyche - training - coaches (B. Murray, Trans.). Dortmund: Verl. MEC.

Reinkemeier, H., Bühlmann, G., & Konietzny, A. (2006). Tiro olímpico con pistola: Técnica · Entrenamiento · Táctica · Preparación Psicológica · Armas: MEC High Tech Shooting Equipment.

RFEDETO. (2014). Reglamento Técnico General para todas las Modalidades de Tiro. Madrid: Real Federación Española de Tiro Olímpico.

Su, F. C., Wu, W. L., & Lee, W. D. (2000). Stance Stability in Shooters. J Med Biol Eng, 20(4), 187-192.

Tang, W. T., Zhang, W. Y., Huang, C. C., Young, M. S., & Hwang, I. S. (2008). Postural tremor and control of the upper limb in air pistol shooters. J Sport Sci, 26(14), 1579-1587. https://doi.org/10.1080/02640410802287063

Viitasalo, J., Era, P., Konttinen, N., Mononen, K., Mononen, H., Norvapalo, K., & Rintakoski, E. (1999). The posture steadiness of running target shooters of different skill levels. Kinesiology, 31, 11.

Zanevskyy, I., Korostylova, Y., & Mykhaylov, V. (2010). Shot Moment in Optoelectronic Training in the Air-Pistol Shooting. Int J Perform Anal Sport.

Zatsiorsky, V., & Aktov, A. (1990). Biomechanics of highly precise movements: the aiming process in air rifle shooting. J Biomech, 23, 35-41. https://doi.org/10.1016/0021-9290(90)90039-6