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Title: Validating the use of a dumbbell to measure body sway in female Olympic air pistol shooting

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Abstract: The present study validates use of a dumbbell to simulate the air pistol in female Olympic shooting, examining, at the same time, the relation between body sway and performance. The study's participants were 23 senior female Olympic pistol shooters who competed at a Spanish air pistol championship. The participants' performance was measured at competition while their COP movements were recorded during two static bipodal balance tests which were performed the day previous to the competition, during the official training time and at the training stands. During one of the tests a 1.5 kg dumbbell was used to simulate the pistol. The calculated Pearson product moment correlations for all variables that refer to the movement of the COP revealed statistically significant correlations between the two tests. Statistically significant inverse linear correlations were also found between performance and COP movements regarding both tests: strong correlations regarding COP movement amplitudes and moderate correlations regarding COP velocities. The study concludes that a) a dumbbell can be validly used to simulate the pistol in female Olympic air pistol shooting, and b) specific balance training programs should be taken into account in order to improve performance in female air pistol shooting.

Keywords: Female Olympic shooting; air pistol; dumbbell; COP; body sway

1. **Introduction**

Olympic shooting includes various shooting disciplines (such as rifle, pistol or shotgun). The pistol Olympic shooting discipline is divided into various modalities, such as air pistol, free pistol and rapid fire pistol for men and air pistol and sport pistol for women. While the modality of sport pistol includes both a rapid fire and a static component, depending on the shooting stage, the modality of air pistol is a totally static process; therefore maximum precision is required. The indispensability of precision in high level Olympic air pistol shooting becomes obvious when taking into account the current world record scores of 393/400 points (ISSF, 2013)

Although many are the factors that influence performance in Olympic shooting (Lakie, 2010), it is widely agreed both in the scientific and the coaching literature that the ability to stabilize the pistol plays a crucial role (Reinkemeier, Bühlmann, & Konietzny, 2006). Hawkins (2011) reports that the ability to stabilize the pistol inside the target area of 9 points is the variable that best predicts performance. Indeed, it is a fact that elite shooters have a better ability to stabilize the pistol, than lower level shooters (Tang, Zhang, Huang, Young, & Hwang, 2008).

The coaching and scientist literature reports that the shooters with better static balance have an advantage when it comes to performance (Mon, 2006; Mon, Zakynthinaki, Cordente, Barriopedro, & Sampedro, 2014; Reinkemeier et al., 2006). Body and COP movements have been shown to be closely related to movements of the pistol: as (Pellegrini & Schena, 2005) have shown, the COP movements on the Y axis are related with pistol movements on the X axis, and vice versa. The ability to stabilize the pistol is therefore partly determined by body movements which, initiating at the body's centre of pressure (COP), are transferred to the pistol following various kinetic chains (Pellegrini & Schena, 2005). Even though a consensus appears to exist (Mason, Cowan, & Gonczol, 1990), that the COP movements affect performance in Olympic shooting, the grade of this influence varies considerably, depending on the modality as well as the sample group. The reported correlations in the literature vary from quiet high, such as 75% (Viitasalo et al., 1999) to no correlation at all (Ball, Best, & Wrigley, 2003). It should be noted, however, that no studies exist that are based on a large sample of female air pistol shooters.

It is worth also noticing that the majority of the studies that can be found in the relevant literature are based on tests which are carried out under laboratory, training or competition simulations conditions (Ball et al., 2003; Hawkins, 2011). During these studies performance is, in many cases, determined by use of optoelectronic systems, like NOPTEL (Hawkins, 2011) or SCATT (Ball et al., 2003), the validity of which has been, however, questioned. Deviations have been found between the shot's actual position and the position estimated by the system (Zanevskyy, Korostylova, & Mykhaylov, 2009). In addition, stress during official competitions can affect a shooter's performance (Chung, O'Neil, Delacruz, & Bewley, 2005) as well as their COP movements (Wada, Sunaga, & Nagai, 2001). The study of (Gulbinskienė & Skarbalius, 2009) reports that performance is also a factor of the number of competitions which the shooter has taken part in. Actual competition conditions are therefore irreplaceable by training or simulation conditions. The number of studies that are based on data recorded under actual competition conditions (where the performance is the actual performance at competition) is, however, limited (Mon et al., 2014a; Mon, Zakynthinaki, Cordente, Monroy Antón, & López Jiménez, 2014). The present study has been also performed during official competition, this way assuring that the measurements of the shooters' performance, as well as their COP movements represent actual competition values.

On the other hand most of the shooting tests found in the literature aimed to measure the COP movements are performed by use of the shooters' own pistol (Tang et al., 2008). With the exception of the study of Mon et al. (2014b) which validates the use of dumbbells to simulate shooting in the male air pistol category, no other studies exist that use, or validate, the use of objects other than pistols during measurements of COP movements. Since, however, the use of fire guns can be dangerous, such guns are strictly permitted only in places where their use is authorized by law. The development and validation of a test during which a real pistol will be substituted by another standard (non dangerous) object is, therefore, of great interest and necessity.

Regarding measurements of the COP movements, various variables are currently used, such as maximum displacements along the X and the Y axis (Era, Konttinen, Mehto, Saarela, & Lyytinen, 1996), total area of COP displacements (Herpin et al., 2010) or maximum and average COP velocities along the X and Y axes (Su, Wu, & Lee, 2000). The study of (Hawkins, 2011) reports that the COP velocities are the most commonly used variables for estimating CP movements.

The objectives of the present study were to:

1. validate the use of a dumbbell to simulate pistol in female Olympic air pistol shooting, and
2. examine the degree at which the shooters' COP movements influence performance in female Olympic air pistol, under real competition conditions and make comparisons with the correlations reported in the literature which correspond to data recorded in a laboratory, or during training, or competition simulations.

2.Materials and methods

2.1 Ethics Statement

The Ethical Board of the Spanish Team Sports Association approved the experimental design of the study. The informed consent document that all the participants signed before data collection was also approved by the Ethical Board of the Spanish Team Sports Association. 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.

2.2 Participants

23 senior female Olympic pistol shooters who competed at a Spanish air pistol championship in 2012 participated in this study. According to the regulations of the Spanish Federation of Olympic Shooting (RFEDETO, 2012b) eligibility to compete required a previously obtained minimum score of 320 points in air pistol. 7 of the participants (30.43% of the sample group) belonged to the elite / high level competition Spanish group, which means that they had achieved the score of 384 during at a previous competition, or the score of 378 at two previous competitions (RFEDETO, 2012b). The participants' profile is shown in Table 1.

Table 1. Participants' profile, mean values ±standard deviation.

Age (years)	31,26	±	11,21
Height (m)	164,4	±	6,35
Weight (Kg)	66,58	±	12,22
BMI (kg/m^2)	24,62	±	4,28
Experience (years)	9,09	±	6,43
Training (hours/week)	6,36	±	8,58
Performance	359	±	14,28

2.3 Experimental protocol

The protocol consisted of two static bipodal balance tests:

(a) Shooting simulation whereby a 1.5 kg dumbbell was used. It should be noted that this weight corresponds to the maximum official pistol weight, as established by the Spanish Federation of Olympic Shooting (RFEDETO, 2012b). The criteria of Gulbinskienė & Skarbalius (2009) were followed to ensure the similarity of the technique with the actual shooting gesture.

(b) Pistol shooting. The use of the shooters' own air pistol was preferred in order to guarantee specificity and to allow adaptability to the shooters' individual characteristics and the subsequent comparison with their performance. According to the article 8.16.0 of the Spanish air pistol regalement (RFEDETO, 2012a), the minimum trigger pressing was a weight of 0.5 Kg, the maximum pistol weight was 1.5kg and the maximum dimensions of all pistols used were 0.42 x 0.2 x 0.05 m .

Both tests were repeated three times, as suggested by (Pinsault & Vuillerme, 2009), thus guaranteeing accuracy of measurements and test reproducibility. Each recording started the moment the shooter was ready and holding the pistol/dumbbell ready to shoot/simulate shooting. (Reinkemeier et al., 2006) report that the pistol shooting time oscillates between 6 and 10 seconds, depending on the shooter and the shot, with 8 seconds being the optimal time. Some shooters, however, exceed this time. For this reason and in order to respect the specific time of each shooter and optimize the data recording of such a specific test, the duration of each test was decided to be 15 seconds. A maximum resting period of 1.5 minutes was allowed between test repetitions.

The data collection was performed the day previous to the competition, during the official training time and at the training stands to simulate competition conditions. For this reason the design of the study's experimental protocol had to respect the limited available time of the official training previous to competition (8 hours). At the same time the test were designed in such a way so as to simulate actual competition paces and rhythms (40 shots in 60 minutes, 90 seconds between shots) (RFEDETO, 2012b).

The initial position for both tests was the natural shooting position of the participants. In order to standardize the tests, the guidelines of (RN Hawkins & Sefton, 2011) were followed regarding feet distance. The maximum feet distance was therefore kept between 0.3 and 0.6 m, as for such distance no differences in the COP movements have been reported.

The tests were performed under conditions of luminosity of 1240 luxon on the shooting stand and 1900 luxon on the target. The distance to the target was 10 m and the height of the target's centre was 1.4 m (measured from the level of the shooting stand). To visually complete the simulation of a shot, the targets used were official paper targets. The shooters performance was calculated as the average of 40 shots at competition.

2.4 Apparatus-equipment

The COP movements on the X (anterior-posterior) and Y (medium-lateral) axes were recorded by use of a portable force platform (Kistler 9286AA) at a frequency of 100 Hz. The shooters' 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. The luminosity was measured with a HT307 luxmeter.

2.5 Statistical analysis

The goodness of fit to the normal distribution of the variables was determined by application of a Kolmogorov-Smirnov test. To examine the correlations between performance and COP movements or morphology of the participants, linear regression was used. Pearson product moment correlations were used to analyse the concurrent validity of the variables for both tests. The level of significance was set at 0.05.

The statistical analysis of the variables was performed using SPSS Statistics 17. The calculation of the displacements, velocities, areas and angles was carried out by use of the mathematical package Matlab R2009a.

2.6 Variables

The following variables which correspond to the participants profile were analysed (see Table 1): Weight (kg), height (m), body mass index (BMI; kg/m^2) experience (years), training (hours per week) and performance over 40 shots.

For the statistical analysis of the COP movement, the following variables were taken into account (see Table 2): Maximum COP displacements on the X and Y axes, total area of COP displacement, average and maximum COP velocities on the force platform plane, average and maximum COP velocities on the X and Y axes. We also analyzed the length of the principal and the secondary axis of the ellipse that best fitted each participant's COP data, as well as the angle between the principal axis of the ellipse and the X axis (for more details regarding these variables see (Mon et al., 2014b).

Table 2. Variables of the shooters' COP movement, mean values ±standard deviation. COP displacements, m*10^{-3}; angle, degrees; area, m*10^{-6}; COP velocities, m/sec*10^{-3}.

	Pistol	**Dumbbell**
Max. displ. X	13.26±3.08	13.60±2.94
Max. displ. Y	8.65±2.32	9.50±2.50
Principal axis	13.37±3.36	13.38±3.30
Secondary axis	10.43±3.01	10.35±2.35
Angle	9.33±10.74	4.59±11.13
Total area	110.13±49.47	116.52±52.90
Aver. velocity X	22.26±4.22	22.00±3.95
Max. velocity X	99.79±17.36	99.24±19.51
Aver. velocity Y	33.03±6.44	32.69±5.98
Max. velocity Y	148.89±27.61	147.80±29.50
Aver. COP velocity	43.84±8.04	43.38±7.54
Max. COP Velocity	155.65±28.51	153.17±30.70

3. Results

By application of the Kolmogorov-Smirnov test for the normal distribution of the sample, the data of all variables was found to be normally distributed (P>0.05) with the only exception being the variable of "training hours" the distribution of which was found to deviate from the normal distribution, P<0.05.

The analysis of the Pearson product moment correlations for the variables that refer to the movement of the COP revealed statistically significant correlations between both tests, for all variables, see Table 3.

Table 3. Pearson interclass correlations between the two tests, for the variables that refer to the movement of the COP. ** Level of significance p<0.01,*** Level of significance p<0.001.

Variable	Pearson correlation coefficient
Max. Displ. X	0,66***
Max. Displ. Y	0,77***
Principal axis	0,7**
Secondary axis	0,88***
Angle	0,59**
Total area	0,71***
Aver. velocity X	0,96***
Max. Velocity X	0,82***
Aver. velocity Y	0,98***
Max. Velocity Y	0,85***
Aver. COP Velocity	0,98***
Max. COP Velocity	0,85***

The statistical analysis (please refer to Table 4) of the data recorded during the first test (shooting simulation by use of a dumbbell) revealed significant inverse correlations between performance and: maximum COP displacement on the X axis ($F_{1,21}$= *11,64; P<0.01*), maximum COP displacement on the Y axis ($F_{1,21}$= *42.9; P<0.001*), length of the COP ellipse principal axis ($F_{1,17}$= *5.72; P<0.05*), length of the COP ellipse secondary axis ($F_{1,17}$= *17.68; P<0.01*), angle between the principal axis of the ellipse and the X axis ($F_{1,17}$= *6.28; P<0.05*), total area of COP displacement ($F_{1,21}$= *30.98; P<0.001*). A linear regression between performance and these six variables for which a statistically significant correlation was found, yielded a value of r^2 adjusted= 0.44; ($F_{6,12,}$= *3.31; P<0.05*).

Regarding now the data recorded during the second test (shooting by use of the shooters' own pistol), significant inverse correlations were found (see Table 4) between performance and: maximum COP displacement on the X axis ($F_{1,21}$= *5.12; P<0.05*), maximum COP displacement on the Y axis ($F_{1,21}$= *6.43; P<0.05*), length of the COP ellipse principal axis ($F_{1,18}$= *10.00; P<0.01*), length of the COP ellipse secondary axis ($F_{1,18}$= *10.9; P<0.01*), total area of COP displacement ($F_{1,21}$= *15.11; P<0.01*). A linear regression between performance and these five variables for which a statistically significant correlation was found, yielded a value of r^2 adjusted = 0.39; ($F_{5,14,}$= *3.40; P<0.05*).

The shooters' performance was also found to be significantly correlated with training (*$F_{1,21}$= 5.43; $P<0.05$*) as well as BMI (*$F_{1,21}$= 5.74; $P<0.05$*), see Table 4. For the rest of the variables no significant correlations were found, $P>0.05$.

Table 4. Pearson correlations between performance and COP movement variables, as well as profile variables. Coefficient of variation=SD/M x100.* Level of significance p<0.05,** Level of significance p<0.01,*** Level of significance p<0.001.

	Variable	r	r^2 adjusted	CV% = SD/M x 100
Dumbbell	**Max. Displ. X**	-0,60**	0,33	3,27
	Max. Displ. Y	-0,82***	0,66	2,33
	Principal axis	-0.50*	0,21	2,85
	Secondary axis	-0,71**	0,48	2,3
	Angle	-0,52*	0,23	2,82
	Total area	-0,77***	0,58	2,59
Shooting	**Max. Displ. X**	-0,44*	0,16	3,65
	Max. Displ. Y	-0,48*	0,2	3,56
	Principal axis	-0,60**	0,32	3,43
	Secondary axis	-0,61**	0,34	3,38
	Total area	-0,65**	0,39	3,1
Profile	**Training**	0,46*	0,17	3,67
	BMI	0,46*	0,18	3,61

4. Discussion

The present study analyzed the relation between performance in female Olympic pistol shooting and COP movement data recorded under competition conditions. For the recording of the data, two tests were performed, the first being a shooting simulation by use of a dumbbell and the second actual shooting by use of the shooters' own pistol. The originality and novelty of the present study becomes clearer when one takes under consideration the significantly low number of studies that can be found in the literature that examine the connection between static balance and performance in female air pistol Olympic shooting.

Regarding the validity of the dumbbell shooting simulation test, the statistical analysis revealed Pearson correlation values between 0,59 y 0,98: moderate to strong (0,59-0,88) for the variables that correspond to COP movements amplitudes and excellent (0,82-0,98) for the variables that correspond to COP movements velocities (Fleiss, 1986). This justifies the use of a dumbbell to simulate a pistol in female Olympic shooting, see also (Mon et al., 2014b).

The statistical analysis of the study's data revealed inverse linear correlations between performance and COP movements regarding both tests: strong correlations regarding COP movement amplitudes and moderate correlations regarding COP velocities (see Table 4). The total COP area was found to be 58% related with performance, as far as the dumbbell test is concerned. This result refers to the study of (Mason et al., 1990) in which a 53% relation between shot position (and thus performance) and total COP movement is reported. In the study of (Ball et al., 2003) although no correlation between performance and COP movement amplitudes is found to exist, a 46% variance is reported in one of the participants, a result which is very similar to the 44% variance found in the present study regarding the significant variables for the dumbbell test and to the 39% variance in the significant variables for the pistol test. The differences between such studies (Ball et al., 2003; Mason et al., 1990) could be due to the differences in the sample groups (mixed male and female shooters as opposed to the female shooter group of the present study) in addition to the fact that the present study corresponds to data recorded under actual competition conditions.

An analysis of the data obtained at world Olympic pistol championships since 1998 confirmed that a coefficient of variation of 2.3 (such as the one found by the present study) would be equivalent to an average of 42 points and a variance of 3.65, in other words an average difference of 80 places in the final classification at Olympic pistol shooting world championships (ISSF, 2013). This fact clearly demonstrates the importance of the correlations found by the present study.

The present analysis also revealed a strong correlation between performance and training hours, a result which agrees with the existing scientific (Gulbinskienė & Skarbalius, 2009) and coaching literature (Reinkemeier et al., 2006). A correlation between performance and BMI in female shooters was also found, in contrast to the study of (Belinchon, 2010) which reports that no specific morphological pattern exist in Olympic shooting. The present study is more in accordance with studies like (Bayios, Bergeles, Apostolidis, Noutsos, & Koskolou, 2006) that report an association of patterns in the shooters' morphology and the type of sport they practice. The relation between performance and BMI, as well as the relation between BMI and COP movements should be further analysed and confirmed by future studies.

5. Conclusions

The study concludes that:

a) a standard, cheap and affordable object such as a dumbbell can be validly used to simulate a pistol in female Olympic shooting; this allows COP movement measurements to be carried out anywhere (in places such as schools, for example) for young talent selection purposes;
b) specific balance training programs should be included along the programs of pistol technique training, in order to improve performance in female air pistol shooting.

References

Ball, K. A., Best, R. J., & Wrigley, T. V. (2003). Inter- and intra-individual analysis in elite sport: Pistol shooting. *J Appl Biomech, 19*(1), 28-38.

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.

Chung, G. K., O'Neil, H. F., Delacruz, G. C., & Bewley, W. L. (2005). The role of anxiety on novices' rifle marksmanship performance. *Educational Assessment, 10*(3), 257-275.

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.

Fleiss, J. L. (1986). *The design and analysis of clinical experiments*: Wiley Online Library.

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 Perform Anal Sport, 11*(3), 499-509.

Herpin, G., Gauchard, G. C., Lion, A., Collet, P., Keller, D., & Perrin, P. P. (2010). Sensorimotor specificities in balance control of expert fencers and pistol shooters. *J Electromyogr Kines, 20*(1), 162-169.

ISSF. (2013). issf-sports.org, from http://www.issf-sports.org/results.ashx

Lakie, M. (2010). The influence of muscle tremor on shooting performance. *Experimental Physiology, 95*(3), 441-450.

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

Mon, D. (2006). Objetivos y ventajas de la preparación física en el tiro olímpico: una primera aproximación. *Tiro Olímpico, 60*, 18-21.

Mon, D., Zakynthinaki, M. S., Cordente, C. A., Barriopedro, M. I., & Sampedro, J. (2014a). Body sway and performance at competition in male pistol and rifle Olympic shooters. *Biomedical Human Kinetics*, 6, 56 - 62.

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

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

Pinsault, N., & Vuillerme, N. (2009). Test-retest reliability of centre of foot pressure measures to assess postural control during unperturbed stance. *Med Eng Phys, 31*, 276-286.

Reinkemeier, H., Bühlmann, G., & Konietzny, A. (2006). *Olympisches Pistolen-Schießen: Technik, Training, Taktik, Psyche, Waffen ; ein Lehr- und Übungsbuch zum sportlichen Schießen mit der Luftpistole, der Sportpistole und der freien Pistole*: MEC High Tech Shooting Equipment.

RFEDETO. (2012a). *Reglamento Técnico Especial para Pistola*. Madrid: Real Federación Española de Tiro Olímpico.
RFEDETO. (2012b). *Reglamento Técnico General para todas las Modalidades de Tiro* (2009 ed.). Madrid: Real Federación Española de Tiro Olímpico.
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 Sports Sci, 26*(14), 1579-1587.
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.
Wada, M., Sunaga, N., & Nagai, M. (2001). Anxiety affects the postural sway of the antero-posterior axis in college students. *Neurosci Lett, 302*(2-3), 157-159.
Zanevskyy, I., Korostylova, Y., & Mykhaylov, V. (2009). Specificity of shooting training with the optoelectronic target. *Acta Bioeng Biomech, 11*(4-P), 63-70.

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