ASSESSMENT OF THE UNCERTAINTY BUDGET FOR AN INTEGRATED SYSTEM IN CLAY PIGEON SHOOTING DISCIPLINE

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The purpose of this study was a part of a wider project to characterize the athletic gesture in the Olympic shooting disciplines, expanding the scientific knowledge in clay pigeon shooting. This project aimed to design and develop an integrated measurement system able to acquire and analyse the shooters‘ physical parameters. An uncertainty budget was assessed, identifying the main sources of uncertainty for their measurement, being a preparatory step for the validation of a measurement system, which should be able to identify the most relevant parameters affecting the shooting performance.

KEYWORDS: clay pigeon shooting, uncertainty budget, Olympic trap discipline.

INTRODUCTION: Depending on the discipline, in the shooting sports, athletes are ranked through scores related to the accuracy targets are hit with, as in rifle/gun shooting, or based on the number of hit targets, i.e. shotgun shooting disciplines. This study focused on the latter, specifically on the trap discipline, which involves different consecutive phases, overall lasting less than 1 second, with targets thrown from a trap 15 m away from the shooter, with a high speed and unknown trajectory. Although the shooter’s goal is to hit as many clay pigeons as possible, this poorly describes the quality of the gesture. Thus, in the past decades, some studies investigated the contribution of body and shotgun balance, (Anderson & Plecas, 2000; Era, Konttinen, Mehto, Saarela, & Lyytinen, 1996; Ihalainen, Kuitunen, Mononen, & Linnamo, 2016; Puglisi et al., 2014), others focused on shooter and shotgun’s kinematic aspects, (Ball, Best, & Wrigley, 2003; Sattlecker, Buchecker, Müller, & Lindinger, 2014), whereas further research investigated the impact of reaction time and shooting time, (Rao et al., 2018), or the sight aspect with performance, as quiet-eye duration, (Causer, Bennett, Holmes, Janelle, & Williams, 2010). Despite some scientific evidence concerning the importance of selected parameters in shooting disciplines, knowledge is still limited (Peljha, Michaelides, & Collins, 2018) in clay pigeon shooting, raising the need to further investigate this discipline.
The purpose of this study was, at first, to identify the most relevant physical parameters involved in shooting studied in the literature, then develop an integrated measurement system, addressing the trap discipline, and validate it by performing a measurement uncertainty budget for each of the selected features.

METHODS: The trap discipline is practised outdoors, in uncontrolled conditions, which might affect the reliability and the robustness of the measurement system. Factors such as wind, humidity, ambient light are the main constraints to consider and cope with when designing the measurement system. Another key element is the sudden start and short duration of the shooting gesture, raising the need of synchronization strategies between devices.
To select the measurement devices to be used, a jury, composed of four researchers and three skilled shooters, carried out the hardware selection, based on a set of seven criteria, among different technologies available for the project. A mark for each evaluation criterion has been provided by each juror, ranking from 1 (worst solution) to 10 (best solution), after testing in real operative conditions with skilled shooters.
The identified criteria were:
HW – hardware integrability, as the compatibility of the instruments with the field, the interface with other instruments and the test conditions.
ST – Setup time, as the amount of time required to set up all devices, i.e. time required for the shooting pitch hardware installation as well as the time for the calibration procedures.

CA – Calibration robustness, as the reliability and accuracy of the device, even if calibrated directly on-site, in different environmental conditions (wind, ambient light, temperature..).
CO – Comfort, indicates the comfort perceived by athletes wearing the instrumentation, so as not to hinder the shooting gesture.
SY – Synchronization, meant as the feasibility of an electrical trigger connection to guarantee the synchronization among the involved devices to collect consistent data.
DH – Data handling, as the overall effort needed to process and elaborate raw data, for instance, the time required to process digitized images or to filter analogue data.
CS – Cost affordability, meant as hardware and software purchasing, maintenance, training and licence fees.
The development of a measurement system starts always by identifying the set of measurands the system should be able to measure, the ranges expected and the uncertainties assessment. From the analysis of the state of the art, we defined a set of measurands to better investigate the shooting gesture. Moreover, we identified two phases: a “preparatory phase” lasting 1 second, before and up to the clay target release, and a “tracking phase”, as the time from the clay target release up to the first shot. All selected features were computed, when possible, for both these two phases. The selected features are:
- Shooting time: is the elapsed time between the clay target release and the first shot event.
- Angular displacements: the relative yaw and pitch angles of the shotgun, head and trunk, with respect to their position 1 s before target release.
- Symmetry index: is the difference between the dominant and non-dominant side ground reaction forces, computed as $2*(F_{dominant}-F_{non\text{-}dominant})/(F_{dominant}+F_{non\text{-}dominant})$
- Quiet-eye time: the time between two successive mayor pupil displacements, denotes the eye’s latency to a stimulus.
- Gaze: as the coordinates of the shooter’s gaze direction intersection with a vertical plane 15 m from the athlete
The uncertainty assessment for each measurand has been performed as follows:
- Shooting time’s uncertainty has been estimated by comparing the shot time provided by the selected system, against the reading of a reference microphone, to detect the shot, and of the current of the solenoid, which holds the clay target inside the throwing machine before release.
- Angular displacements’ uncertainty was calculated using a MonteCarlo method, starting from the recorded marker’s positions and their uncertainty, (JCGM 100:2008).
- Symmetry index uncertainty was assessed using the GUM approach, (JCGM 100:2008).
- Quiet-eye time uncertainty estimation followed the analytic GUM approach (JCGM 100:2008), taking into account the image framerate, giving a standard uncertainty $u(pupil)$ of 3 ms, the operator uncertainty $u(\text{operator})$ of 6 ms, due to the manual detection of the frame of the first saccade or the shot time (given the assumption of a uniform distribution of an error of maximum 2 frames), the shooting time uncertainty $u\,(\text{Shooting Time})$ 4 ms, and the uncertainty related to the first movement algorithm detector, u (algorithm) of 3 ms (supposing a uniform distribution of an error of maximum 5 samples).
- Gaze was estimated employing a linear interpolant model trained by using the pupils’ coordinates and known spatial calibration points, specifically 30 points placed 15 m away from the athlete. 60 of the trials performed were used to train the model, while the remainder was used to assess the uncertainty associated with the gaze assessment model.

RESULTS: *Table 1* summarizes the results for the device tested, detailing partial marks for each criterion. Device total score was then obtained adding up each partial mark, equally weighted, and rescaling into a range from 1 up to 10. The selection was used to define the optimal solution for the proposed application, which employed a marker-based optoelectronic system (DX 100, BTS) in an area of 4x4 m^2, at 3.2 m height. Four IR cameras, synchronized with each other with their proprietary acquisition unit, were exploited to monitor the athlete and shotgun’s range of motion, employing passive marker placed following a modified Plug-In Gait protocol. Two force plates (P6000 BTS), monitored an area of 0.48 m^2 under the shooter’s feet, recording the ground reaction forces. Cameras and force platforms were hardware synchronized by the same control unit (SMART DX100). The eye movements were measured by using a custom headset of eye-tracking glasses (Pupil Labs e200b w120), redesigned to be comfortable for the shooters. The eye-tracker consist of two eye cameras for recording pupils displacements and a world camera, logging the shooter's field of view. Times and outcomes, as well as the shooting scheme and target direction, were recorded by a mobile app connected with the target thrower (Shooting Data by Fabbrica d'Armi P.Beretta).

Table 1: device selection criteria, * denotes the best performer for each quantity

Quantity	Device	HW	ST	CA	CO	SY	DH	CS	total
Kinematics	BTS*	8	8	8	8	10	9	2	**7.6**
	Optitrack	8	8	3	8	7	3	4	5.9
	Picoflexx	3	4	4	3	3	3	7	3.9
	Xsens	8	8	3	9	10	5	2	6.4
Accerelations	Kistler	3	4	10	3	7	7	3	5.3
	Axivity	3	8	5	8	6	5	8	6.1
	Shimmer*	8	8	7	8	8	8	3	**7.1**
Timing	ELFIPA*	10	10	10	10	10	9	6	**9.3**
	Wilcoxon (mic)	10	8	8	10	10	7	3	8.0
Eye movements	PupilLabs*	6	3	4	5	4	4	6	**4.6**
	Tobii	3	7	6	3	4	7	1	4.4

The measurement system's core was the master unit (NI compactDaq), which managed all the signals flow. It detected the electrical digital signals associated with target release and firing, coming from the shooting pitch machine control system (by ELFIPA), as well as coordinated the whole framework, by acquiring data from each device at its sampling rate, ranging from 100 Hz up to 200 Hz.

Table 2: Uncertainty budget

Measurand	U(95%)	Range	Unit	Measurand	U(95%)	Range	Unit
Pitch angle	0.25	0÷10	Deg	Quiet-eye time	0.016	0÷0.35	s
Yaw angle	0.25	-35÷35	Deg	Gaze X – Linear	0.34	-6÷6	m
Symmetry index	2	-200÷200	%	Gaze Y – Linear	0.48	0÷2.5	m
Shooting time	0.008	0÷1	s				

Table 2 summarizes all the measurands estimated uncertainties. For the shooting time, 328 independent trials have been analysed computing the error between the first shot time provided by the ELFIPA system and the shot time obtained processing solenoid and microphone signals. For the angular displacements, 30 000 runs have been generated following a normal distribution function with mean (μ=0 mm) and standard deviation (s=0.2 mm). Whereas, for the symmetry index uncertainty, the partial derivates of formula (1) were calculated to get the combined uncertainty, while for the quiet-eye time uncertainty was applied the uncertainty propagation. The gaze uncertainty was evaluated from a set of 15 trials, independent from the ones used to train the model, computing their root mean square error.

DISCUSSION: Despite some limitations of the use of infrared cameras in an external environment due to sunlight, adjustable exposure time allowed us to isolate markers reaching uncertainty value 0.25 degrees over a displacement range of 0° – 10° for pitch angles and -35° – 35° for yaw. Typically, the shooters align their body segments with the shotgun during the "preparatory phase", attempting to maintain the adopted configuration even in "tracking phase", to increase the likelihood of success. Thus, accurate measurements of angular displacements would allow to deeper understanding of the relationship among body segments and shotgun. The uncertainty value of 2% over a range of -200÷200%, made the symmetry index (SI) meaningful for describing the shooting gesture. The tendency is to move the weight on the front foot during the "preparatory phase" (SI negative), being the athletes placed on one of the two platform's diagonals, then SI rises to positive values due to shotgun swing during the "tracking phase" up to end having negative SI values few instants of time before the shot.

The first shot time uncertainty value of 1% over the measurement range, allowed to integrated the ELFIPA system into the measurement setup, providing additional field attributes, as the target direction and outcomes through “Shooting Data” app, leading to a complete shooter’s analysis combining timing, outcomes with kinematic and dynamic features.
By contrast, it’s evident that ocular features, especially the shooter’s gaze estimation is still far from the required standard accuracy for this kind of discipline, even if shooter’s gaze was estimated 15 m away. The uncertain value for the linear regression model is better in X coordinate than Y coordinate, probably due to different eye’s structures governing the motor control, whereas the quiet-eye feature might suggest how the shooter’s stress level vary over the shooting session, affecting the performance. The quiet-eye uncertain value limits the possibility to include this feature into the experimental setup, as well as for the gaze estimation since both features were estimated by using the same eye-tracking glasses, which should be further enhanced to improve data quality, accuracy and comfort.

CONCLUSION: This work presents a preliminary uncertainty budget assessment of the developed measurement system. Being able to measure the selected features and estimate their uncertainty values might lead to a better and deeper understanding of the trap discipline, providing validated tools for further investigations, as well as guidelines for the improvement of the measurement system presented. Further measurements and analysis might yield to innovative training techniques to support shooters and coaches.

REFERENCES

Anderson, G. S., & Plecas, D. B. (2000). Predicting shooting scores from physical performance data. *Policing*, *23*(4), 525–537.

Ball, K. A., Best, R. J., & Wrigley, T. V. (2003). Body sway, aim point fluctuation and performances in rifle shooters: Inter- and intra-individual analysis. *Journal of Sports Sciences*, *21*(7), 559–566.

Causer, J., Bennett, S. J., Holmes, P. S., Janelle, C. M., & Williams, A. M. (2010). Quiet eye duration and gun motion in elite shotgun shooting. *Medicine and Science in Sports and Exercise*, *42*(8), 1599–1608.

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. *Journal of Biomechanics*, *29*(3), 301–306.

Ihalainen, S., Kuitunen, S., Mononen, K., & Linnamo, V. (2016). Determinants of elite-level air rifle shooting performance. *Scandinavian Journal of Medicine and Science in Sports*, *26*(3), 266–274.

JCGM 100:2008. Evaluation of measurement data, Guide to the expression of uncertainty in measurement. *BIPM* Joint Committee For Guides In Metrology - 2008

Peljha, Z., Michaelides, M., & Collins, D. (2018). The relative importance of selected physical fitness parameters in Olympic clay target shooting. *Journal of Human Sport and Exercise*, *13*(3), 541–552.

Puglisi, M. L., Rocca, R., Sarra Fiore, A., Gibiino, C., Buscemi, A., Petralia, M. ., & Nicotra, R. (2014). Evaluation of Postural Balance in Skeet Shooting. *International Journal of Education and Research*, *2*(12), 53–60.

Rao, H. M., Khanna, R., Zielinski, D. J., Lu, Y., Clements, J. M., Potter, N. D., … Appelbaum, L. G. (2018). Sensorimotor learning during a marksmanship task in immersive virtual reality. *Frontiers in Psychology*, *9*(FEB).

Sattlecker, G., Buchecker, M., Müller, E., & Lindinger, S. J. (2014). Postural Balance and Rifle Stability during Standing Shooting on an Indoor Gun Range without Physical Stress in Different Groups of Biathletes. *International Journal of Sports Science & Coaching*, *9*(1), 171–184.

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