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ORIGINAL ARTICLE

Validity and reliability of an opto-electric training system in elite and national level ISSF air rifle shooters

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Abstract

The validity of a commonly used optoelectronic training system was examined by identifying the variables that predicted shot score, investigating their ability to discriminate standard, and assessing the predictive variables' test–retest error. A repeated-measures approach assessed test–retest error, a cross-sectional approach compared standards of shooters and an observational approach examined predictors of shot score. 21 elite and 8 national-standard athletes participated. Multiple linear regression, independent t tests, typical error and coefficient of variation assessed predictors of shot score, discrimination between standards and test–retest error respectively. Stability of aiming predicted 84.2% of the variance in shot score. Six Scatt Expert variables, 10a0, 10a5, 10.0, 10.5, Speed in the last 250 mm, and stability of aiming, discriminated standard ($P < 0.05$). Test–retest error ranged from a coefficient of variance of 0.72% for 10a0 to 30.69% for Accuracy of Aiming. Stability of aiming had a typical error of 0.55 mm and a coefficient of variance of 13.93%. Results suggest that this optoelectronic training system possesses construct validity if stability of aiming is used as the outcome measure.

Keywords Biomechanics · ISSF rifle shooting · Validity · Optoelectronics

1 Introduction

Olympic air rifle shooters have an angular error limit of 0.016° to hit 10.0 (shot score 0–10.9 points) with every shot [1]. Such accuracy is vital as the best athletes had to average 10.49 points across a match to make the Tokyo Olympic (2021) men's air rifle final. Averaging such a score is no easy feat, as the 10-ring is 0.5 mm in diameter and must be touched by a projectile 4.5 mm in diameter. Considering these margins, practitioners have investigated how to improve shooting performance, leading to the analysis of technical factors, which equate to 81–83% of the variance in the shot score (SS) [2, 3]. The technical factor components of interest are stability of hold (ability to have a small aiming area), accuracy of aiming (ability to have the aiming area in the centre of the target), stability of triggering (ability to not deflect aimpoint at the onset of triggering), time (time spent aiming), anterior–posterior balance (centre of pressure deviation in the Y-Axis), and medial–lateral balance (centre of pressure deviation in the X-Axis) (see Table 2). Ihalainen et al. [2] and Lang and Zhou [3] used Optoelectronic systems and force platforms to measure these components. Optoelectronic systems cannot measure anterior–posterior or medial–lateral balance.

Optoelectronics is a subfield of photonics (the physical science of light waves). An optoelectronic system is any electronic device which can find, detect, or control light [4]. In shooting, there are a few optoelectronic devices such as Noptel (Noptel Oy, Version Sport II, Finland), Scatt MX-02 (SCATT Electronics LLC, Version 26 × 31 × 70 mm, Russia) and MX-W2 (SCATT Electronics LLC, Version, 34 × 35 × 60 mm, Wireless system, Russia) and Trace (FOCUSD Technologies OÜ, Version TRACE 10 Gen. II, Estonia). These systems quantify a range of variables split into the previously mentioned technical factor components. Optoelectronic training systems provide a practitioner with large amounts of data; nonetheless, the value of such data is questionable due to limited validation research.

To provide useful data, a measurement tool must be specific, valid, and reliable [5, 6]. Specificity requires that a measurement tool/test mimics the sporting context or

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demands of performance [7]. Validity of a test can be demonstrated in three ways [8]: logical validity is claimed where a test clearly measures a critical component essential for a context e.g. a test of distance jumped to quantify long jump performance; Criterion validity can be claimed when a 'new/simpler' test agrees or correlates strongly with an established 'gold standard' or 'criterion' test and; Construct validity can be claimed when a test is able to discriminate different demographics, such as a) skill level or b) sport specialism (or both). Reliability refers to a test's ability to produce similar results on separate occasions under standard conditions with no change in the performer's skill level [9]. Reliability is, therefore, an essential component of validity. The validity and reliability of a testing tool must be assessed to establish its value for assessing and tracking changes in performance or performance-related factors.

The Noptel optoelectronic device has previously been shown to discriminate elite and national standard Finnish shooters (construct validity). When used in a technical factor component model [2], elite athletes had greater aiming accuracy and cleanness of triggering values than national standard athletes. To date, no such investigation has been done with the Scatt MX-02 optoelectronic device. This is surprising as Scatt systems are more widely used in ISSF shooting. Research has investigated the accuracy of assessing movement with the Scatt MX-02, reporting questionable accuracy [10]. When testing the system in a stationary rig and moving the Scatt device a known distance, the system did not reciprocate this value, displaying the largest error in the left and up directions [10]. This led Zanevskyy et al. [10] to create a corrective factor to counteract these errors. To date, no study has documented the test–retest error of the Scatt MX-02.

Shooting literature is in relative infancy, with few intervention studies performed in ISSF shooting [11]. Nevertheless, optoelectronic systems are used for training and monitoring [12]. Optoelectronic systems provide augmented feedback, helping athletes contextualise their intrinsic feedback for quickening skill acquisition [13]. Understanding which variables are important to monitor is critical for efficient and accurate coaching. Until now, it has been unclear which variables within the Scatt system are the most useful for monitoring. Lang and Zhou [3] recently created a principal component model, condensing the variables into components and highlighting the critical aspects of shooting performance. The reliability of these variables, as measured by the Scatt MX-02 system, for monitoring over time, predicting performance outcomes and discriminating elite from national-standard shooters is currently unknown.

The aim of the study was to investigate the construct validity and test–retest reliability of the Scatt shooting system. The latter was judged by the ability of shot-specific variables to discriminate between skill levels.

2 Method

2.1 Participants

The participants were elite and national-level athletes (Table 1). Athletes were recruited from high-performance/national squads in Austria, Croatia, Czech Republic, Denmark, Germany, Iran, Lithuania, Norway, Poland, Slovakia, Sweden, United Kingdom, and the United States of America. Recruitment was conducted through social media recruitment posts and direct targeted messaging. This recruitment strategy allowed for a bigger sample of elite-level athletes because one country only has a small population of them. Males and females were included in the same group due to no significant difference in competition scores [14]. An elite athlete was defined as a participant who had competed as a senior in the following competitions: European Championships or Games, Asian Games, Pacific Games, Pan America, African Championships, Commonwealth Games, World Cups or Championships, or Olympic Games. A national-level athlete was defined as a participant who had placed in the top 15 of their home country's national championship. Before participating and in writing, all participants gave informed consent, and the Department of Sport, Exercise and Rehabilitation Research Ethics Committee at Northumbria University granted ethical approval (Ref: 45091).

2.2 Design

2.2.1 Procedures

The procedure was designed to mimic ISSF match conditions used at World Cups and Olympic Games, where the

Table 1 Participant demographics

	Males	Females	Age	Years of experience	3 highest competition average
Elite level	11	10	26.33 ± 3.90	10.76 ± 4.33	628.34 ± 2.18
National level	1	7	24.25 ± 3.56	7.58 ± 2.83	621.11 ± 4.53

A breakdown of the elite and national level participant data, showing sex, age, years of experience and the athlete's three highest competition score average.

aim is to achieve the highest score possible. All participants shot two simulated 60-shot air rifle competitions within 1 week according to ISSF rules and previous research procedures (10 m distance to the target, 10-min set-up, 15-min sighting time, 75-min competition time) [3]. Participants had to sight their rifles into the middle of the target as certain variables are sensitive to being centred. Then the 60-shot match commenced with a 75-min time limit [3]. The participants used an air rifle compliant with the ISSF rules. To simulate a match, all shots had to be live shots (shooting a projectile).

Athletes were required to attach their own Scatt MX-02 (SCATT Electronics LLC, Version 26 × 31 × 70 mm, Russia) or MX-W2 (SCATT Electronics LLC, Version 34 × 35 × 60 mm, Wireless system, Russia) systems to their rifle barrel using the V-shaped prism provided with the device. Either Scatt system can be used as they use the same optics. Tape on the barrel was not used as this dampens the system's sensitivity. The athletes could place the system at any level of cant (angle of the device) to the barrel's centreline. The Scatt sensor had to be set to 10 m as the proper distance is required for calibration [10].

The shooting was conducted at the participant's home range, without the authors present at the time of collection. Both trials had to be shot within 7 days to reduce training effects. The two trials were shot on different days to eliminate fatigue effects. Once shot, the participants sent the two Scatt data files via email to the authors for analysis.

2.3 Statistical analysis

2.3.1 Data extraction

The Scatt Expert software (SCATT Expert, Version 20.05.31, Computer software) was calibrated to a ballistic ratio (BR) of 30. The BR is a predictive factor within the Scatt Expert software. Its purpose is to predict how the flight of a projectile will be influenced by the rifle's movement and the shot's subsequent placement on the target due to this. A BR of 30 was an arbitrary number. To date, no research provides a suggested value for ISSF 10-m rifle shooting. 30 was chosen as it provided a Scatt Expert Score close to the athletes' three highest competition averages. The control interval on the Scatt Expert software was set to 1 s [3]. The variables highlighted in Table 2 were extracted from the Scatt expert software into Microsoft Excel (Microsoft Corporation, 2008). These variables are split into the respective components created by Lang and Zhou [3] (shown in Table 2). Variables within the Scatt Expert software manual (SCATT_MX-02S_MANUAL_ENG.cdr, 2022) that have not been placed in a component were still included in the analysis but not in a component, this includes variables in the 'shot-list tab' and variables in the 'match summary'.

Table 2 Scatt expert software variables

Component	Variable	Description
Overall performance	Shot score	Score as measured in ISSF air rifle shooting (0–654)
stability of hold	10a0 (%)	Percentage of aiming time spent inside the 10-ring drawn around the mean location of the aiming point during the last second
	10a5 (%)	Percentage of aiming time spent inside the 10.5-ring drawn around the mean location of the aiming point during the last second
Aiming accuracy	10.0 (%)	Percentage of aiming time spent inside the 10-ring during the last second
	10.5 (%)	Percentage of aiming time spent inside the 10.5-ring during the last second
Stability of triggering	D (mm)	Distance between the aiming point during the last second and breach at the triggering moment
	S1 (mm/s)	Average speed of the aiming point during the last second before the shot
	S2 (mm/s/250)	Average speed of the aiming point during the last 250 ms before the shot
Time	Aim time (s)	Aiming time spent continuously on the target before the shot
Scatt expert software	Horizontal movement (Hmm)	Horizontal distance travelled (mm) in the last second of aiming
Manual variables	Vertical movement (Vmm)	Vertical distance travelled (mm) in the last second of aiming
	Stability of aiming (mm)	The average points of aim in a 1-s interval, taken 1 s before the shot, measuring the diametral dispersion of these average aiming points
	Accuracy of aiming (mm)	The average location from all average aiming points described in the Stability of aiming variable are calculated and its distance from the centre of the target is measured
	Average shot process (s)	The average time (s) between shots during a full match duration
	Stability of time (%)	Stability of time interval between each shot (if all shots are equally spread the stability is 100%)

A list of extractable variables from the Scatt expert software. The table shows which component the variables belong to; as concluded by Lang and Zhou [3], any variable not included in a component is at the bottom of the table

All variable results are based on the complete 60-shot trial average.

2.3.2 Predictors of shot score

The assumptions of linearity, independence of scores, multivariate normality, homoscedasticity, and minimal multicollinearity were checked and verified [15–17] before running a Pearson's correlation to identify variables correlated to SS. Multicollinearity was classified as any two predictor variables with an $R > 0.80$ or a variable which increased a regression model's variance inflation factor > 10. The variable with the smallest relationship to the shot score from the two collinear variables was not used in a subsequent multiple regression model [18]. After this variable selection/reduction process, a backwards elimination multiple-linear regression using JASP software (JASP Team 2020, Version 0.14.1) was conducted to identify significant predictors of SS, therefore addressing one component of construct validity. Elite and national-level athletes were grouped, and only the first trial was used because the athlete only gets one match attempt in ISSF competitions to make the final. Significance was accepted at $p < 0.05$.

2.3.3 Discriminating skill/standard

Assumptions of normality of data and equal variance were checked using box plots and Levene's test respectively [19, 20]. Subsequently, differences between elite and national standard athletes were examined using independent samples t test (or Mann–Whitney U if assumptions were violated) using JASP software, therefore addressing the second component of construct validity. Effect size (Cohen's d) was also calculated and was interpreted against effect size categories of small ($d = 0.2$), medium ($d = 0.5$) and large ($d \geq 0.8$ [21].

2.3.4 Test–retest error

Test–retest reliability was quantified as systematic and typical error (TE) from the first and second trials of all participants using a custom-made Microsoft Excel spreadsheet [22]. Absolute measures of reliability were used to provide values for the smallest-detectable change, displaying the upper and lower error limits. To contextualise the TE, the coefficient of variation (CV) (%) was also calculated [22].

3 Results

3.1 Prediction of shot score

Eight variables were significantly correlated with SS (10a0, 10a5, 10.0, 10.5, Hmm, S2, D & Stability of Aiming (SoA)) (see Table 3). Three variables (10a5, 10.0 & S2) had significant multicollinearity and were excluded from the subsequent multiple regression analysis. The remaining variables with a significant correlation to shot score were entered into a backwards elimination multiple linear regression analysis. In the final model, only SoA significantly predicted SS ($R = 0.92$, $R^2 = 0.84$, $SEE = 0.44$, $F(1,27) = 144.276$, $p < 0.001$, $B = -5.286$, 95% $CI = -6.189$ to -4.383). The regression equation for predicting SS was as follows: $SS = (-5.286 \times SoA) + 645.926$.

3.2 Discriminators of skill level

Table 4 displays the six variables that discriminated skill level (10a0, 10a5, 10.0, 10.5, S2 & SoA). Three variables violated Levene's test (10a0, 10.5 & Average Shot Process), thus a Mann Whitney U test was performed instead.

3.3 Test–retest reliability

Table 5 displays the error values for SS (dependent variable) and all predictive variables.

4 Discussion

To test the validity of the Scatt MX-02 optoelectronic system, a model to predict SS was created, highlighting SoA as the only predictive variable. Six variables, (10a0, 10a5, 10.0, S2 and SoA) were able to discriminate elite from national standard shooters. Test–retest reliability of discriminating variables ranged from small (CV 0.72%) to very large (CV 30.61%). SoA possessed acceptable reliability (CV 13.93).

SoA has not been included in a model to predict SS in the shooting literature. Lang and Zhou [3] used the Scatt Expert software and force plate data to create a principal component model of success. The authors concluded that the five components of holding and aiming, stability of triggering, time, anterior–posterior balance, and medial–lateral balance predicted SS. Lang and Zhou's [3] principal component model predicted 83.1% of the variance in SS. In the present study, 84.2% of the variance was explained by SoA alone, which is currently not a part of any component in the previous research [3]. The regression model is not surprising as Spancken et al. [11] previously hypothesised that a smaller mean aim point area (rifle stability), coupled with better aiming accuracy (located in the centre of the target) in the last second before shot release, led to better SS. SoA encompasses both of these elements.

Differences in models of shot success between this study and previous studies could also be due to the broader range of skill levels. In Lang and Zhou's analysis [3], only elite athletes were analysed. Including both skill levels

Table 3 Pearson's correlation matrix of the scatt expert software variables

Variable	Shot score	10a0 (%)	10a5 (%)	10.0 (%)	10.5 (%)	D (mm)	S1 (mm/s)	S2 (mm/s)	Aim time (s)	Hmm	Vmm	Stability of aiming (mm)	Accuracy of aiming (mm)	Average shot process (s)
Shot score	–													
10a0 (%)	0.706***	–												
10a5 (%)	0.66***	0.821***	–											
10.0 (%)	0.694***	0.737***	0.774***	–										
10.5 (%)	0.706***	0.668***	0.811***	0.908***	–									
D (mm)	− 0.446*	− 0.582***	− 0.607***	− 0.885***	− 0.766***	–								
S1 (mm/s)	− 0.306	− 0.465*	− 0.561**	− 0.146	− 0.22	0.059	–							
S2 (mm/s)	− 0.388*	− 0.467*	− 0.535**	− 0.214	− 0.279	0.121	0.923***	–						
Aim time (s)	0.102	0.036	0.051	0.322	0.291	− 0.367*	0.214	0.029	–					
Hmm	− 0.413*	− 0.616***	− 0.585***	− 0.255	− 0.232	0.132	0.891***	0.821***	0.214	–				
Vmm	− 0.121	− 0.204	− 0.404*	0.01	− 0.15	− 0.046	0.888***	0.812***	0.185	0.586***	–			
Stability of aiming (mm)	− 0.918***	− 0.699***	− 0.653***	− 0.691***	− 0.691***	0.38*	0.302	0.394*	− 0.044	0.405*	0.128	–		
Accuracy of Aiming (mm)	− 0.023	− 0.086	− 0.088	− 0.39*	− 0.397*	0.501**	− 0.143	− 0.172	− 0.356	− 0.029	− 0.244	− 0.012	–	
Average shot process (s)	− 0.158	0.081	0.013	0.152	0.022	− 0.17	0.001	− 0.067	0.527**	− 0.056	0.062	0.158	− 0.08	–
Stability of time (%)	0.014	− 0.037	0.001	− 0.235	− 0.197	0.285	− 0.119	0.021	− 0.356	− 0.096	− 0.145	− 0.079	0.376*	− 0.643***

Results of all variables entered into a Pearson's Correlation, showing Pearson's R-values

*P ≤ 0.05, **P ≤ 0.01, ***P ≤ 0.001

Table 4 Skill level differentiation results table

Component	Variable	Elite average	National average	t	P value	Cohen's d (95% CI)
Overall performance	Shot score	627.13 ± 5.66	619.68 ± 6.17	3.10	**0.005**	1.29 (0.39, 2.16)
Stability of hold	10a0 (%)	99†	97†	135.00†	**0.007**†	0.61 (0.22, 0.83)†
	10a5 (%)	77.71 ± 8.14	65.00 ± 9.87	3.55	**0.001**	1.47 (0.56, 2.37)
Aiming accuracy	10.0 (%)	90.29 ± 9.38	81.13 ± 7.88	2.45	**0.021**	1.02 (0.15, 1.87)
	10.5 (%)	50†	35.5†	135.00†	**0.014**†	0.61 (0.22, 0.83)†
Stability of triggering	D (mm)	1.09 ± 0.29	1.24 ± 0.19	− 1.35	0.189	− 0.56 (− 1.38, 0.27)
	S1 (mm/s)	12.75 ± 2.18	14.25 ± 1.79	− 1.73	0.095	− 0.72 (− 1.55, 0.12)
	S2 (mm/s)	11.92 ± 2.30	14.03 ± 1.53	− 2.38	**0.025**	− 0.99 (− 1.83, − 0.12)
Time	Aim time (s)	12.01 ± 3.82	11.73 ± 3.53	0.18	0.859	0.08 (− 0.74, 0.89)
Scatt expert software manual variables	Horizontal movement (Hmm)	8.59 ± 1.47	9.83 ± 1.40	− 2.04	0.051	− 0.85 (− 1.69, 0.00)
	Vertical movement (Vmm)	7.61 ± 1.70	8.26 ± 1.21	− 0.99	0.334	− 0.41 (− 1.23, 0.41)
	Accuracy of aiming (mm)	0.75 ± 0.60	0.73 ± 0.32	0.12	0.903	0.05 (− 0.77, 0.87)
	Stability of aiming (mm)	3.57 ± 0.88	04.93 ± 1.25	− 3.30	**0.003**	− 1.37 (− 2.25, − 0.47)
	Average shot process (s)	51†	55†	76.5†	0.732†	0.089 (− 0.51, − 0.37)†
	Stability of time (%)	61.24 ± 20.14	65.43 ± 12.26	− 0.52	0.610	− 0.23 (− 1.08, 0.64)

Displaying the averages for both elite and national level shooters with standard deviations. This includes the effect size and p values for each variable

†Mann Whitney U test was performed, giving a median value instead of mean and standard deviation, a U value instead of a t value, and a ranked-biserial correlation instead of a Cohen's d value. Significant p values ($p < 0.05$) are in bold. 95% confidence intervals are included for all variables

Table 5 Test–retest reliability data

Component	Variable	Systematic error	Typical error	Lower error	Upper error	CV (%)
Overall performance	Shot score	− 1.00	2.90	− 3.91	1.90	0.46
Stability of hold	10a0 (%)	0.21	0.70	− 0.50	0.91	0.72
	10a5 (%)	1.38	3.73	− 2.35	5.10	4.97
Aiming accuracy	10.0 (%)	0.38	4.32	− 3.94	4.70	4.91
	10.5 (%)	− 0.90	6.66	− 7.55	5.76	14.93
Stability of triggering	D (mm)	0.00	0.10	− 0.10	0.10	9.17
	S1 (mm/s)	− 0.02	1.07	− 1.10	1.05	8.15
	S2 (mm/s)	− 0.32	1.02	− 1.34	0.71	8.30
Time	Aim time (s)	− 0.24	1.10	− 1.34	0.86	9.30
Scatt expert software	Horizontal movement (Hmm)	− 0.01	0.59	− 0.60	0.58	6.58
Manual variables	Vertical movement (Vmm)	0.01	1.00	− 0.99	1.01	12.81
	Accuracy of aiming (mm)	0.03	0.23	− 0.20	0.26	30.61
	Stability of aiming (mm)	− 0.05	0.55	− 0.59	0.50	13.93
	Average shot process (s)	− 3.96	12.28	− 16.24	8.31	22.73
	Stability of time (%)	1.39	11.13	− 9.74	12.52	17.60

The table displays reliability data for all predictive and outcome variables. This includes systematic and TE, coefficient of variation (CV) and the upper and lower combined error limits

can increase the variance in the data and reduce statistical power on some variables, such as 10a0, 10.5 and Hmm, which were all correlated with the SS, yet not significant predictors in the multiple linear regression. Considering the variance, it is unsurprising that only one variable is significant in the multiple linear regression [15]. When multiple variables are included in a multiple linear regression with high variance, the chances of making a type 2 error are increased [17]. This happens as variables with high variance have an elevated degree of error. When adding another variable into a regression model, it can claim a part of another variable's error in its prediction, therefore not explaining a significant amount of the outcome variable itself and, subsequently, not being a significant variable within the multiple linear regression model [17].

Notably, no time variables were significantly correlated with SS. This contrasts with previous research reporting athletes tend to get higher scores with greater aiming times [23]. The influence of aim time on SS has also been included in a principal component model to predict shot scores using the Scatt optoelectronic system [3]. However, only elite athletes were used, and not a mix of elite and national-level athletes. The latter has implications for predictive models as some components could be more important for elite athletes compared to lower-level athletes [2]. A Pearson correlation was previously performed and found correlations between SS and aim time with similar skill levels [24]. Nevertheless, like the current study investigating the validity of the Scatt MX-02, Ihalianen et al. [2] found no link between time variables and SS; they also used the same skill levels in their assessment. Not only are the time variables not correlated with the SS they also do not discriminate between skill levels, challenging the claim of Spanken et al. [11] that aim time could be used to discriminate skill level.

The similarity of our multiple linear regression model and that of Ihalianen et al. [2] ends with time, as their study did not have a representative variable for SoA. Their model, which used a Noptel system, also includes stability of hold variable in the X-axis, the timing of triggering (TIRE), aiming accuracy (Cog_{hit}) and cleanness of triggering (ATV). These four variables predicted 81% of shot score variance, less than SoA in our regression model using the Scatt system.

The six variables capable of discriminating skill level were 10a0, 10a5, 10.0, 10.5, S2, and SoA. Ihalainen et al. [2] also found that 10a0 and 10.0 could discriminate skill level. They used the Noptel system and did not have variables for 10a5 or 10.5. However, this study investigating the Scatt's validity indicates that these variables are helpful to include within the Noptel training system. Notably, both studies found accuracy of aiming variables to discriminate skill level. It has been demonstrated that elite athletes have better visual acuity than lower-level counterparts and better binocular vision time and hand–eye coordination [25]. With the apparent need to improve aiming accuracy to facilitate skill level improvement, future research should focus on creating training interventions to improve these variables and investigate the correlation between perception and action in this context [26].

The Hmm variable in this study was not significant ($p < 0.051$), whereas Ihalainen et al. [2] found this variable could discriminate skill level with the Noptel system. This contrast is most likely due to sample size differences, with Ihalainen et al. [2] using 40 participants in their study with more equally distributed groups. A p value of 0.051 should not be overlooked as, in the literature, an alpha of 5% is arbitrary for sports science [27]. Future research should further investigate the differences in horizontal movement between elite and non-elite athletes.

As previously mentioned, SoA was the only variable in the regression model that predicted SS, it also discriminated skill level. However, SoA had only moderate reliability with a CV of 13.93%, meaning, an athlete would have to change by this percentage in SoA between two trials to confidently conclude there is an actual change in value. Previous work has claimed good test–retest reliability at a CV of 1.2–1.8% in squash-specific fitness testing, considerably lower than this study [28]. The CV of the 30–15 fitness test also ranges between 1.5–6% and has been found to have good test–retest reliability [29]. Both previously mentioned studies have a lower CV than SoA. Yet, Hopker et al. [30] reported a CV of up to 13.1% (similar error to SoA) and claimed good reliability in recording peak power on a non-motorised treadmill. Hopker et al. [30] also demonstrate that field-based testing is not as reliable as laboratory testing, therefore, it should not be expected that a field-based test has equal test–retest reliability compared to laboratory tests. A trade-off must be made between reliability and practicality or specificity of testing [31]. Therefore, it could be suggested that SoA has adequate test–retest reliability as the Scatt MX-02 system can be used at home ranges, making it practical and specific to competition environments, more so than controlled laboratory settings. As the Noptel system has been used in most research, and in light of the error with the Scatt system, it would be interesting to examine the reliability of the Noptel system, as it has not previously been reported. Knowledge of the reliability of different systems would help practitioners decide which one is best for testing and monitoring.

There is no consensus in the literature on how to define a test as reliable, with some studies setting a CV of 5% as the cut-off for deeming a field-based test as reliable [32, 33], and others using 10% [34]. This method of a cut-off value for classifying reliability is questionable as all tests are context-specific, all studies contain error in their estimation of CV (i.e. there will be a confidence interval around the point estimate), and the TE should be interpreted against the smallest worthwhile change to judge if the test is capable of detecting a meaningful change amidst the test–retest noise [35]. Therefore, future research needs to investigate the smallest worthwhile change in variables within the Scatt Expert software and compare them against the TE values to contextualise the error data further. Nevertheless, knowing the TE and CV of the variable SoA will help practitioners estimate sample sizes and will also aid practitioners in interpreting their own SoA data [22].

The Scatt Expert software offers other avenues of analysis; for example, the trace (visually represented aiming trajectory), showing where an athlete is aiming at a given time, showing patterns not captured by the variables such as pulse (heart rate) into the rifle or dropping under the 10-ring on the descent through the target. Dropping under the 10-ring can be an issue as this requires the athlete to work against gravity to push the rifle back onto the centre of the target. Increases in muscle activation have been linked with decreases in stability of hold [36]. Lifting back into the 10-ring is a pattern of movement not captured in the predictive variables. Thus, this visual form of data capture allows a coach to interpret the shot process and make technical changes to improve the athlete's performance whilst also giving context to the predictive variables. Future research should also investigate this more subjective use of the Scatt optoelectronic system and how it can be utilised.

4.1 Limitations

The data in this study was not collected in a controlled environment like a laboratory setting. It could be argued that using athletes' home ranges is more related to the environments the participants are competing in, reducing ecological differences between laboratory settings to shooting ranges. Laboratories could increase/vary cognitive load compared to using a shooting range for those unfamiliar with shooting in laboratory settings, thus resulting in a less representative study design for testing athletes [37]. However, more errors could be brought into the data due to slight procedural differences, such as different interpretations of written instructions, facilities, and equipment. However, these cannot always be managed in the real world; therefore, this study design is indicative of actual shooting performance.

This study uses a BR of 30 as an arbitrary value to standardise all participant's levels of Scatt sensitivity. No previous research has investigated the best BR to analyse Scatt expert data. This questions whether the variables show a likeness to the actual shooting. When BR is lowered, variables in the Scatt expert software, such as 10a0, 10a5, and D, become less sensitive to the rifle movements' effects on the projectile's trajectory. For example, if an athlete has a 10a0 of 95% at a BR of 30, they could score 100% with a BR of 0. However, a BR of 0 has a small probability of representing actual shooting. Additionally, the BR could influence the reliability of variables i.e., 10a0 has a low TE, and the range of scores within 10a0 is meagre due to being at the scale limit (98.67% out of 100%). Increasing the BR would most likely lower the average score for 10a0 and allow for more varied results, which could increase the TE. A future study needs to investigate the best BR to represent actual shooting for each discipline of ISSF accurately, allowing for better interpretations of variables. Once an accurately representing BR is found which as accurately as possible represents the actual shot score, a study should be conducted to examine the criterion validity of the Scatt MX-02 system score compared to an ISSF-certified electronic target, so coaches are informed of the scoring error of the Scatt and what could be expected on an actual scoring system.

It is recommended that future Scatt Expert versions move away from using percentages for 10a0 and 10a5. A percentage scale has a limit (100%) and is not sensitive enough to detect a change in athletes who scored 100%. Instead, using millimetres could increase the accuracy of recordings, providing a score not relative to the size of the 10-ring. A different approach using absolute values would highlight how much smaller the athlete's hold diameter is against the 10-ring diameter.

In this study, elite and national-level athletes were included in the regression analysis and the error calculations could be influenced by smaller participant numbers compared to previous studies. Ihalainen et al. [2] varied regression models between skill levels, with different predictors involved in a model, or the same predictors having varying importance. For example, DevY in Ihalainen et al.'s study was a better predictor of SS in the national level athletes than the elite athletes. It is unclear if similar trends would have occurred in this study as all athletes were grouped. The requirement for different and more specific models could arise between the sexes. While there are no sex differences in competition scores [14], this does not mean that both sexes get the same result the same way. Future research should investigate the differences in regression models for elite and national-level athletes and examine the differences between men and women, helping coaches be more specific with training interventions.

This research has the unique disadvantage of having a large sample of elite athletes compared with national-level athletes, meaning the linear regression is biased toward elite athletes. This bias can affect t-test inferences as having unequal sample size groups with unequal variance leads to increased chances of type 1 or 2 errors [38]. In this study, 10a0, 10.5, and Average shot processes all have unequal sample sizes and unequal variance. Hence, the results of these test should be interpreted with caution and interpreted in line with previous research.

Athletes could use either the Scatt MX-02 or W2 systems in this study. Both systems use the same optics for capturing information. However, no previous research has compared the agreement between the systems. For this reason, it is unknown if this has affected the data in this study and is, thereby, a limitation. This study also did not control for the use of two different Scatt systems used for both trials for the same athlete. Again, the accuracy of multiple Scatt devices of the same model, and if there is any calibration error between devices, is not known.

This study is the first to use athletes from different countries, with other studies focused on populations from one country [2, 3]. Countries can have various technical preferences, ideologies, and focuses when training their athletes

[39]. This is clear as some athletes enter the target from varying positions, from the top, bottom and even side when approaching the 10-ring. The wide variation in techniques could influence the variance in the data. It would be interesting for future research to identify the differences in methods between elite athletes and see what typical fundamental principles elite athletes adhere to.

5 Conclusion

This study aimed to investigate the construct validity and reliability of the Scatt MX-02 optoelectronic training system. SoA was found to significantly predict SS and discriminate between elite and national-level shooters. Practitioners should lower the importance they place on variables that do not predict performance and which cannot discriminate skill level. Practitioners should be aware when monitoring the SoA variable day-to-day that there is a sizeable TE, and observed change should be interpreted against the test–retest error. Future research should attempt to highlight the smallest worthwhile change of the Scatt Expert variables and further investigate this device for longitudinal use considering the reported test–retest error. Nevertheless, the results suggest that the Scatt MX-02 paired with the Scatt Expert software has construct validity when analysing the variable SoA. SoA in this study had a TE of 0.55 mm, and a CV of 13.93%. The test–retest reliability data is provided so practitioners can interpret their results in light of the measurement error when testing elite and national-level ISSF air rifle athletes. The measurement error data can also be used to inform estimates of the required sample size to power future intervention studies and as a guide to the smallest-detectable change.

Author contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Jack Bale. The first draft of the manuscript was written by Jack Bale and Mick Wilkinson commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data Availability Data is available upon request.

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

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