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Quality Requirements for Front and Rear Support in Relation to the Precision of a Bolt Action, Big Calibre Precision Rifle

The aim of our study was to identify which support conditions result in producing the best accuracy with a bolt action, large calibre firearm, even over long distances. Precision is the feature that shows how closely impact points are grouped relative to each other.[3] According to Litz, precision is primarily determined by non-deterministic coefficients. He also states that the choice of the right equipment is primarily aimed at reducing the uncertainties of the shooter as much as possible. He says: "The challenge is if the shooter wants to use the same equipment for different purposes, because then the shooter has to make compromises."

In our study, a total of 11 different front and rear support combinations were tested. For each method, we varied weapon support strategies and surfaces. We fired five shots with each method and investigated the precision, weapon displacement characteristics, and the group of shots as a putative determinant of precision. The data obtained showed significant variation in the precision of each method. There was also a significant difference in the values of the recoil length and the post-firing backward slide of the shot. The rear support was a combination of a rice bag and a gripped monopod, or a rear eared shooting bag. In terms of retention, both sliding and controlled handling were effective as compared with a pinched grip.

Keywords: **precision shooting, long-range shooting, precision, bolt action rifle, support methods**

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3 Bryan Litz: Scope Tracking: Tall Target Test. Applied Ballistics with Bryan Litz. *YouTube,* 12 June 2015.

1. Literature review

The main aim of group-shot shooting in F-Class competitions is precision, i.e. to achieve the narrowest possible groups of hits. In this type of competition, shooters shoot in prone position, usually at distances of 300 m, 600 m and 1,000 m. As Simonyi writes: "In this style, excellent individual shooting technique, excellent wind-reading ability, good quality rifle, ammunition and scope are very important."[4] Of course, it is also important that the group is as close as possible to the centre of the target area. In addition to the above said, precision is a basic requirement for tactical sniping competitions. These competitions, however, lay down rules for the use of support equipment.

To support their weapons, shooters can use front, rear and centre support variations. Single-point support is not very effective for high accuracy, and therefore, the methods of fixation used on tripods are not utilised in such competitions and will thus not be addressed in this study. In most competitions, the use of two-point support is a permitted method, with bipods at the front and shooting bags at the rear being the most common. In some competitions, the use of monopods at the rear is allowed, but this may result in a reclassification. Precision is part of the so-called "monopod" PRS *(Precision Rifle Series)* competitions, but not as much as in the F-Class competition series. PRS competitions are, by their nature, more liberal in their approach to support, as the aim in this series is primarily to hit metal targets in different time frames, positions and from various objects at known and unknown distances. Competitors may use two or one support, gun straps, shooting bags, etc. However, precision is not as important in PRS competitions. Instead, the ability to read the elements (mainly the wind) or the speed and stability of the shooting position are more crucial.

2. Methods

2.1. Protocol

In this study, we will look at the most common double (front and rear) supports used in most competition situations. As the main objective is to understand the mechanism of operation and features of these devices, we will try to minimise all other influencing factors. There are two main groups of factors to be considered that can significantly influence the final result. The *weather factors* and the so-called shooting errors *that the shooter can make*.

Of all the weather factors, *wind has* the greatest impact on the projectile. This effect was minimised by conducting the tests at a wind-protected firing range. Additionally,

[4] Ottó Simonyi: *A mesterlövész. Vadászatról és sportlövészetről* [The Sniper. About Hunting and Sport Shooting]. Vác, Cyberkinetic Kft., 2021.

we tried to minimise shooting error by utilising an experienced shooter, who worked out each shot and executed the shot to the best of his or her ability. During the execution, the shooter payed great attention to the best possible "natural point of aim", i.e. where the crosshairs of the scope end up when the shooter is in a relaxed state in his/her shooting position. It is the place where the crosshairs will rest for a short period in his/her natural respiratory pause.[5] In general, this is an important firing rule because if the shooter applies force to the barrel or grip with the shoulder or the palm of the firing hand in order to keep the centre of the crosshairs on the target, the barrel of the gun will be off the target at the moment of firing and the bullet will no longer be pointing at the target during its stay in the barrel and at the moment of exit. The other important criterion was the firing process established by the shooter. In the firing process, the shooter pressed the two-stage trigger (having a resistance of ~0.6–0.7 kg) which was pulled in a gentle manner, with a long forward stroke, until the action was smooth and even. The accuracy of the firing process was taken high level by the shooter using a pre-test, post-test method of checking that the crosshairs did not move off target during dry firing.

To ensure the most harmonious and accurate interaction between ammunition and barrel, we used loaded ammunition (with carefully selected and grouped components) rather than factory ammunition for the greatest consistency as described in the literature. The primary parameter for this consistency was to minimise muzzle velocity dispersion and optimise tube vibration harmony. Therefore, a precisely measured, bullet seating depth, the so-called "jam point", i.e. the rise point where the projectile touches the rifling, was set at minus 0.002 inch, or 0.05 mm, of the total L6 ammunition length (by C.I.P. regulations).[6] The Hornady 147 grains (9.52 g) projectile (2.64 inch – 6.71 mm diameter), which has one of the highest ballistic coefficients (BC: G7 = 0.697) in its category, was designed to achieve the factory-specified velocity at 15 °C (822 m/s). The projectiles were grouped by weight in hundredths of milligrains and the brasses were categorised by H_2O, grain cubic content for maximum accuracy. For consistent extraction force, we used "fire-formed" Hornady Creedmoor brasses already fired, i.e. formed to the chamber, the case neck was *annealed* by an induction annealer machine, the length was adjusted (trimmed to uniformity), and the neck was lined. The primer hole was cleaned, standardised, and *large primary* ignition was applied using CCI 250 *boxer* primers.

In the evaluation, we sought economy, accuracy and applicability. Using predefined and pre-set support variations, we shoot 5–5 bullets at circular paper targets. Fewer shots than this, are not suitable for determining accuracy.[7]

[5] See www.longrangeshooting.org/articles/natural-point-of-aim

[6] Gunmakers' Company and The Guardians of the Birmingham Proof House: *Rules, Regulations and Scales Applicable to the Proof of Small Arms.* London, 2006.

[7] RocketmanOU: *Statistics, Shooting and the Myth of the Three Shot Group.* 2020.

2.2. Target cards, precision assessment

The main objective was to assess precision, so we did not focus on ballistic deviations. We used targets with a white centre made by Swiss Arms, in the classic size of 14 × 14 cm, compatible with a classic catcher. These targets are made of thicker paper for better stability in the catcher. The diameter of the white centre is 17 mm. We fired with a predefined elevation value, set by loading and fixing the tactical turrets of the scopes. The scope's tactical turret "ladder test" *(Tall Target Test),*[8] which is used to verify the accuracy of the clicks or elevation showed that the accuracy of the 300 m ballistic elevation of the turret was 100%.

Aiming at the centre of the circular target, the main objective was "group shooting". The sizes of the groups were measured in "Minutes of Angle" or MOA, the most commonly used angle measuring unit in precision shooting. The so-called "Extreme Spread" (ES) value evaluation method, which calculates precision based on the distance between the farthest hits of a given group of hits, was disregarded[9] although this evaluation is also presented, as it is the most commonly used evaluation method in shooting circles.

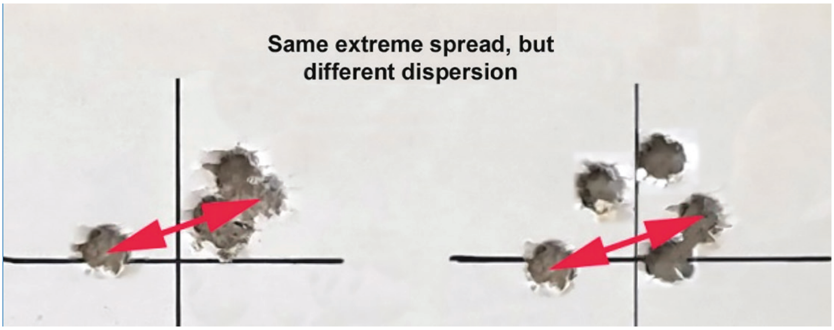

Figure 1: We have disregarded the so-called "Extreme Spread" (ES) value evaluation method, which calculates precision based on the distance between the furthest hits in a given hit group
Source: Compiled by the author.

A valid evaluation method for precision is the "Mean Radius" or "Average to Centre" method, which not only calculates the accuracy based on the distance between two points, but also uses the information contained in all the points in the group to determine the accuracy of the rifle, ammunition or support used. The average radius gives the possibility to determine the quality of dispersion with fewer shots.[10]

8 Litz (2015): op. cit.
9 Cal Zant: Works Cited for Statistics for Shooters Articles. *Precision Rifle Blog,* 2020.
10 Guns and Ammo: *Long Range Shooting: Understanding Extreme Spread and Standard Deviation.* 05 September 2018.

2.3. Post-shot target assessment

An effective way to assess possible shooting errors, as well as the supports and surfaces is to analyse the evaluation shot after shot.

The two components of this are the direction of the bounce of the crosshair's centre and the distance (position) of its impact relative to the centre of the target.

After each shot, the direction and distance (described in the study as the displacement "force") were recorded. The direction was given by marking whole clock directions, and the displacement force was defined on a scale of 0–20 where one unit represented an angular displacement of approximately 0.2 MOA (~0.06 mil), which is a displacement of 1.75 cm relative to the midpoint over the 300 m distance.

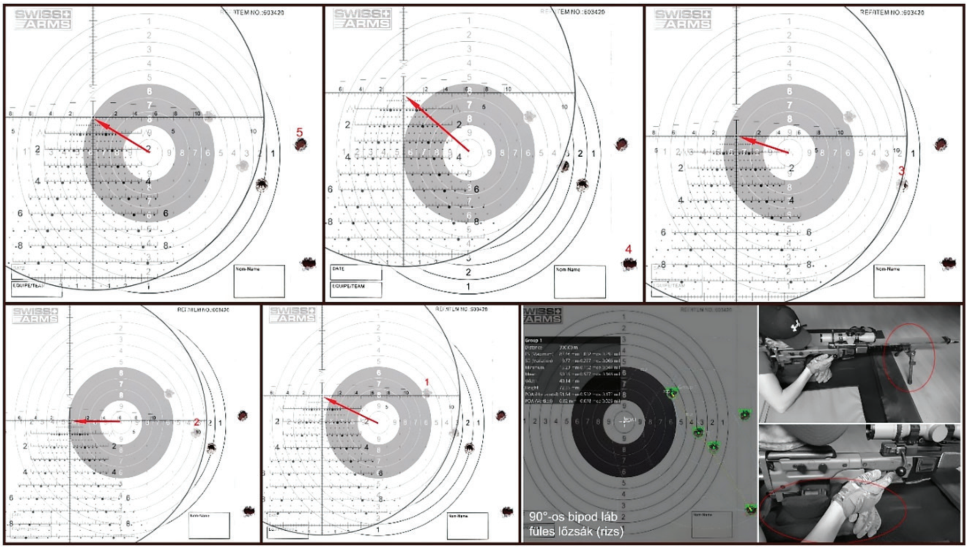

Figure 2: Evolution of the shot image after each shot in relation with the centre of the crosshairs and the centre of the target area – calculation method (1 unit of displacement = 1.75 cm at 300 m, or 0.2 MOA, or ~0.06 mil)

Note: The size of the crosshairs is only an illustration, slightly reduced compared to the size of the target.

Source: Compiled by the author.

2.4. Tools used

The study focuses on the use of a single calibre, the 6.5 Creedmoor. With other calibres the recoil force may be different. The recoil forces are accurately given by the Gordon Reloading Tool (GRT) in Joules for ammunition loaded with the given components. In our case, the recoil energy was 7 Joules. The weight of the weapon was 8 kg.

The first support was an Atlas style LRA Light Tactical Bipod. Dimensions: leg length: 21–29 cm, support span: 30–37.5 cm, tilt angles: 0°, 22°, 45°, 90°, weight: 0.8 kg.

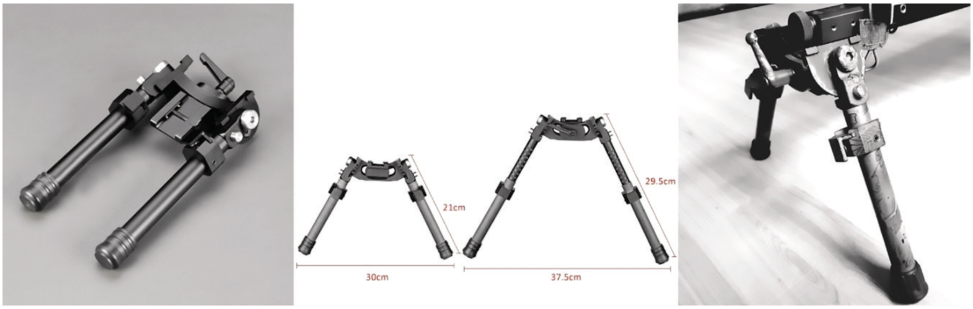

Figure 3: Atlas style LRA Light Tactical Bipod front support – hard rubber foot end plug (dimensions: leg length: 21–29cm, support span: 30–37.5cm, tilt angles: 0°, 22°, 45°, 90°, weight: 0.8kg)
Source: Compiled by the author.

The tools used for the back support included: rice-filled standard shooting bag (dimensions: 15 × 15 × 5 cm, weight: 0.5 kg), PET granulate filled rear eared bag (dimensions: 18 × 11 × 11 cm, weight 1.25 kg), Accu-Shot Accuracy International AT Monopod BT57-QK, lifting height 7.5–10.5 cm.

Figure 4: Cser Industries rear ear bag (PET granulate filled), standard rice shooting bag, BT57-QK: Accu-Shot Accuracy International AT Monopod (from left to right)
Source: Compiled by the author.

The adjustable butt plate used in the study was an Accuracy International rubber butt end combined with a Canadian made 4-way-adjustable butt end bracket with original AI rubber butt plate.

Figure 5: Adjustable butt plate – Accuracy International rubber butt end and a 4-way-adjustable butt plate bracket from a Canadian manufacturer
Source: Compiled by the author.

The footage was recorded with a high-speed video camera at 960 frames per second in 1080p quality, triggered by motion detection software and stopped after 0.4 seconds. The camera used was the high performance camera of a Samsung 9 Plus phone. This recording speed allows for a time of 0.00104 s, which is suitable for recording the movement of the barrel while the bullet is in the bore.

Camera placement took into account a slight wide angle of view, which was corrected in software. Regardless of this, the camera was placed as far away from the barrel of the gun as possible, so that it was in the same place and at the same height. A reference frame with mm-precision scale was placed behind the barrel, fixed firmly so that it would not be displaced by the shock wave generated by the muzzle break. From the resulting images, we were able to determine the horizontal and vertical displacements to an accuracy of 0.5 mm.

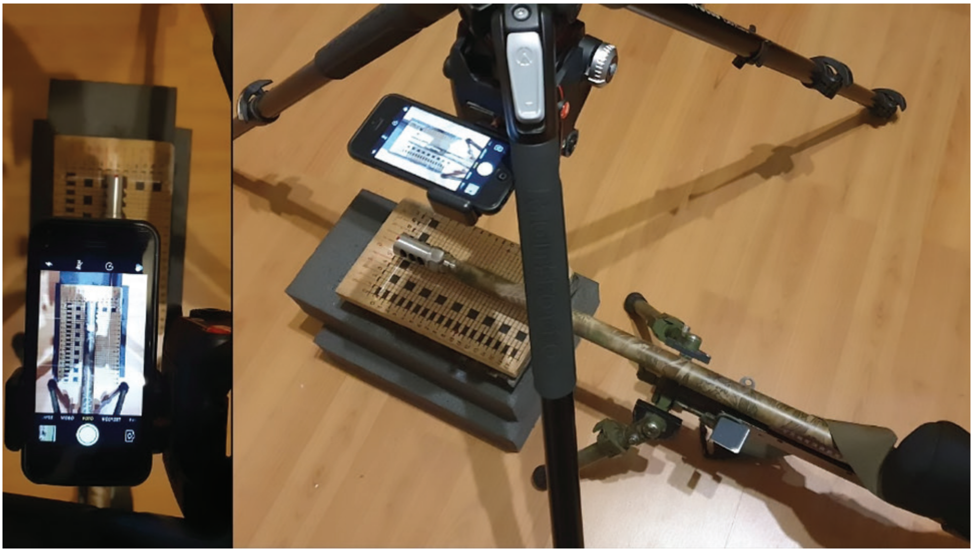

Figure 6: Measuring the recoil distance with a high-speed camera
Source: Compiled by the author.

For lateral displacements towards the barrel mouth or muzzle break, a camera with a vertically oriented downward field of view mounted on a tripod was placed with the aforementioned parameters and reference grid.

The projectile velocities were measured with a Magnetospeed magnetic projectile velocity meter, which was not mounted on the barrel but on the forestock, so as not to affect the barrel vibrations in the swinging barrel design. The system software of Magnetospeed software version number 3.0.3.

The shots were fired at 5 °C with 5 °C gunpowder.

The time of the projectile in the barrel at the above mentioned loading values – *Optimal Barrel Time (OBT)* was 1.3084 ms (0.001308s).

Table 1: The weapon system

Make of weapon	Accuracy International Arctic Warfare 2012 English made sniper rifle (England, Portsmouth)
Tube and calibre	Proof Barrel, 6.5 Creedmoor, 24" inch long, for Accuracy International
Chamber	Factory CIP Chamber
Riflescope	Schmidt & Bender, Ultra Short 5–20 × 50, Tremor 2 reticle
Trigger force	7N (0.7kg)
Ammunition used	loaded, jam point –0.002 inch long L6 value, fire formed, standardised Hornady case, Hornady 147 grn ELD Match bullet
Applied gunpowder	Vihtavouri 555, 42.2 grn
Applied primers	CCI 250 large

Source: Compiled by the author.

Figure 7: Accuracy International Arctic Warfare 2012 English sniper rifle (England, Portsmouth)
Source: Compiled by the author.

Figure 8: Hornady 147grn ELD Match projectile
Source: https://proshooting.hu/termekkepek/800/hornady-eld-match-65-mm-147-gr-lovedek15430990370.jpg

Table 2: Environmental conditions

Distance	300 m
Objective	circular paper target
Target area zones	target area diameter 17 mm, target sphere 0.05 mil (15 mm with 15 mm masking)
Wind	0 m/s
Air pressure	1001 hPa
Moisture content	52%
Firing direction	131 degrees
Altitude above sea level	129 m

Source: Compiled by the author.

Theoretical values: The theoretical data was obtained using the Gordon Reloading Tool (Patreon Nightly ver. 18.55) software for loading ammunition.

Shooting conditions, supports, surfaces used: The support, gun grip and recoil damping parameters that were varied as a part of the experimental methods were divided into the following categories:

Support forms

- Front supports
  - conventional bipod with rubber bung feet with variable foot angles
  - rice filled barricade bag
- Rear supports
  - a rice filled standard rear bag
  - plastic (PET) granulate filled rear eared bag
  - tilting monopod (forward tilting system)
- Weapon holding
  - gripped
  - controlled
  - permissive (way giving)
- Supporting base surface
  - hard
  - absorbing
- Recoil absorption
  - compensated with muzzle break
  - non-compensated

Detailed description

- Methods of weapon holding
  - In the so-called "gripped" method of weapon holding, the shooter pulls the weapon into the shoulder and applies pressure through the butt end. The grip is held either by a full grip (with the thumb wrapped around it) or by extending the thumb forward on the side of the gun, with the other fingers holding the grip firmly. The cheekbone rests on the cheekpiece, supporting all or part of the weight of the head, ensuring a consistent cheekbone

position that returns to the same position, creating the identity of the sighting in the scope. The recoil exerts an immediate or near-instant force on the shoulder, stopping the glide.
  - The case of "controlled" gun grip is similar to the gripped method, but in this case the shooter allows the gun to move slightly, but keeps it under control with the grip hand. The thumb is extended forward above the trigger guard to support and "control" the pre-firing position of the weapon as well as the glide during recoil. The shoulder is not pressed firmly against the butt.
  - The "permissive" handling of weapons. In this method, the shooter does not apply any pressure to the butt end of the rifle, thus ensures vibration-free aiming and the possibility of the weapon sliding backwards. The cheekbone is not pressed against the adjustable cheekpiece, which also reduces any vibration that may occur during aiming, but reduces the possibility of consistent head aligning and target view development. With this method, a complete "clear" sight picture ensures targeting identity. The pistol grip is not tightly held.
- Methods used for the support surface of the weapon
  - *Support on hard surfaces.* In this study, the bipod was supported on concrete for hard surfaces. In one case, the monopod was used as a back support on Orca fabric placed on concrete for its retained shape, which was treated as a solid surface given the thinness of the material. The solid wood base was not used in the study.
  - *Support on a vibration absorbing surface.* In this study, vibration absorbing surfaces were used under the front support in two cases. In the first test, a 4 kg Cser Barricade Bag filled with plastic PET granules was utilised. In the second test, a 12 × 6 × 1.5 cm bag filled with sand integrated into a 30 × 60 × 3 cm recortan sheet was placed under the bipod feet (Figure 9). In one rear support test, as mentioned in Figure 2, no vibration absorbing support was used. The rear bag was filled with plastic PET granules and the conventional bag was filled with rice.

Figure 9: Bipod feet placed on sand bags integrated in a recortan sheet
Source: Compiled by the author.

- Gun recoil absorption methods
  - With muzzle break. The recoil damping was solved with the Gen 2 Little B* Self Timing Muzzle Break (Figure 10) developed by American Precision Arms, which provides world-leading damping and target return for the calibre.[11] According to Simonyi, a muzzle brake is suitable for a given calibre if it has a positive effect on the gun's rate of displacement and the amount of projectile dispersion. He describes the advantages of using a muzzle brake as "useful because it reduces recoil, improves the scatter pattern and makes the hit observable in the scope".[12]
  - Without muzzle break.
  - A tilt-absorbed backward-sliding force, whereby the bipod moves backward around the anchor points of the legs as axes of the weapon system. This tilt is bipod dependent. Bipod legs left loose will tilt or "slacken" during the recoil while legs turned with tight tolerances will allow little tilt and will compensate by sliding the legs. Bipod legs tilted at 90° are more likely to compensate by tipping, due to the longer lever arm, than bipod legs tilted at 45°. 45° tilted bipod legs compensate for both pitching and sliding. Also by tilting, the recoil force is reduced for rear supports by angled, hand-held monopods. These have the advantage of holding the target quickly, but the tilting makes it more likely that the end of the barrel will be off target during the shot while the projectile is in the barrel.
  - Slip-absorbed forces are released by the recoil of the weapon system, giving the barrel a better chance of staying level. Such methods include the sled-solved base of F-Class bipods, or the heavier F-Class rest, which allow the front part of the stock to slide in the U shape top of the rest, resulting in frontal upsets. As for the rear supports, the various bunny-ear rear bags and brackets, of differing effects depending on the design, serve the same purpose. Their efficiency can be increased by using the so-called "bumper brackets". The effectiveness of these devices can be increased by the use of "bag riders", which are tubes or rails mounted on the bottom of the gun butt and which fit precisely into the cavity provided by the eared bag, thus facilitating the retention of the rider's position. The AIAW system allows the folded, fixed monopod (Accu-Shot Accuracy International BT57-QK) to function as a "bag rider" when using an eared bag (Figure 2).

Figure 10: Gen 2 Little B Self Timing Muzzle Break developed by American Precision Arms*
Source: www.americanprecisionarms.com/products/gen-2-little-bastard-muzzle-brake

[11] Cal Zant: Muzzle Brake: Summary of Field Test Results. *Precision Rifle Blog,* 21 August 2015.
[12] Simonyi (2021): op. cit.

Combined methods used

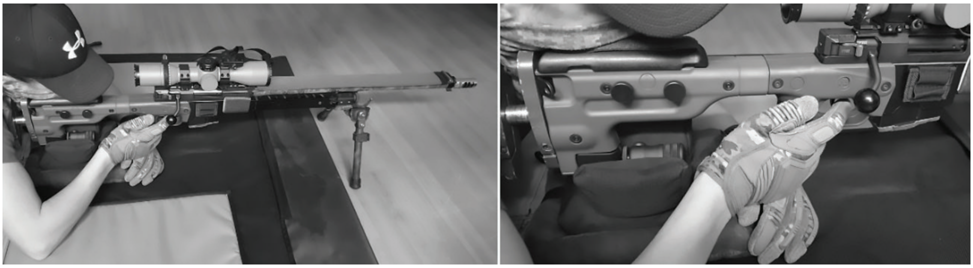

Figure 11: Method No. 1 – Front support (standard tactical bipod, 90°, resting on concrete surface – hard rubber foot end plug). Rear support (horizontal monopod resting on a tabbed rice bag – passive, support hand for gripping and regulating the eared rearbag).
Source: Compiled by the author.

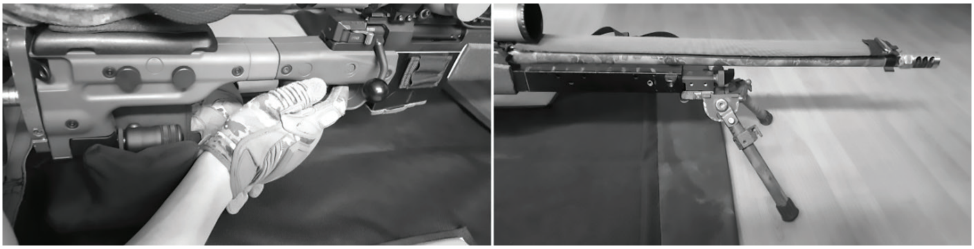

Figure 12: Methods No. 2 – No. 3 – The second and third shooting positions and support conditions are identical. Two control strategies. No. 2: Gun left in slide (shooter leaves recoil, does not support against the shoulder). No. 3: Controlled supported weapon (shooter, with the butt slightly rotated and elevated, adjusted to his/her shoulder, supports the recoil with his/her shoulder, tracing the recoil, transforming its energy to his/her shoulder). Front support (standard tactical bipod 45° foot, resting on concrete surface – hard rubber leg end plug). Rear support (horizontal monopod resting on an eared bag – support adjusted by hand).
Source: Compiled by the author.

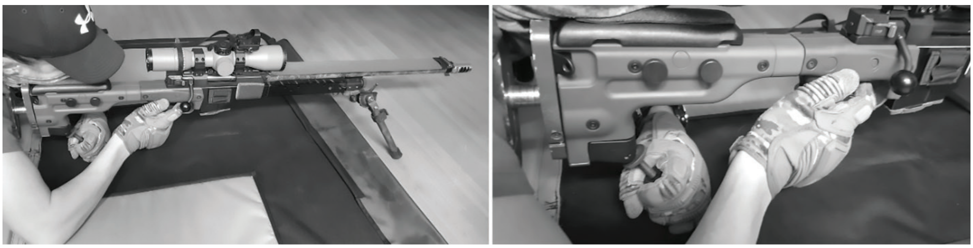

Figure 13: Method No. 4 – Front support (standard tactical bipod, 45° leg angle, resting on concrete surface – hard rubber leg end plug). Rear support (tilted, passive support resting on wooden surface, manually gripped and controlled monopod – recoil force absorbed by tilting).
Source: Compiled by the author.

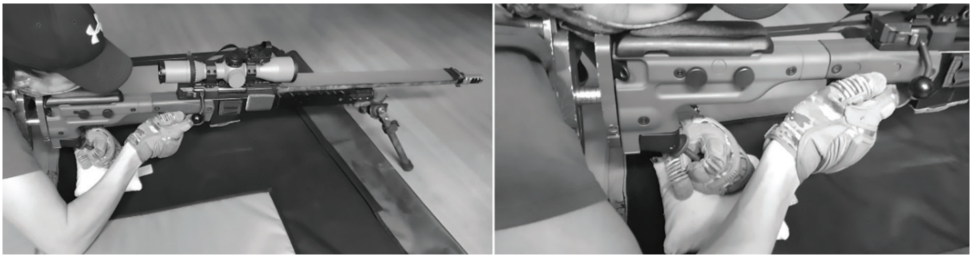

Figure 14: Method No. 5 – Front support (standard tactical bipod, 45° leg angle, resting on concrete surface – hard rubber leg end plug). Rear support (tilted, passive support resting on rice filled rear bag, manually gripped and controlled monopod – recoil force absorbed by tilting).
Source: Compiled by the author.

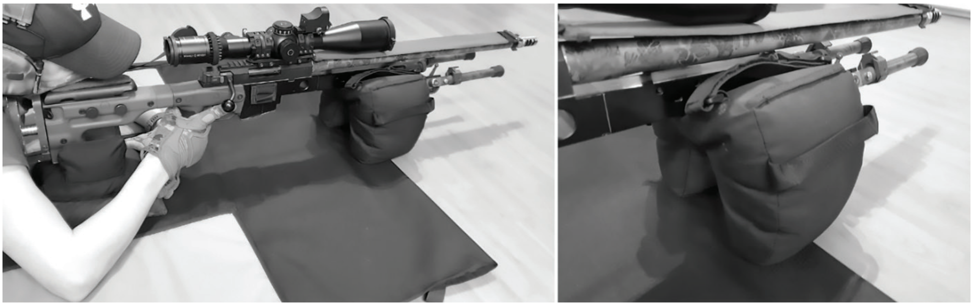

Figure 15: Method No. 6 – Front support (Barricade Bag [~4kg] filled with plastic granules from Cser Ind.). Rear support (eared bag).
Source: Compiled by the author.

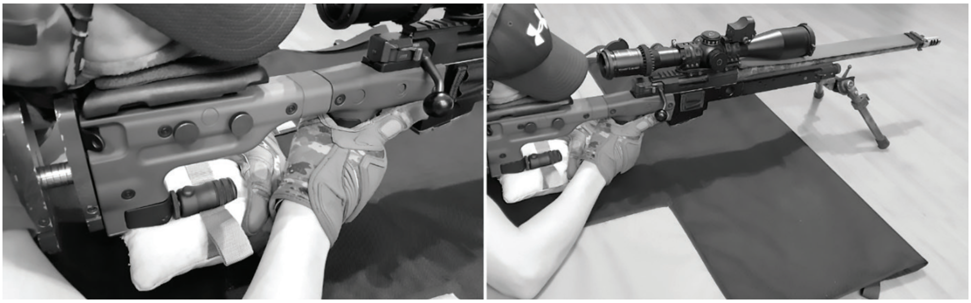

Figure 16: Method No. 7 – Front support (standard tactical bipod, 45° leg angle, resting on concrete surface – hard rubber leg end plug). Rear support (rice filled standard rear bag).
Source: Compiled by the author.

Figure 17: Method No. 8 – Without muzzle break. Front support (standard tactical bipod, 45° leg angle resting on concrete surface – hard rubber leg end plug). Rear support (tilted, passive support resting on a rice-filled rear eared bag, hand-controlled monopod).
Source: Compiled by the author.

Figure 18: Method No. 9 – Without muzzle break. Front support (standard tactical bipod, 45° leg angle, legs resting on sand-filled neoprene bags). Rear support (tilted, passive support resting on eared bag, hand-controlled monopod).
Source: Compiled by the author.

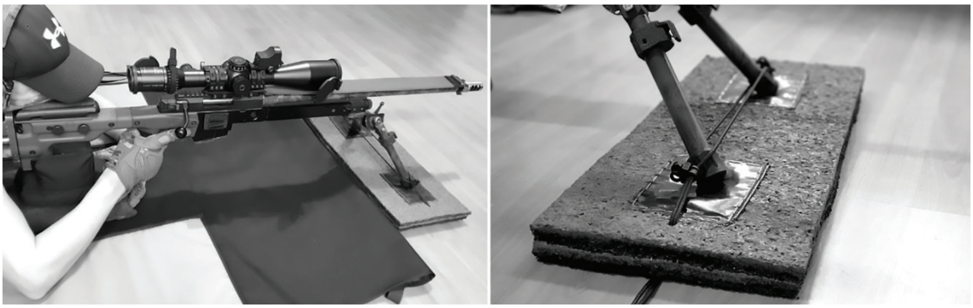

Figure 19: Methods No. 10 and No. 11 – The tenth and eleventh shooting positions and supporting conditions are identical. Two control strategies. No. 10: Gun left in slide (shooter leaves recoil, does not support against the shooter). No. 11: Controlled supported weapon (shooter, with the butt end slightly rotated and elevated, adjusted to his/her shoulder, supports the recoil with his/her shoulder, tracing the recoil, catching its energy with his/her shoulder). Front support (standard tactical bipod, 45° leg angle, feet cut and fitted into recortan base, resting on 2 cm deep sand pads). Rear support (rear eared bag).
Source: Compiled by the author.

Statistical procedures used: The results were analysed using Statistica 8.0 software.

Comparisons were made using one-sample T-tests and Pearson correlation. The probability coefficient was set at $p < 0.05$.

3. Hypothesis

1. We hypothesise that shots fired with one calibre using different supports and different gun grip methods will show significant variation in accuracy when fired by one shooter.
2. rom the methods chosen, those that give the most accurate spread patterns are those that ensure the smallest barrel movements in all directions during the time the projectile is in the barrel. We hypothesise that the support methods that best meet this criterion are those that absorb the recoil force by back-slip rather than by tilting.
3. We assume that the follow up view after the shot is a good indicator of accuracy. The shorter the distance of the jump from the target and the more uniform the direction, the smaller the spread of hits will be.
4. We hypothesise that the second most accurate results will be obtained by firing a bipod on a vibration absorbing surface, with the possibility of the bipod legs slipping during displacement.
5. It is assumed that the least accurate results are obtained by firing a bipod on solid ground with a tilting bipod.

4. Results

4.1. Evaluation of precision and accuracy

All tests resulted in two measurable parameters. First, the mean radius of group shots, which represented the *precision,* in other words the distance of the hits to each other, i.e. the spread. We also calculated the diameter of the resulting pattern for better clarity. This data is more important for the evaluation of the supports or the shooting errors. We also examined the ES, or extreme spread (MOA, [minutes of *angle*], degrees). This data measured the distance between the two hits furthest apart for a given image. This data set does not always characterise the group, since this data can include anomalies due to a single miss or a target hit that may be far from the shot group due to a defective projectile or charge or a change in bullet velocity. In the English literature, these anomalies are called a "flyer", which degrades the characteristics of the group, even though the shooter does not make a shooting error.[13]

The second measurement determined in this study is *accuracy,* which is the closeness of the average shot of the group to the target centre. This feature is

[13] Cal Zant: Works Cited for Statistics for Shooters Articles. *Precision Rifle Blog,* 2020.

characterised by two parameters. The first was the number of scores scored and the second was the distance (mm) from the target centre of the group.

Table 3: Determination of the precision by spread images, with applied supporting methods, using extreme spread ES, standard variations SD, Mean Radius MR, Mean Radius × 2 MR2, and extreme spread vs mean radius2× ES vs MR × 2 methods in MOA
*Note: *** best value, ** second best, * third best value*

No.	Description of methods	Front support style-tilting (b), sliding (cs)	Rear support style tilting (b), sliding (cs)	ES Extreme Spread	SD variation	Mean Radius	Mean Radius × 2	ES vs MR × 2
				(MOA)	(MOA)	(MOA)	(MOA)	(MOA)
1	90° bipod, ear bag	b	cs	1.002	0.227	0.294*	0.588*	0.41
2	45° bipod, ear bag, permissive handling	b/cs	cs	0.753**	0.178	0.302	0.604	0.146*
3	45° bipod, eared bag controlled	b/cs	cs	0.933	0.22	0.288**	0.576**	0.356
4	45° bipod, mo-nopod resting on wooden surface	b/cs	b	0.924	0.127***	0.393	0.786	0.137***
5	45° bipod, mono-pod on rice bag	b/cs	b	0.697***	0.17*	0.252***	0.504***	0.193
6	barricade bag, ear bag	cs	cs	1.007	0.283	0.378	0.756	0.248
7	45° bipod, rice bag	b/cs	cs	1.134	0.313	*0.416*	0.832	0.301
8	45° bipod, wit-hout muzzle brake, eared bag	b/cs	cs	*1.329*	0.286	0.378	0.756	0.563
9	45° bipod on sand bag without muzzle brake, eared bag	b/cs	cs	1.183	0.278	0.322	0.644	0.538
10	45° bipod, re-cortan base, ear bag permissive holding	b/cs	cs	0.866	0.172	0.3	0.6	0.268
11	45° bipod, recor-tan base, ear bag, gripped holding	b/cs	cs	0.759*	0.158**	0.311	0.622	0.138**

Source: Compiled by the author.

According to the results, the support variation with the best effect on precision, based on Extreme Spread (ES) calculations, was a 45° bipod and monopod on standard rice bag support combination which resulted in a 0.697 MOA spread (Table 3). The second best support variation was the 45° bipod combined with an ear bag, with permissive handling (weapon left sliding [not shouldered]). This combination resulted in a slightly better ES value compared to the third best variation which consisted of the ear bag with gripped handling (weapon shouldered), combined with the 45° bipod on sandbags integrated into a recortan base. All three support variations had a 45° tilted leg bipod as the first elevation. The highest ES value was shown by the 45° bipod, no pipe mouth support variation with a value of 0.1329 MOA.

The way of measurement that best indicates precision[14] is the Mean Radius (MR) method. With this evaluation method, the best support variation was the 45° bipod combined with a monopod on rice bags which resulted in a spread of 0.252 MOA (Table 3). The second best support combination was a 45° bipod with an ear bag and controlled handling. The third best method, based on MR measurements, was a 90° bipod combined with an ear bag. The highest MR value was obtained using a 45° bipod, rice bag combination with a MOA value of 0.476.

4.2. Evaluation of the image displacement force, direction and back kick values

Table 4: Muzzle velocity (m/s), recoil value (mm), round score (points), view displacement (mil) and displacement direction (hr) data measured at the applied supports
*Note: *** minimum value, ** second minimum, * third minimum*

No.	Description of methods	Projectile muzzle velocity (m/s) avg., SD	Horizontal recoil value (mm) avg., SD	Avg. and SD of round scores (points)	View displacement rate (mil) avg., SD	View displacement directions (in hours) avg., SD
1	90° bipod, eared bag	810.4	29*	2.4	3.2***	9.7
		2.302	*4.796*	*2.608*	*0.447*	*0.671*
2	45° bipod, eared bag, permissive handling	813	26.2	5.8**	3.5*	10.9
		2.915	*3.768*	*2.280*	*0.500*	*0.652*
3	45° bipod, eared bag controlled	811.4	17.4	6.6***	3.8	11.9
		2.408	*0.548*	*2.702*	*0.758*	*0.894*
4	45° bipod, mo-nopod resting on wooden surface	813.2	27	5.2*	8.2	12.2
		4.658	*2.449*	*2.049*	*1.789*	*0.447*
5	45° bipod, mono-pod on rice bag	810	21.2	5.8**	8.8	12.3
		1.871	*0.837*	*1.789*	*1.304*	*0.274*

[14] Cal Zant: Works Cited for Statistics for Shooters Articles. *Precision Rifle Blog,* 2020.

No.	Description of methods	Projectile muzzle velocity (m/s) avg., SD	Horizontal recoil value (mm) avg., SD	Avg. and SD of round scores (points)	View displacement rate (mil) avg., SD	View displacement directions (in hours) avg., SD
6	barricade bag, eared bag	815.2	12.75*	5	7.4	10.8
		2.950	*0.500*	*2.915*	*0.418*	*0.447*
7	45° bipod, rice bag	812.8	18.6	2	10.2	11.3
		3.421	*1.140*	*2.345*	*1.789*	*0.758*
8	45° bipod, without muzzle brake, eared bag	812.6	29.6**	5	12.5	10.7
		1.949	*3.130*	*3.742*	*3.317*	*2.683*
9	45° bipod on sand bag without muzz-le brake, eared bag	812.2	32.2***	3	13.2	11.2
		3.701	*3.421*	*2.236*	*2.280*	*1.037*
10	45° bipod, recortan base, eared bag permissive holding	786	16.4	3.8	3.6	11
		4.528	*1.817*	*1.304*	*0.894*	*1.000*
11	45° bipod, recortan base, eared bag, gripped holding	788.4	14.2	4.2	3.4**	10.9
		5.128	*1.304*	*4.025*	*0.894*	*0.418*

Source: Compiled by the author.

4.3. Recoil values

The recoil value is mainly generated by the resistive force at the moment of firing, which depends on the weight of the rifle, on the bullet velocity, weight, friction force and gas pressure. The smaller this force, the less likely the end of the barrel is to jump off the target during the time the projectile is in the barrel, thus creating the possibility of a more accurate hit, with a well-defined ballistic calculation. The recoil force as a function of the accuracy of the hit is accompanied by the support conditions that actually "control" the recoil. The results obtained for the combination of support methods and methods to reduce recoil are shown in Figure 20.

The lowest recoil value, 12.6 mm, was obtained using a combination of barricade bag and ear bag. This value can be evaluated in relation to the extent to which the weapon system modulates in other directions during the recoil, which we determined by the position of the sight after the shot. Ultimately, the results of the shooting and the two parameters mentioned above can characterise the effectiveness of the support methods.

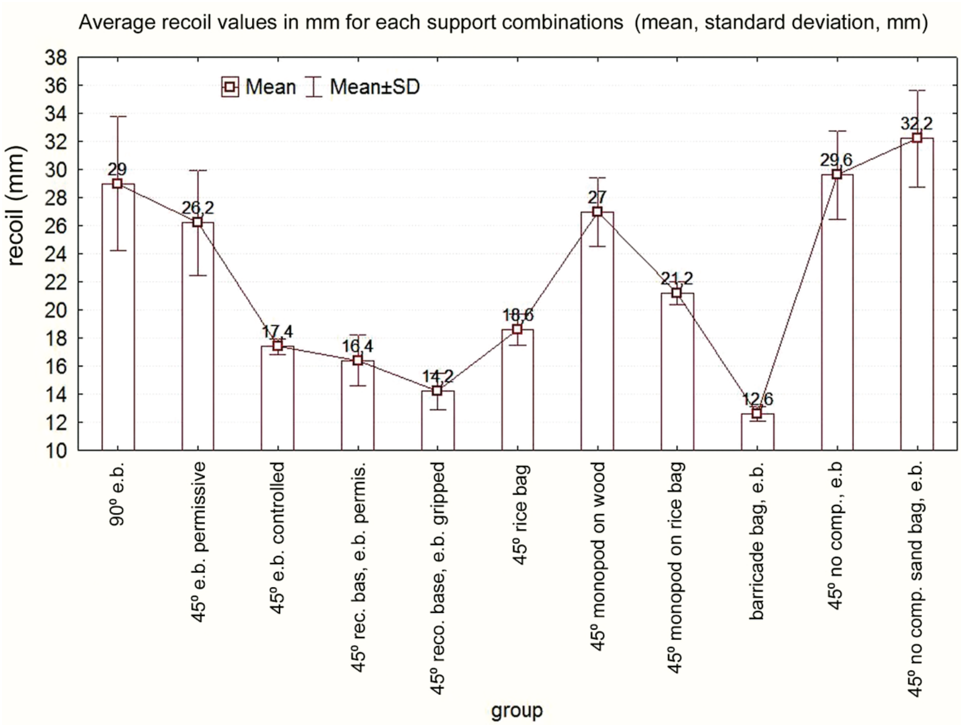

Figure 20: Average recoil values in mm for each support combination (mean, standard deviation, mm)
Source: Compiled by the author.

The mean of the total recoil values was 22.21 mm (N = 55, SD = 6.97), indicated by the red line in Figure 21. In terms of recoil, we can talk about support methods with recoil values below and above the average.

As expected, the two methods that did not use a muzzle break, the 90° bipod – ear bag combination and the 45° bipod – ear bag left in the slide combined with a monopod on a wooden surface, resulted in high backsliding. For the 90° bipod – ear bag combination, the possibility of the bipod being fixed under the barrel as an axis, as well as the relative height and the bipod moving backwards around the axis of rotation due to the larger lever of force, was also assumed. With the weapon left in the slide, the shoulder does not form an obstacle behind the backward moving weapon and a longer backward movement was expected. The rear support left on a wooden surface, movement around the axis of rotation of the monopod, and the slight sliding on the wooden surface all combined to cause the greater recoil. The slippage is eliminated when the monopod is placed on a rice bag, a change that caused a significant reduction in the recoil value ($t = 5.0104$, $p = 0.001039$).

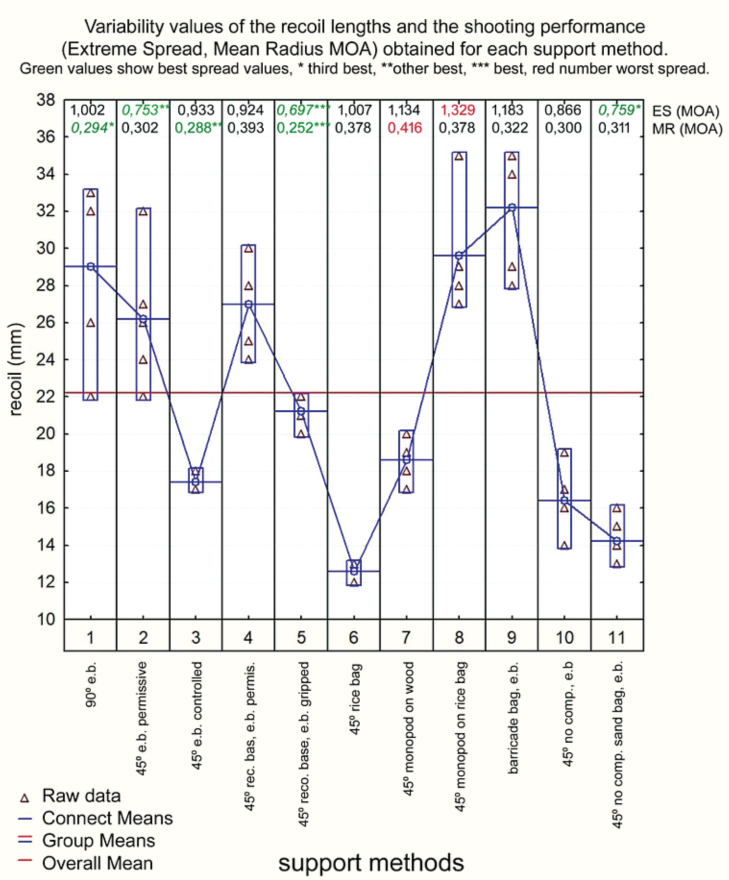

Figure 21: Variability values of the recoil lengths and the shooting performance (Extreme Spread, Mean Radius MOA) obtained for each support method

*Note: Green values show best spread values, * third best, ** other best, *** best, red number worst spread.*

Source: Compiled by the author.

The magnitude of the recoil showed no correlation with the magnitude of the view displacement, except in one case. The combination of a 45° bipod on a flat bag filled with sand with an ear bag and without a muzzle brake was only correlated in two cases. The smaller the backward displacement, the smaller the displacement of the bipod ($r = 0.9231$; $p = 0.0253$). This implies that the amount of backward displacement is not responsible for the amount of displacement of the image.

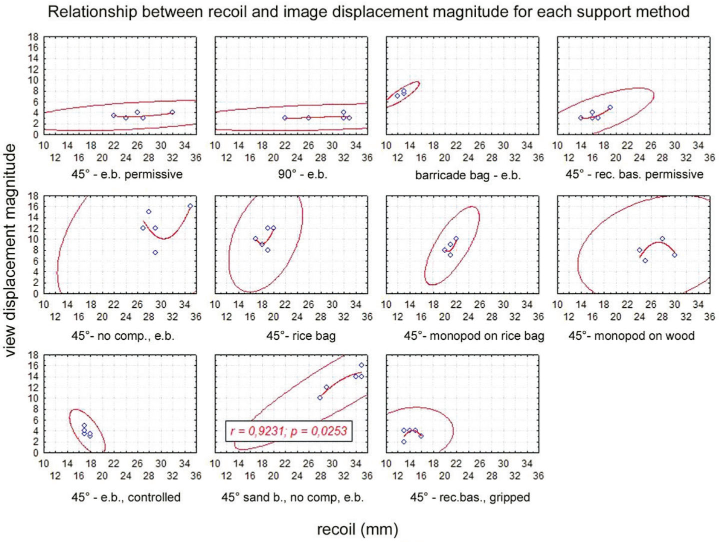

Figure 22: Relationship between recoil and view displacement magnitude for each support method

Note: A correlation was obtained only for the case of the combination of 45° bipod, eared bag, without compensator, placed on a sand-filled flat bag (r = 0.9231; p = 0.0253).

Source: Compiled by the author.

The strength of the recoil did not show any correlation with the scores achieved. That could mean that the success of the competitions are not determined by the magnitude of the recoil.

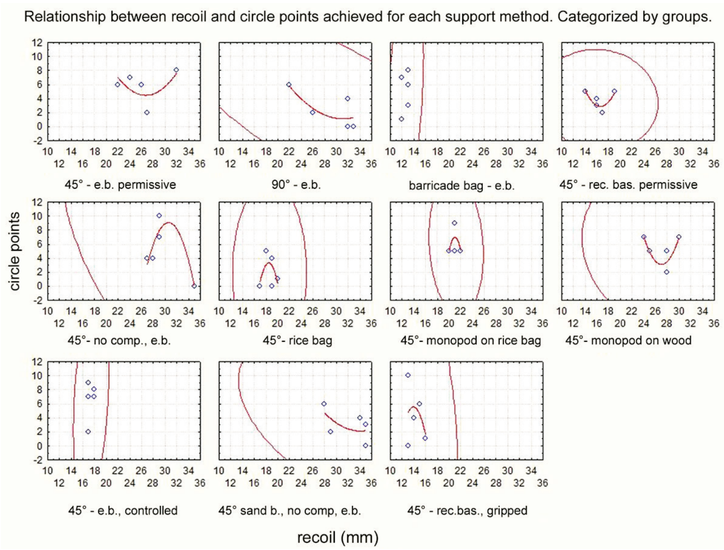

Figure 23: Relationship between recoil and circle points achieved for each support method (categorised by groups)

Source: Compiled by the author.

The rate of recoil and the direction of view displacements also showed no correlation except in one case. A correlation was found between the mentioned parameters in case of method barricade bag and eared bag (r = –0.9186; p = 0.0276). It was concluded that the length of the recoil does not influence the direction of the shot displacement (Figure 24).

In summary, the results obtained show that the length of recoil observed in the different front and rear support variations does not affect the direction of the developing reticle view, the length of its displacement, or the effectiveness in terms of circle points, except in one case. From this we concluded that there is no use in studying the rate of recoil in terms of these parameters, i.e. indirect accuracy. In the future, research should focus on changes that are happening during the time when the projectile is in the barrel. It should be noted that the above statement is for each separate case and the 5–5 shots should be treated with caveats due to the smaller number of elements.

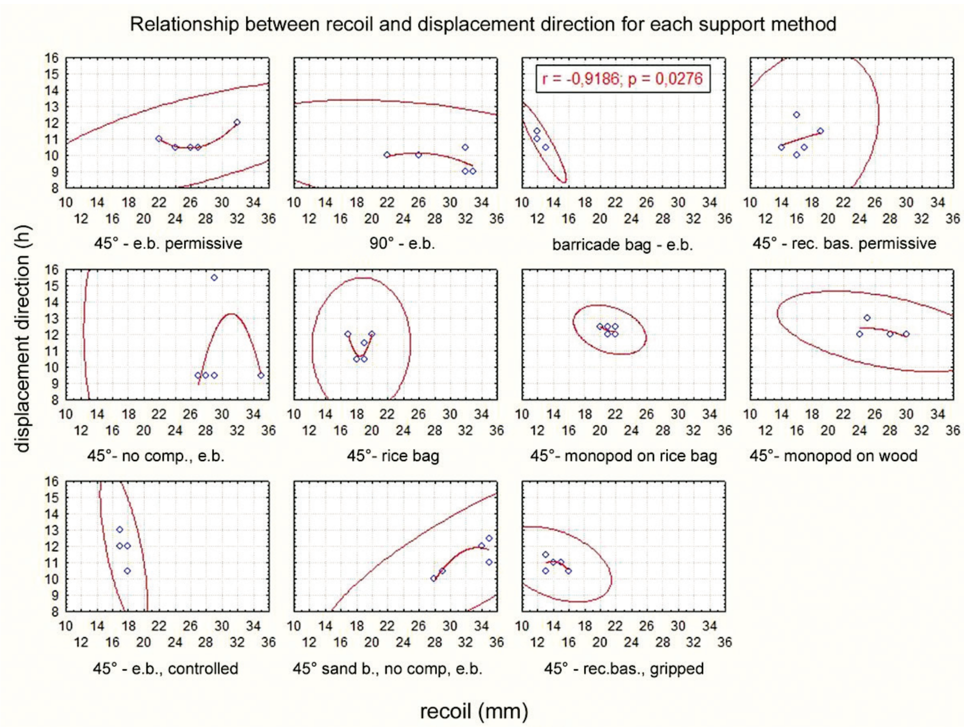

Figure 24: Relationship between recoil and displacement direction for each support method
Note: A correlation was obtained for the combination of barricade bag, eared bag (r = –0.9186; p = 0.0276).
Source: Compiled by the author.

4.4. Post-shot reticle centre vs. target centre view assessment

The target image observed after firing shows the relationship between the centre of the crosshairs and the centre of the target in units of 0.2 MOA (1.75 cm, or 0.06 mil). This post-fire view was a good characterisation of the jump-off from the target. In PRS competitions, the possibility of correction only becomes an option if the shooter can see the impact, i.e. the "jump-off" is small. Based on our hypothesis, this feature may also be an indicator of accuracy.

As shown in Figure 25, three groups could be distinguished. A small, medium and large jump group from the given support methods.

The smallest jumps were typically characterised by a jump unit of 3.2–3.6, with a jump of 0.64–0.76 MOA (5.6–6.6 cm, 0.196–0.228 mil). The difference between the small and medium groups was significant ($t = -14.429$, $p < 0.001$, F-ratio variances $= 3.761$, $p = 0.00432$).

- 90° bipod, eared bag
- 45° bipod, eared bag, permissive handling
- 45° bipod, eared bag controlled
- 45° bipod, recortan base, eared bag, permissive
- 45° bipod recortan base, eared bag, gripped holding

The medium group had a jump of 7.4–8.8 units, which translates to 1.48–1.76 MOA, (12.95–15.4 cm, 0.444–0.528 mil). The difference between the overall results of the medium and large groups was significant ($t = -4.9202$, $p < 0.001$, F-ratio variances $= 4.0515$, $p = 0.0132$).

- 45° bipod, monopod resting on wooden surface
- 45° bipod, monopod on rice bags
- barricade bag, eared bag

The large jump group was 10.2–13.2 leap units, which was 2.04–2.64 MOA (17.85–23.1 cm, 0.612–0.792 mil).

- 45° bipod, rice bag
- 45° bipod, without muzzle brake, eared bag
- 45° bipod without muzzle brake, on sand support bag

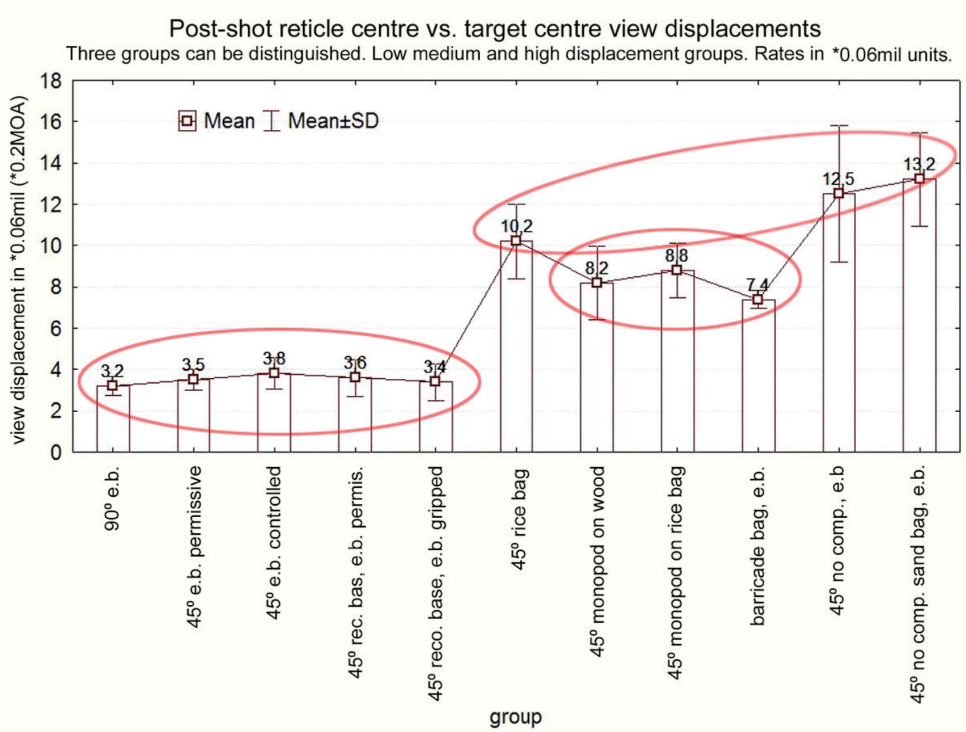

Figure 25: Post-shot reticle centre vs. target centre view displacements
Note: Three groups can be distinguished: low medium and high displacement groups (rates in 0.06 mil [0.2MOA] units).
Source: Compiled by the author.

The most stable support methods that stayed on target were those that could be described as "traditional". In national level competitions, the regulations state that a tactical bipod and a single rear bag may be used. In point of view, the eared bag is more advantageous because the ears, properly filled with sand or other material, provide greater stability in the lateral directions. During Hungarian precision competitions (big calibre, optical sighting), most competitors use a bipod and a shooting bag tilted at some angle, or a shooting bag with ears. During site placement to support the weapon, it would be essential to place the bipod on soil or sand, in other words, on a stable but not hard surface. Beginners often make the mistake of placing the bipod on a sponge or polyfoam surface (onto the shooting mat), thus reducing stability. Another potential issue is a surface that is too hard, such as concrete, on which rubber-tipped bipods can bounce. This is why the first five supports in Figure 25 can be called conventional. The sandbags integrated into the recortan base were designed to model the vibration absorbing properties of the bipod foot placed on sand. The higher degree of bounce caused by the 45 degree bipod foot plus rice bag combination can be attributed to the properties of the rice bag; however, this combination had the best spread results.

4.5. Displacement directions

After the moment of the shot, the movement direction of the crosshairs were determined by the dial of the clock. After each shot, the position of the arrival of the centre of the crosshairs and the centre of the target were compared and determined in 0.5 o'clock directions, and the results were averaged. This way, we obtained the direction in which the rifle started and arrived during the shots. Overall, we can say that the rifle was displaced from left to right and upwards, but that the different support variations did have an impact on this crosshair movement.

As shown in Figure 26, the 45° bipod-monopod method of trajectory displacement direction (mean: monopod end resting on tree: 12:15 h; monopod end resting on rice bag: 12:20 h) showed a significant difference from the 90° bipod-eared bag (mean: 9:45 h) support combination ($p = 0.00143$).

We are unable to accurately determine the causes of the trends in the image displacement data, as this may depend on several parameters, either individually or in combination, which we detail below:

- the direction of firing force transmission by the trigger
- the lateral movement of the weapon on the rear support due to the softness, hardness and fullness of the support materials
- the displacement effect of the force of the shooter's cheekbone on the muzzle
- structural failure of the first support (minimum probability, due to the quality of the first support)
- unevenness of the surface under the first support (minimum probability, due to its thorough inspection)
- inadequate water levelling (minimum probability because we tried to minimise it with a water level indicator before each shot – uniform implementation)
- the actual coincidence of muzzle vibration harmony and the ammunition powder charge and L6 length and NOD points

The two support methods that clearly showed upward displacements were the 45° bipod and the two rear monopod supports, which are logical and well defined influencers of displacement direction.

The monopod was held in such a way that the non-firing, i.e. back or passive, hand gripping the monopod by the handhold was angling the monopod (monopod pointing downwards relative to the pivot point on the stock) such that we could point to the centre of the target by leaning on the monopod. Retaining the weapon moving backwards at the moment of firing is relatively difficult at this point, as the monopod resting on the fulcrum will swing backwards along the axis of rotation, causing the weapon system, i.e. the barrel, to move upwards. In this case, the crosshairs are forced upwards away from the target and the rate of jumping from the target is very high.

In terms of accuracy (hitting spread), the largest deviations were obtained for shots without muzzle brake, where muzzle brake did not affect the target retention (SD = 2.28 hours for 45° – bipod on sandbag – muzzle brake, SD = 1.037 hours for 45° – bipod on sandbag – muzzle brake).

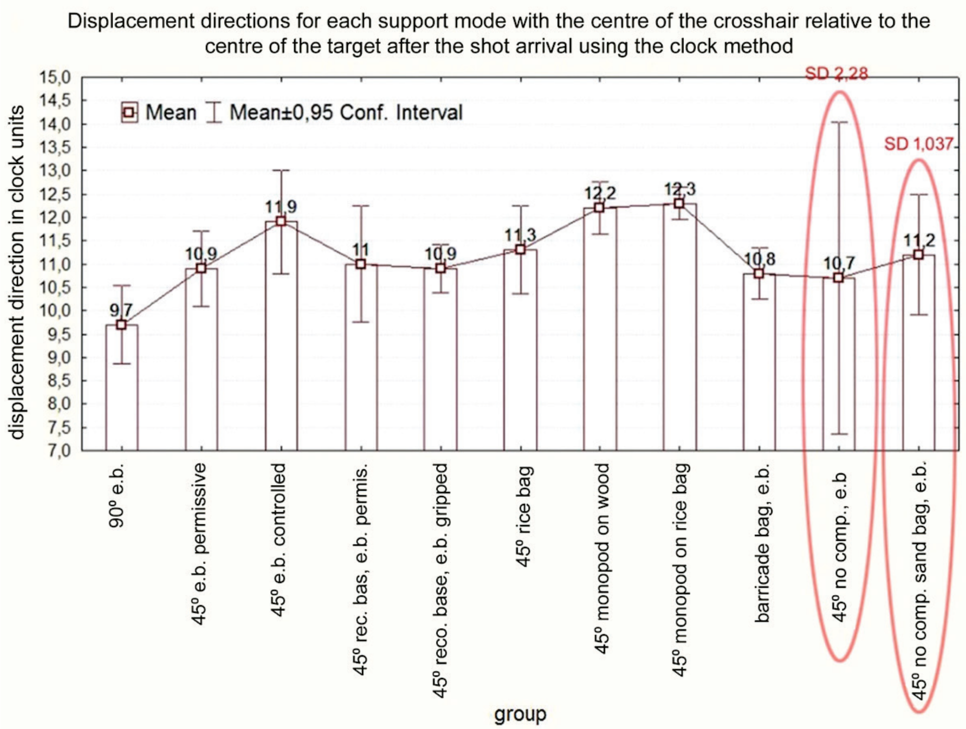

Figure 26: Displacement directions for each support mode with the centre of the crosshair relative to the centre of the target after the shot arrival using the clock method (clock)
Source: Compiled by the author.

4.6. Comparisons

By comparing the Pearson correlation of each parameter, we sought to determine the context in which any significant correlation can be interpreted in terms of the accuracy and precision of the shooting events in relation to each other for each support combination.

The recoil distance showed a significant correlation with the magnitude of the perceived displacement of the view after the shot ($r = 0.4381$, $p < 0.001$). This phenomenon can be considered natural and confirms the justification of the post-shot target image check in order to allow the shooter to control for possible errors that may occur during the shot. These errors include both the shooter's error and the error caused by overpressure from overloaded ammunition that produces a more pronounced recoil.

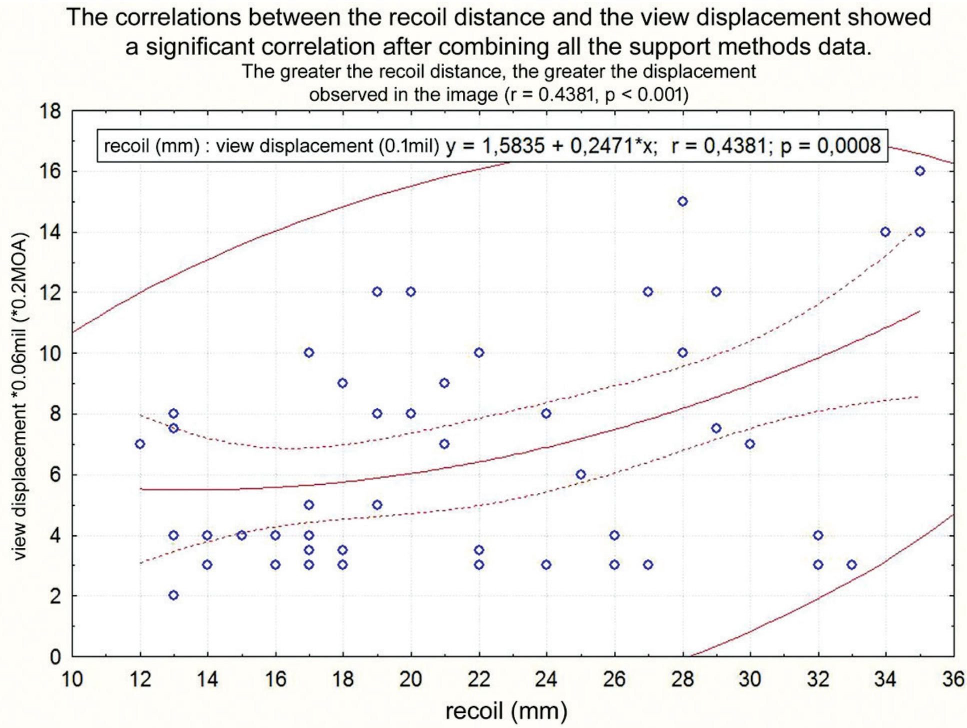

Figure 27: The correlations between the recoil distance and the view displacement showed a significant correlation after combining all the support methods data – the greater the recoil distance, the greater the displacement observed in the image (r = 0.4381, p < 0.001)
Source: Compiled by the author.

No significant correlations were found between the accuracy indices (ES, SD, MR, points) of the shooting series and the shooting and recoil data. We also found standard deviation values between support methods with both above-average and below-average recoil values for the first three accuracy values (Figure 21).

The relationship between precision and accuracy data is clear. The inverse proportionality of the correlation of the race performance score values with the horizontal group centre distance and the target centre distance values is also understandable ($r = -0.7503$, $p < 0.02$), as is the correlation with the group centre distance and target centre distance values ($r = -0.8501$, $p < 0.001$). This means that the smaller the horizontal or overall distance of the groups from the target centre, the higher the score achieved. However, no correlation was found between the distance between the vertical group and the target centre and the score ($r = -0.4635$, $p = 0.111$).

5. Conclusion

From the support variations, the best method in terms of precision, based on *Extreme Spread* (ES) and *Mean Radius* (MR) calculations, was to use a 45° bipod with a monopod and rear rice bag support combination, resulting in ES = 0.697 MOA and MR = 0.252 MOA. The second best variation was the 45° bipod and eared bag combination with permissive method (the weapon left sliding, and not shouldered), which measured at 0.753 MOA. However, the values from this support combination were similar to the values of the 45° bipod on recortan integrated sandbags and eared bag combined with the gripped rifle method (weapon shouldered).

The lowest recoil value was obtained with the combination of barricade bag and eared bag, which had an average recoil value of 12.6 mm for the five shots.

The length of recoil developed during the different front and rear support methods did not affect the direction of the view image, the length of its displacement, or the effectiveness in terms of circle points, except in one case. In other words, there is no benefit to studying the extent of recoil in terms of these parameters, i.e. indirect accuracy.

The methods that were best at staying on target were those that could be described as "traditional".

Overall, we found that the weapon moved left to right and upwards during the shots, but that different support combinations affected this movement. Two support methods that clearly produced upward displacements were the 45° bipod, rear monopod combinations.

Correlation tests showed that recoil distance was significantly correlated with the magnitude of the view displacement ($r = 0.4381$, $p < 0.001$).

No significant correlations were found between the precision indicators (ES, SD, MR, points), displacement view, and recoil data. However, the correlation with precision data is clear. The inverse proportionality of the correlation of the point values (indicators of competition performance) with the horizontal group centre and target centre distance values is also clear ($r = -0.7503$, $p < 0.02$), as is the correlation with the group centre and target centre distance values ($r = -0.8501$, $p < 0.001$).

Our first hypothesis proved to be correct, that there is a significant difference in precision between the different types of rest combinations, i.e. it does not matter which front and rear rests are used in sport shooting competitions and how the shooter handles the gun during the shoot.

Our second hypothesis regarding the degree of recoil in each support scenario was not proven correct since we found no correlation between the degree of recoil and accuracy in individual cases of different support methods. A comparison of all the data, however, showed that the degree of recoil was significantly related to precision. The other part of our hypothesis, that the support methods that absorbs gun recoil movements during firing is more accurate, was not confirmed. However, this assumption is compounded by the fact that the we did not apply one specific support method which used the "only recoil" method, utilised by the traditional F-Class or other precision competitions, (for example ski-mounted wide F-Class bipod or special shooting "base" or "benchrest"). We used a barricade bag implemented mainly in

PRS competitions, which, although it provided the lowest recoil value, but was not among the methods that provided the highest accuracy.

Our hypothesis that the magnitude of the displacement of the image after the shot is related to accuracy was confirmed (magnitude of image displacement vs. ES: $r = 0.6922$, $p = 0.018$), but it was not related to the more narrowly defined value of accuracy (MR) (magnitude of image displacement vs. MR: $r = 0.4946$, $p = 0.122$).

It was also assumed that the first support method (Figures 9, 10, 20) placed on three vibration absorbing surfaces – where the bipod was placed on a bed of sand or bags – would give the second most accurate results was only partially fulfilled. The method without a muzzle break was not accurate despite the sand bed. From the two other methods, the vibration absorbing front support produced narrow spread only when firing with a tight, gripped gun.

Finally, our hypothesis that the least accurate results would be obtained with a bipod on solid ground, which is based on the principle of tipping, was not clearly determined because the accuracy did not depend primarily on the front support alone, but on the combined properties of the front and rear supports.

In the study, the tilting-sliding method was mixed for the front and rear supports. No method was investigated that was clearly and explicitly a sliding support for the front and rear cases. These are part of the F-Class applications we already mentioned. These do not allow lateral movement deviations in a well-defined way. The initiation and deceleration of the gun slide is easy and does not cause any jump during the time the projectile is in the barrel that would adversely affect accuracy. In future research, we will focus on this aspect.

6. Summary

The aim of our study was to find under which support conditions bolt action, high-calibre firearms produce the best accuracy at long range.

In this study, we chose 11 different front and rear support methods that are most commonly used in domestic, precision competitions. In these methods, we used a tactical bipod and barricade bag as front supports combined with an eared bag, rice bag or a monopod as rear supports. Muzzle breaks were used in most of the methods, but in two cases we fired without it. During the shooting we used: a) permissive (way giving or untensioned) method, where the shooter lets the gun slide freely backwards; b) gripped method, where the gun is pulled tightly into the shoulder; c) controlled handling method, where we applied support but the gun could move in a controlled way. Accuracy was determined by the spread (ES, MR) and circle values (circle units) generated by bullet on paper target area by MOA and point parameters. During firing, we examined the length of the weapon recoil, the direction and extent of view displacement relative to the target centre, and the velocity of the projectile.

As expected, the data obtained showed significant variation in precision between each support combination. There was also a significant difference in the values of the recoil length and the shot bounce after the shot. The directions of barrel displacement were essentially in the quarter between the 9 and 12 o'clock positions.

All of the most precise trial results were obtained using a muzzle break with a 45° bipod as the first support. For the rear support, a combination of a rice bag and a gripped monopod, or an eared bag was optimal. Regarding the method of retention, both permissive (sliding) and controlled handling were effective compared to the gripped method. Less optimal spread was obtained with: no muzzle brake, barricade bag as front, and rice bag lifted and controlled as rear support.

The correlation studies showed that the length of recoil developed had no effect on the view directions, the length of the view displacement, nor the effectiveness counted in circle points, except in one-one case when recovery methods were examined separately. However, when all the data were pooled, recoil distance showed a significant correlation with the amount of post-shooting displacement of view in relation of crosshair centre and target centre ($r = 0.4381$, $p < 0.001$).

In future studies we will be analysing the front and rear supports used in F-Class competitions and comparing these data with the present results to see which methods allow for the best precision.

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