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US Army Research Laboratory

Effects of Sight Type, Zero Methodology, and Target Distance on Shooting Performance Measures While Controlling for Ammunition Velocity and Individual Experience

by Patricia Burcham, William Harper, and David Scribner

NOTICES

Disclaimers

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14. ABSTRACT

The goal of this study was to characterize shooting performance differences between universally zeroed weapons (zeroed by a weapons expert) and individually zeroed weapons (zeroed by the shooter), as well as sight system types and target distance (m). Independent variables included two zeroing methods, four weapon sights, and four ranges (100–400 m). Dependent variables included shooting accuracy, radial error, and shooting response time. Individual factors such as shooter experience or ability and ammunition velocity properties may both have covariate effects. There were some significant differences between universal and individual zero. There were also several significant covariate effects that included velocity data that were strongly associated with dependent variables as well as individual shooting experience. Trends indicated significant advantages for magnified optics over iron sights and nonmagnified optics. A shooting model to examine multiple connections among different variables in the shooting process is recommended.

15. SUBJECT TERMS

weapon zero, individual, universal, optics, ammunition velocity

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1. Introduction and Project Background

A true weapon zero is the calibration of sights on a weapon so that when they are aligned with a target at a specified range, and with specific ammunition, a round fired from the weapon hits the aiming point within the margin of error of the weapon[*] (Dees et al. 1971). However, US Soldiers do not typically employ a true zero. They instead use an individual zero (shooter zeroes his own weapon) based on the rationale that any individual differences in sight alignment for each individual will be eliminated by correcting the sight for the individual firing the weapon. In the US Army, it is common practice to begin live fire training by zeroing the weapon to the individual that is firing. Dees et al. (1971) state that teaching an individual to zero before teaching to shoot would seem to ensure that the inaccuracies in the sighting system when training begins would have a negative impact on training for marksmanship.

The US Armed Forces have historically used individual zero for all assault rifle training and firing. It is commonly believed that a weapon should be zeroed by the person who is to fire the weapon so that any eccentricities in sight alignment would be eliminated. When initial rifle training is conducted, allowing an error in the sight alignment process to be captured in the rifle zero precludes the shooter from making a correction to a more standard sight alignment since he would not be able to accurately fire. Having a novice zero a weapon may lead to incorrect sight alignment carrying through the entire training process and may have negative training impacts. The other impact of having novice shooters zero their rifle before training is that it can take a large amount of time, ammunition, and cost. While the trainee is learning to fire during the process, an increase in dedicated marksmanship training rather than extensive time spent zeroing a weapon may be a more effective alternative.

Some research has also shown that a universal zero (zeroed by a weapon expert) may have some merit. Dees et al. (1971) found that a collimator[†] produced iron sight zero followed by a three-round correction was equal in target hit percentage to an individual zero. There has been unpublished anecdotal evidence (Ortega et al. 1993, 1994) and published evidence (Harper et al. 2011) that suggests that for most cases there is no difference between an individually zeroed weapon with iron sights and a commonly zeroed weapon (i.e., all weapons zeroed by one shooter) with iron

[*]The margin of error for each weapon will be determined by manufacturer specifications for dispersion when using new weapon barrels, or by measurement using a weapon-specific dispersion measurement tool.

[†]A laser bore sight alignment device.

sights for targets less than 300 m. It may be that individual zero differences may be far less than the aiming error in most cases.

With the prevalent use of the M68 reflex sight (close-combat optic with collimated red dot), as well as illuminated, telescopic sights such as Trijicon's Advanced Combat Optical Gunsight (ACOG), the difference between a universal zero and an individual zero may be reduced further. This is due to reduction in the parallax of the sighting system, making individual eye positions less critical. For most novice shooters, the individual zero may have little effect for the backup iron sight or powered optical sight and possibly no effect for a reflex sight such as the M68 Close Combat Optic (CCO), or an illuminated telescopic sight such as the ACOG.

Besides the possible training benefits of a universally zeroed weapon, there are other benefits as well. Weapons could all be zeroed prior to going to the range, saving critical experimental preparation time. Moreover, the ammunition and time spent on zeroing a rifle can afford more time toward training exercises. Lastly, any Soldier would be able to pick up any weapon and feel confident that the weapon zero will be equivalent to the zero setting on their own weapon. Weapons could also be manufactured with the universal zero and would in turn never require a zero by the end user for accurate performance.

The goal of this study is to characterize the shooting performance differences between universally zeroed weapons and individually zeroed weapons. Factors such as target range, sight type (iron sight vs. red dot vs. holographic vs. telescopic) and experience or ability of the shooter may have interactive effects with the zeroing technique on the ability of Soldiers to hit targets.

Within the small arms research community, it is generally believed that there is no significant difference in marksmanship performance of Soldiers engaging targets up to 300 m away as a function of zeroing methodology. In other words, marksmanship performance is not influenced whether the weapon was individually or professionally zeroed (universal zero). This knowledge is based on unpublished analyses of small arms error budgets (total error of shooting system, i.e., aim error, wind, and trigger pull) using iron sights. There has yet to be a definitive study that examines the effects of universal zero and individual zero on shooting performance.

The M68 uses a collimated red dot technology for aiming the weapon system. This technology reduces parallax of the sighting system, making eye position less critical. If the eye position is less critical due to reduction in parallax, weapon zeroes for different Soldiers might be even closer than with iron sights. The biggest source of error in the sight might be the interpretation of the aiming dot (top of dot, center of dot, etc.) or the Soldier's individual notion of where on the target to place the dot.

It is understood that certain skilled shooters will always need the extra precision afforded by an individual zero. Snipers and designated marksman have shooting skills and equipment that reduce aiming error. In these conditions, an individual zero will make a difference in shooting performance because the differences in individual zeroes will not be masked by the large errors in aiming performance. This study is not intended to impact tactics, techniques, and procedures for this elite subset within the US Armed Forces' community of shooters. Instead, the goal is to provide clarity on an outstanding question of shooting efficacy relative to two alternative zeroing methodologies—the standard practice of individually zeroing the weapon versus the more efficient alternative of universally zeroing the weapon. If the impact on accuracy is minimal to negligible between methodologies, a revision of zeroing practices for US Army marksmanship training may be warranted.

This study aims to address the following main hypothesis and rationale: If the weapon sights had a true zero, the shooter may learn to properly line up behind the sights and have a correct cheek-to-stock weld. He will not accurately hit the target without doing so. It might be a better training strategy to teach a shooter to shoot with a weapon that is correctly zeroed before teaching the shooter to zero a weapon.

2. Synopsis

Weapon zeroing involves setting the sights to enhance firing accuracy. This study examined differences in shooting performance for a Soldier firing an individually zeroed weapon relative to a professionally calibrated universal zero. The current investigation sought to explain whether zeroing conducted by an individual differs significantly from a professionally calibrated zero. A weapons expert calibrated the weapons used in the experiment to a universal zero. Each weapon was re-zeroed at the start of each day. The shooting tasks encompassed time stressed firing (time pressure dictated by exposure time) at targets between 100 and 400 m, using four different commonly used weapon sights. The main goal of this study was to determine how zeroing methodology affected shooting accuracy. If no significant differences exist between zeroing methodologies, then it may behoove the tri-service shooting community to use the professionally calibrated universal zero to reduce training time and ammunition cost. If our hypotheses are not supported, and instead significant performance degradation is recorded when Soldiers fire using a universal zero at ranges less than 400 m, this data will effectively lay the issue to rest and cease occupying the interest of tri-service shooting, training, and small arms research personnel as a viable potential alternative to the status quo.

3. Participants

Sixteen Soldiers 1st BCT, 10th Mountain Division participated in this study. Soldiers were secured by the PM Individual Weapons. During the evaluation, participants wore the field duty uniforms with the Advanced Combat Helmet, Improved Outer Tactical Vest, and eye protection. Each Soldier completed a Demographic Data form (Appendix A).

Participants were not required to have any specific Military Occupational Specialty, though for the purposes of this study they were required to be experienced shooters that were successfully qualified with a rifle within the past year as sharpshooter or better. Our rationale for using experienced shooters, rather than novices, was based on the argument that the prospect of minimal discrepancy between zeroing methodologies was likely to be maximized by asking skilled shooters to perform. In this way, the performance variability inherent to an exercise featuring novice shooters was minimized, as were potentially errant conclusions based on the patterns of error that typically accompany novice performance.

3.1 Pretest Orientation

Soldiers who volunteered for the study were given an orientation on its purpose and the details of their participation. They were briefed on objectives and procedures, and were told how results were used and the benefits the military can expect from this investigation. Any questions the participants had regarding the study were answered.

3.2 Demographics and Visual Acuity

Demographic (Appendix A) and visual acuity data (Appendix B) were taken on each participant. Demographic data was provided by the participants using a Demographic Data form (Appendix A). These data were then added to visual acuities, lens verification, and refractive error data that were recorded for analysis.

Standard visual acuity techniques using appropriate Snellen charts were used to determine both uncorrected and habitually corrected monocular and binocular visual acuities for both distance and near. Ocular dominance was determined using the sighting method. Participants were also asked to report their normal shooting eye and shooting handedness.

4. Objectives

The objectives of this research effort included determining what effect a universal zero—using multiple, commonly employed weapon sight-types—has on the ability to hit targets at various ranges relative to an individual zero of the weapon.

5. Apparatus

5.1 M-Range

M-Range is a live-fire shooting range used to evaluate shooting performance of small arms systems (.50 caliber or smaller). It consists of four parallel firing lanes with target positions from 10 to 550 m on the two left lanes and targets from 10 to 1,000 m on the two right lanes. Figure 1 provides an aerial photograph of the US Army Research Laboratory's (ARL) Human Research and Engineering Directorate's (HRED) M-Range. Target control is automated using customized computer algorithms, which enables the operator to program target presentation scenarios and to record live-fire marksmanship data. The target positions can support a variety of target types (E-type silhouettes [Fig. 2], 3-D IVAN targets, etc.), which are presented and retracted using pneumatically operated arms. Target control parameters include target sequence, range, presentation time, and duration, and may be varied to accommodate a broad selection of experimental scenarios. Accuracy and timing data are recorded using shot microphones placed at the shooter's position and behind each target. The supersonic projectile of each shot, whether firing in semiautomatic or full automatic mode, generates a shock wave that is detected by the microphones. Shock wave timing is used to triangulate shot location, accurate to within 5 mm, and is expressed as an x-y coordinate relative to the target plane. Shock waves from shots that miss the target by up to approximately 3 feet to the left and right and 6 feet above the target are also captured.

Fig. 1 ARL HRED M-Range performance research facility

Fig. 2 Olive drab "E" type silhouette targets at M-Range

5.2 Weapons

The M4/M4A1 5.56-mm carbine (Fig. 3) is a lightweight, gas-operated, air-cooled, magazine-fed, selective-rate, shoulder-fired weapon with a collapsible polymer butt stock. A shortened variant of the M16A2 rifle, the M4 is equipped with a shorter barrel, collapsible stock, and optional accessory rails. The M4 provides shooters operating in close quarters with improved handling and the capability to rapidly and accurately engage targets at extended ranges, day or night, with accurate, lethal fire.

5.3 Sighting Systems

The M150 ACOG is a fixed 4×-magnified optic designed for the US Army's M4 weapon system. It incorporates dual illumination technology using a combination of fiber optics and self-luminous tritium.

Standard M4 Carbine Iron Sight

Vortex Razor 1-6x

M68 reflex sight

(close-combat optic with collimated red dot)

M150 Advanced Combat Optical Gunsight (ACOG)

Fig. 3 Display of each sight/optic type

5.3.1 Iron Sights

Iron sights are composed of two component sights, formed by metal blades: a rear sight mounted perpendicular to the line of sight and a front sight that is a post, bead, or ring. Iron sights align the rear aperture with the front post relative to the target. Iron sights are designed to be adjustable for sighting in firearms by adjusting the sights for elevation or windage.

5.3.2 M68 CCO

The CCO M68 is a nontelescopic (unmagnified) reflex sight that is designed for the "eyes-open" method of sighting. It provides Soldiers with the ability to fire with one or two eyes open, as needed for the engagement sequence in the shot process.

The CCO provides a red-dot aiming point using a 2- or 4-min of angle diameter reticle, depending on the variant. The red dot aiming point follows the horizontal and vertical movement of the firer's eye, allowing the firer to remain fixed on the target. The M68 reflex sight uses a single collimated red dot as a reticle for alignment with the target. Participants were informed that the red dot is the only aim point and that no centering or focusing on the front sight post was required.

5.3.3 ACOG

The M150 ACOG incorporates dual-illumination technology using a combination of fiber optics and self-luminous tritium. This allows the aiming point to always be illuminated, without the use of batteries. The tritium illuminates the aiming point in total darkness, and the fiber optic self-adjusts reticle brightness during daylight according to ambient light conditions. This allows the operator to keep both eyes open while engaging targets and maintaining maximum situational awareness.

Designed to the exact specifications of the US Military, the unique reticle pattern provides quick target acquisition at close combat ranges while providing enhanced target identification and hit probability out to 800 m using the Bullet Drop Compensator. The M150 features external windage and elevation adjusters.

5.3.4 Vortex Razor

The high-end Vortex Razor is a reflex sight built with highly polished glass that is clear and crisp from edge to edge. Exceptional resolution and a wide field of view present a clear sight picture. The daylight bright red dot is easy to see and paints targets regardless of lighting conditions or background.

6. Experimental Design

Assignment of zeroing method and weapon sight/optics were counterbalanced between participants to mitigate effects of order on performance. Each participant completed all experimental firing scenarios in a unique counter-balanced presentation order (Appendix C).

While this is not reflected in the design shown in Appendix C, it should also be noted that care was taken to ensure that a given weapon was not consistently zeroed according to a singular methodology. To clarify, each M4 carbine used in the study was zeroed individually and universally equally often. This mitigated any weapon-specific shooting characteristics (e.g., increased round dispersion for a particular barrel) that might erroneously skew performance data for either zeroing condition. Test participants participated in the study during daylight hours from 0800 to 1630 and completed all firing over an 8-day period.

7. Experimental Conditions

There were eight live-fire conditions in this study:

1) M68 reflex sight, universal zero
2) M68 reflex sight, individual zero
3) M150 rifleman optic (ACOG), universal zero
4) M150 rifleman optic (ACOG), individual zero
5) Vortex Razor, universal zero
6) Vortex Razor, individual zero
7) Iron sights, universal zero
8) Iron sights, individual zero

7.1 Range Familiarization

Once the participants met the basic criteria to serve in this study and were briefed on the experimental procedure, they proceeded with range familiarization. They were thoroughly briefed on the conduct of the study, all standard operating procedures, and safety requirements relative to the facility.

Shooters were shown a visual example of the aim point prior to initiating the trial. The aim point was a center of mass location on the target. Shooters were told to aim at the center of mass location of the target. They were scored on how close the round hit relative to that point and they were timed on how long it took them to fire each round.

7.2 Training

One training trial (a round total of 12) for each condition was completed prior to data collection trials.

7.3 Testing Sequence

Participants individually approached the firing line and assumed control of an M4 carbine from range safety personnel. This weapon was either the same weapon zeroed and employed by the participant during the training session just completed, or a weapon fitted with the same sight/optics configuration used during the training session, but universally zeroed by a weapons expert. Participants were simply handed the weapon without elaboration regarding how it was zeroed.

Soldiers attempted to aim and fire accurately before the target went down. Participants fired all conditions in the prone, supported position. Participants were told that their performance was judged for accuracy and timing, but that they should prioritize accuracy over target engagement time during each experimental trial.

The experimental firing scenario began when a pop-up, E-type silhouette target was randomly presented at one of the four designated ranges (100, 200, 300, or 400 m). Test participants were given a firing scenario consisting of firing one shot at each target. The target remained exposed in the raised position for 8 s or until successfully hit. If hit, the target immediately dropped out of sight and the remainder of the 8-s temporal interval continued in the absence of a visible target. One training trial (a round total of 12) for each condition was completed prior to data collection trials.

At the conclusion of the 8-s temporal interval a 3-s inter-target delay commenced, followed immediately by the appearance of the next target. As described for the training scenario, target exposure order with respect to range and position was randomly determined. Each trial was conducted with the weapon that the participant individually zeroed, and was repeated using the universal zero whereby the weapon was zeroed by a subject matter expert (SME).

The experimental session comprised a 28-target scenario (i.e., 7 targets × 4 ranges). Between iterations of the 28-target experimental firing scenario, participants were allotted a 5-min break. Each participant completed two trials for each of the four sight conditions (iron sights, the M68 CCO, Vortex, and ACOG). Upon completion of a fourth iteration of the experimental firing scenario, the participant was allotted a 10-min rest period.

Following the 10-min rest period, the participant proceeded to fire two additional 28-target scenarios in the same weapon sight/optics condition, but using the weapon that was zeroed using the alternate methodology (i.e., individual or universal zero, as applicable). This set of two 28-target scenarios was followed by another 10-min break.

In total, each experimental session using a given weapon sight/optics configuration was repeated four times: two 28-target scenarios using the individually zeroed weapon, and two 28-target scenarios using the universally zeroed weapon. Each experimental session for a given weapon sight/optics configuration will thereby result in a total of 112 rounds fired (i.e., 56 using the individual zero and 56 using the universal zero).

At the conclusion of the rest period that follows the fourth 28-target scenario, the participant was excused for the rest of the day. On the next day, the participant began the training–experimentation sequence anew using a weapon fitted with one of the alternate sight/optics systems. Once the participant completed each training–experimentation sequence using each of the four prescribed sight/optics systems, their participation in the shooting phase of study was considered complete.

7.4 Independent Variables

The independent variables were as follows:

1) Zeroing method (individual zero, universal zero)

2) Weapon sight (iron sight, M68 reflex sight, Vortex Razor sight, and ACOG sight)

3) Range to target (100, 200, 300, or 400 m)

7.5 Dependent Variables

The dependent variables were as follows:

1) Shooting accuracy, calculated by hit percentage

2) Shooting accuracy, calculated by radial error of misses from the center of the target

3) Shooting response time (RT; i.e., time to shoot)

8. Data Analysis

Separate 2 (zeroing method) × 4 (weapon sight) × 4 (range to target) within-subjects Analyses of Covariance (ANCOVAs) were conducted for the hit percentage, radial aiming error data (radial error for short) and the target engagement time data (time to shoot). Covariates of ammunition velocity, and experience with the chosen sight types, were used as covariates to eliminate error variance associated with these highly related pre-experimental ammunition and individual difference measures.

8.1 Results

Multivariate Analyses of Covariance (MANCOVAs) were planned as two of the three dependent variables were suitably correlated (Tabachnik and Fidell 2013). The correlations revealed two significant correlations among the dependent variables (DVs): among the transformed hit percentage and radial shooting error, $p= 0.000$, $r= –0.344$, and among hit percentage and time to shoot, $p= 0.000$, $r= –0.310$. There was no significant correlation among time to shoot and radial distance, $p= 0.515$, $r= 0.021$; however, ANCOVAs were chosen because violations of both Box's and Levene's tests were significant for all MANCOVA analyses.

ANCOVAs were performed on all of the dependent variables of hit percentage, radial error, and time to shoot. Normality of the dependent variables was assessed via data plots to assess the distributions visually and by examination of Q-Q plots. Hit percentage data was transformed using a cube function to allow for a normal skewness value in the distribution (Tabachnik and Fidell 2013). The distribution outliers were eliminated from the data set by excluding any z-score data value outside of the range –3.27 to 3.27 (99.9%) of the normal distribution, removing 27 outliers, N=966.

The normality for the DVs must be discussed as the hit percentage DV would not be considered normal. Upon further investigation, the data of this set contains a ceiling effect of a high hit percentage for this distance. SMEs would likely affirm that a high hit percentage is the norm for this type of data, especially when target exposure times and circumstances allow long enough response time to acquire and engage these relatively short-range targets for modern rifle performance. For this reason, the assumption of normality was not met because "normal" data of this type and target exposure time would be expected to have a ceiling effect, creating a negative skew in the data. As distances increase, this skewness decreases.

Further assumptions of homogeneity of variance-covariance, or Box's Test, were not available in Statistical Package for Social Sciences (SPSS) for ANCOVA analyses because of the within-subjects only design. Nontransformed data are presented for mean differences and for post-hoc tables to distinguish these data from the cube function transformed data used in statistical analyses. Homogeneity of variance for lane sum deviation measures was assessed previously through F_{max} ratios (Appendix D), which were well below the recommended 10:1 ratio, with the exception of the 100-m data for hit percentage, which yielded a 16:1 variance ratio. The analyses were continued, as this variance ratio is explained by the exceedingly high number of hits at close distance, 100 m, a normal ceiling effect for such data. All ANCOVAs were run using repeated measures procedures in a 4×2×4 model with covariates of velocity and various weapon sight configuration experiences.

8.2 ANCOVAs

Hit Percentage. Mauchly's test of sphericity was violated for all variables of sight type, zero method, and distance, and all interactions. Sphericity could not be assumed for outcome statistics and the Greenhouse-Geisser statistic, with modified degrees of freedom, was used for all univariate analyses. It was determined that Pillai's Trace would be used for all multivariate test statistics over the Wilk's Lambda, as the Pillai's Trace statistic is more conservative and assumes unequal variances among groups (Mertler and Vannatta 2010).

1) Main Effects.

1A-Sight Type. Univariate main effects for sight type were significant for hit percentage, *Pillai's Trace*=(3, 954) = 3.398, $p = 0.017$, partial $\eta_2 = 0.011$. Statistical power reported for sight type was adequate ($1-\beta = 0.768$). The effect size could be considered very small accounting for 1.1% of the explained variance due to treatment. Post-hoc comparisons of adjusted means using Least Significant Difference showed that only iron sights were significantly different from each of the other sight types (Table 1). Statistical power reported for sight type was adequate ($1-\beta = 0.768$).

Table 1 Post-hoc analyses for hit percentage (raw) by sight type

Sight comparison	**p**	**Std. error**	**Mean difference**
Sight comparisons			
Iron Sights–M68	0.003	0.018	–0.162
Iron Sights–M150	0.000	0.018	–0.201
Iron Sights–Vortex Razor 1–6×	0.000	0.018	–0.222
M68–M150	0.191	0.018	–0.039
M68–Vortex Razor 1–6×	0.166	0.018	–0.060
M150–Vortex Razor 1–6×	0.941	0.018	–0.021
Mean values for hit percentage by each sight type			
Iron Sights	Mean = 0.690 SD = 0.323		
M68	Mean = 0.855 SD = 0.198		
M150	Mean = 0.890 SD = 0.188		
Vortex Razor 1–6×	Mean = 0.911 SD = 0.147		

Note: SD = standard deviation

1B-Zero Method.

There were no significant differences for weapon zero method.

1C-Distance. Univariate effects for distance were significant for both hit percentage, *Pillai's Trace*=(3, 954) = 1419.043, $p = 0.000$, partial $\eta_2 = 0.817$, and for distance while controlling for velocity of the ammunition *Pillai's Trace*=(3, 954) = 1987.003, $p < 0.000$, partial $\eta_2 = 0.862$. Both of these effect sizes could be considered very large effect sizes, accounting for 81.7% and 86.2% of the explained variances due to treatment. It can be seen that the concomitant variable, or covariate of velocity of the ammunition, contributed an additional 4.5% of the explained variance in this case. Statistical power reported for both of these main effects was maximized at ($1-\beta = 1.0$).

Post-hoc comparisons of adjusted means using Least Significant Difference showed that all distances were significantly different from each other with the exception of 300–400 m (Table 2). These results are also graphed in Fig. 4. It should be noted in Fig. 4 that dotted boxes incorporate homogeneous data points within that are not significantly different from each other. However, different dotted boxes, as a whole, indicate significant differences from each other.

Table 2 Post-hoc analyses for hit percentage by distance (m)

Distance comparison	p	Std. error	Mean difference
Distance comparisons			
100–200 m	0.001	0.002	0.008
100–300 m	0.000	0.002	0.014
100–400 m	0.000	0.001	0.017
200–300 m	0.002	0.002	0.006
200–400 m	0.000	0.002	0.009
300–400 m	0.083	0.002	0.003
Mean values for hit percentage by distance (m)			
100 m	Mean = 0.992 SD = 0.037		
200 m	Mean = 0.866 SD = 0.205		
300 m	Mean = 0.761 SD = 0.260		
400 m	Mean = 0.705 SD = 0.287		

2) Interaction Effects (Sight Condition by Distance, Controlling for Ammunition Velocity).

Univariate effects for the interaction effect of sight type by distance were significant for hit percentage, *Pillai's Trace* (9, 948) = 1.933, $p = 0.044$, partial $\eta^2 = 0.018$, and for sight type by distance while controlling for the concomitant or covariate of ammunition velocity *Pillai's Trace* = (9, 948) = 2.344, $p < 0.013$, partial $\eta^2 = 0.022$. Both of these effect sizes could be considered very small effect sizes accounting for 1.1% and 2.2% of the explained variances due to treatment, in each of these outcomes, with the concomitant variable explaining an additional 1.1% of the variance. The statistical power reported for each of these effects was very good at $1-\beta = 0.845$, and increasing to 0.917 when accounting for the covariate of ammunition velocity. There were no other significant interaction effects for hit percentage.

Table 3   Mean hit percentage (raw) for interaction of sight type by distance controlling for velocity

Hit percentage comparison	Distances (m) (SD)			
	100	200	300	400
<u>Sight comparisons</u>				
Iron Sights	0.981 (0.061)	0.716 (0.265)	0.545 (0.297)	0.498 (0.345)
M68	1.00 (0.000)	0.897 (0.152)	0.762 (0.215)	0.736 (0.217)
M150	0.995 (0.025)	0.920 (0.153)	0.875 (0.175)	0.765 (0.252)
Vortex Razor 1–6×	0.993 (0.033)	0.941 (0.108)	0.870 (0.169)	0.832 (0.180)

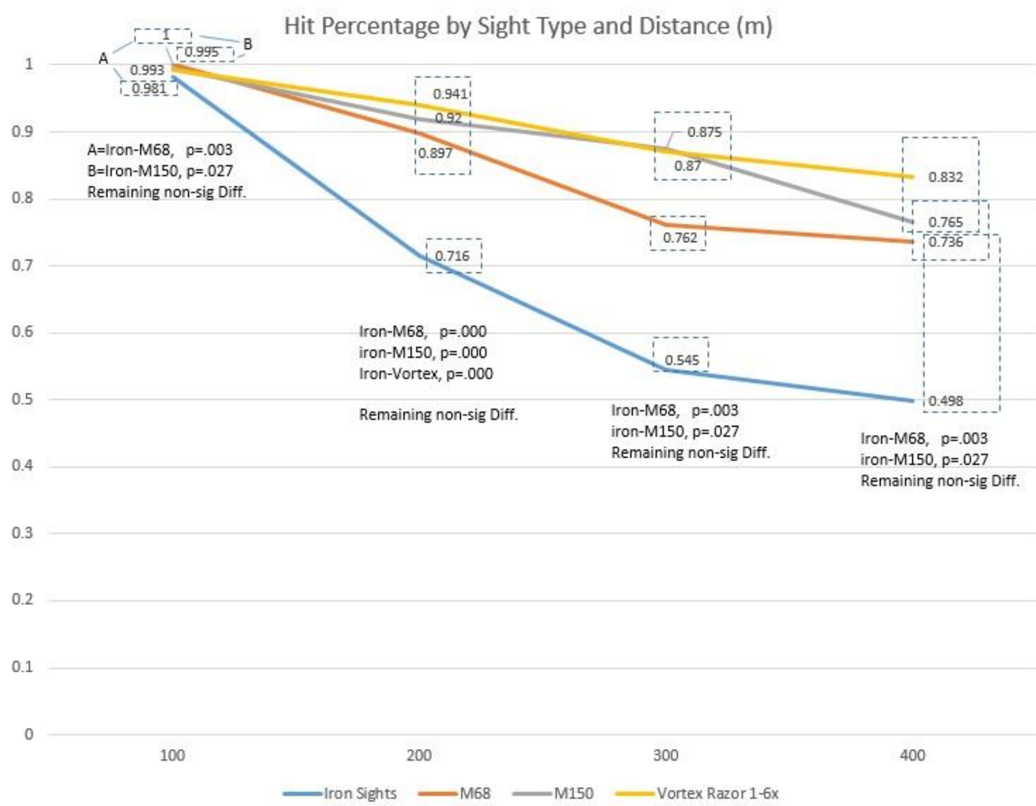

Fig. 4   Hit percentage for sight type by distance controlling for ammunition velocity

Radial Error (inches). Mauchly's test of sphericity was violated for all variables of sight type, zero method, and distance, and all interactions; therefore, the Greenhouse-Geisser statistic was used because sphericity could not be assumed. It was determined that Pillai's Trace would be used for all multivariate test statistics over the Wilk's Lambda, as the Pillai's Trace statistic is more conservative and assumes unequal variances among groups (Mertler and Vanatta 2010).

1) Main Effects.

<u>1A-Sight Type</u>. There were no significant differences for the main effect of sight type.

<u>1B-Zero Method</u>. There were no significant differences for the main effect of zero method.

<u>1C-Distance</u>. There were univariate main effects for distance that were significant for radial error, *Pillai's Trace*=(3, 954) = 1570.750, p = 0.000, partial η_2 = 0.832; for radial error while controlling for velocity of the ammunition *Pillai's Trace*=(3, 954) = 2131.874, p < 0.000, partial η_2 = 0.870, and for radial error while controlling for the concomitant or covariate of iron sight experience *Pillai's Trace*=(3, 954) = 3.786, p < 0.010, partial η_2 = 0.012. The first two of these effect sizes could be considered very large effect sizes, accounting for 83.2% and 87.0% of the explained variances due to treatment. The last effect size would be considered very small, accounting for 1.2% of the explained variance in this case. Statistical power reported for the first two of these main effects was maximized at (1−β =1.0). The third main effect power was reported to be very good at (1−β =0.816). There were no significant differences for the main effects, either sight type or zero method. The means for radial error by distance are shown in Table 4. Post-hoc comparisons of adjusted means using Least Significant Difference showed that three of the six pairwise comparison distances were significantly different from each other (Table 5).

Table 4 Means for radial error by distance

100 m	Mean = 21.057 SD = 3.84
200 m	Mean = 23.366 SD = 6.26
300 m	Mean = 21.061 SD = 7.18
400 m	Mean = 18.445 SD = 7.37

Table 5 Post-hoc analyses for radial error by distance (m)

Task difficulty comparison	**p**	**Std. error**	**Mean difference**
<u>Distance comparisons</u>			
100–200 m	0.249	0.064	–0.074
100–300 m	0.355	0.046	0.042
100–400 m	**0.000**	**0.031**	**0.077**
200–300 m	0.062	0.062	0.116
200–400 m	**0.000**	**0.054**	**0.251**
300–400 m	**0.021**	**0.058**	**0.135**

2) Interaction Effects (Sight Type by Zero Method, Controlling for Iron Sight Experience).

There were significant two-way interactions of sight type by zero method while controlling for iron sight experiences that were significant for radial error, *Pillai's Trace*=(3, 954) = 2.534, p = 0.056, partial η^2 = 0.008. This effect size could be considered very small effect sizes accounting for 0.8% of the explained variances due to treatment. An interesting facet of this is that when iron sight experience is eliminated, the significance changes to nonsignificant (p=0.921). Table 6 clarifies the mean and standard deviation (SD) for each value. There were no other significant interaction effects. These data are shown graphically in Fig. 5. It is interesting to note that the concomitant variable of iron sight experience in this interaction effect changes the reported statistical power (1−β) from 0.070 to 0.627, which is a remarkable change in the power of this interaction effect with the covariate of iron sight experience. There were no other significant interaction effects.

Table 6 Radial distance (inches) (raw) for sight type by zero method controlling for iron sight experience

Hit percentage comparison	Universal	Zero method (SD) individual
Sight comparisons		
Iron Sights	**25.869 (7.347)**	**23.932 (7.302)**
M68	21.124 (5.927)	20.011 (5.011)
M150	**16.960 (5.443)**	**20.159 (5.272)**
Vortex Razor 1–6x	**19.238 (6.014)**	**21.740 (5.668)**

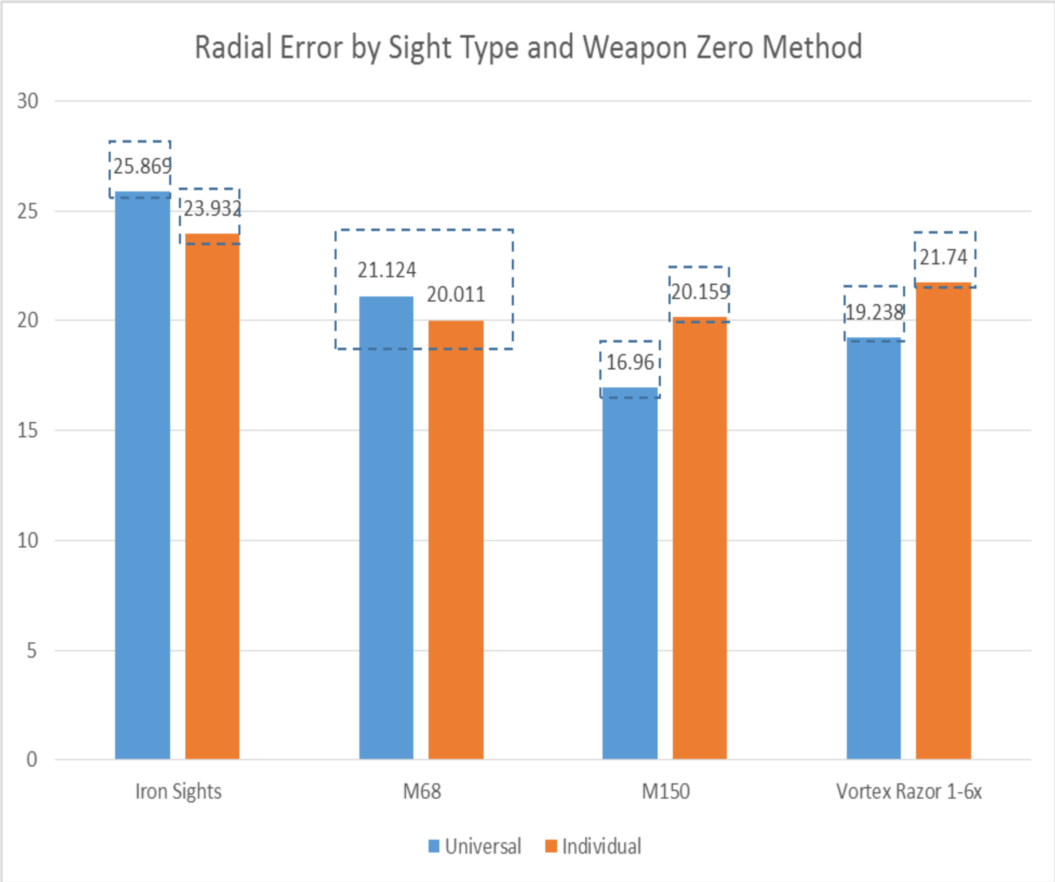

Fig. 5 Radial error for sight type and zero method controlling for iron sight experience

Time to Shoot (seconds). Mauchly's test of sphericity was violated for all variables of sight type, zero method, and distance, and all interactions; therefore, the Greenhouse-Geisser statistic was used because sphericity could not be assumed. It was determined that Pillai's Trace would be used for all multivariate test statistics over the Wilk's Lambda, as the Pillai's Trace statistic is more conservative and assumes unequal variances among groups (Mertler and Vanatta 2010).

1) Main Effects.

1A-Sight Type. There were no significant differences for sight type.

1B-Zero Method. There were no significant differences for zero method.

1C-Distance. There were univariate effects for distance that were significant for both time to shoot (s), *Pillai's Trace*=(3, 954) = 2867.692, p = 0.000, partial η^2 = 0.900 and for time to shoot (s) while controlling for velocity of the ammunition $F(3, 954) = 3538.729$, $p < 0.000$, partial $\eta^2 = 0.918$. These two effect sizes could be considered very large effect sizes, accounting for 90.0% and 91.8% of the explained variances due to treatment. Statistical power (1−β) was 1.00 for both main effects.

Post-hoc comparisons of adjusted means using Least Significant Difference showed that three of the six pairwise comparison distances were significantly different from each other (Table 7).

Table 7 Post-hoc analyses for distance (m) by time to shoot (s)

Task difficulty comparison	p	Std. error	Mean difference
Sight comparisons			
100–200 m	0.000	0.149	–0.684
100–300 m	0.006	0.299	–0.829
100–400 m	**0.001**	**0.379**	**–1.218**
200–300 m	0.422	0.180	–0.145
200–400 m	**0.038**	**0.257**	**–0.534**
300–400 m	**0.001**	**0.117**	**–0.389**
100 m	Mean = 3.50	SD = 0.854	
200 m	Mean = 4.241	SD = 0.840	
300 m	Mean = 4.461	SD = 0.900	
400 m	Mean = 4.888	SD = 0.965	

2) Interaction Effects.

There were no significant interaction effects.

8.3 Discussion

This study examined differences in shooting performance for a Soldier firing an individually zeroed weapon relative to a professionally calibrated or a universal zero. The current investigation sought to explain differences among marksmanship shooting measures via independent variables of sight type, whether zeroed by an individual or from a professionally calibrated zero, and by distance to the target (m). A weapons expert calibrated the weapons used in the experiment to a universal zero and was verified by another SME. The shooting tasks encompassed firing from the prone supported firing position at targets between 100 and 400 m, using four different commonly used weapon sights. The main goal of this study was to determine how zeroing methodology affects shooting accuracy. There are several implications of these findings. The results suggest that using a universal zero may be acceptable in testing events where limited time is available to individually zero several weapons or optics. The results may also make feasible the idea that a weapon with a built-in sight could be "factory zeroed" and never require zeroing, especially modern optics with fixed or variable magnification. The results show that perhaps a rifle with a magnified optic could be mechanically zeroed in a unit and Soldiers could then confirm zero and make minor adjustments at extended ranges.

Target Exposure Time and Hit Percentage. Stern and Yudowitch (1955) were some of the first researchers to examine hit probability as it relates to target exposure time. This study cleverly mapped the differences in aiming error by classifying proficient shooters versus newly trained recruits with no previous shooting experience. Aiming error for both rifles and carbines is presented in Table 8. These data demonstrate a trend for older weapons systems and are not thought to reflect the same pattern for today's military weapons; yet the general trend demonstrates a pattern of increased aiming accuracy as target time increases. The overall aiming error ratio, in mils, for experts to novice shooters was 2.3 to 1 and increases for standing versus prone fire. Unharassed accuracy for permanent targets with the rifle was 3 mils. We suggest that in future studies of this type, that realistic and varying target exposure time ranges be used to represent varying enemy target characteristics.

Table 8 Aiming error (mils) for both rifles/carbines by target exposure time

Target exposure time (s)	1	1.5	2	4	8
Rifle/carbine aiming error	20.3	10.3	7.5	4.5	3.3
Pistol aiming error	40.0	29.0	24.2	19.5	17.2

Radial Aiming Error. Aiming error can be directly associated with marksmanship accuracy under forced target exposure times. For example, Scribner (2002) found that target exposure time for live fire targets significantly affected hit percentage in 2, 3, and 4-s target exposures and hit percentages dropped from 79.9%, to 67.0%, to 31.9%, respectively. Based on previous studies, it is expected that target exposure time will significantly affect accuracy by decreasing hit percentage and accuracy on multiple measurement regimes as target exposure time decreases. Further, it is also expected that hit percentage and accuracy will suffer a degradation of at least 50% under this set of target exposure times, based on previous research. We suggest that, to more realistically understand the utility of a military rifle optic, specific target exposure times be used to examine radial aiming error data, which should change systematically with changing target exposures.

Muzzle Velocity Changes. The change in muzzle velocity can change the vertical drop of any cartridge (Litz 2014). The idea is to minimize the spread in velocity, or at least characterize the ammunition to know the spread in velocity prior to shooting studies.

Individual Differences. Individual differences have been shown to be significant in many human performance studies (Weaver et al. 2003). There are a number of individual differences in shooters and marksmen that may be readily assessed with available metrics and tests. These may include such differences as age, time in service, experience, physical/anthropometric differences, physical fitness, steadiness of hold, dextrality, visual acuity, and even cognitive factors (Scribner et al. ND). In this study, self-reported experience ratings with the different sight configurations were used to characterize the primary individual differences.

Visual Acuity. For an example that applies to this study, there is a strong relationship between visual acuity and marksmanship performance (Du Toit et al. 2011, Wells et al. 2009). Specifically, Wells et al. reported a statistically significant correlation of 0.735 between marksmanship scores and visual acuity, with marksmanship scores decreasing with acuity scores dropping from 20/25 to 20/50. There were no outcomes of a covariant of visual acuity in any of the marksmanship performance measures in this study, and it is not known why, other than that the homogeneity of the variance was too high.

9. Conclusions and Recommendations

There were some significant differences between universal and individual zero. In particular, the individual zero was more beneficial to marksmanship performance in terms of hit percentage, while a universal zero was more beneficial in hit percentage for the magnified optics. Future studies may be held to further validate these findings and possibly examine methods that would allow for methods to universally zero a weapon with only one or two shots fired. This could save time, ammunition, and cost. Range time could be used for teaching marksmanship skills and focus higher level marksmanship training. There were several covariate effects as well, which will be discussed in the recommendations.

Recommendations:

1) **Velocity Data.** Because the covariate of ammunition velocity is so strongly associated with the dependent variables, it is suggested that future shooting studies capture a) the lot descriptor of ammunition shot in the study and b) a random sample of each lot's velocities to establish a range of velocity changes within the ammunition. As highly technical as shooting sports and

marksmanship may be, skilled marksmen know that increased ammunition velocity changes are undesirable in terms of mechanical accuracy. The lot number, round specifications, and velocity spread sample at the muzzle should be captured in all future shooting studies.

2) **Individual Shooter Experience.** All shooter experience and pre-experimental shooting performance should be captured, as these are also highly important and influential individual differences to capturing more variance within the error term of dependent variables (Stafford et al. 2004; Weaver et al. 2003).

3) **Zero Methodology.** While this study did not capture absolute evidence of the effect of zeroing, it did yield findings that indicate that there is more to be learned in this area. Trends indicated that individual zero was slightly more beneficial for iron sights with no significant differences for the M68, a nonmagnified optic, while there were significant advantages for a universal zero method for the M150 and Vortex 1–6× optic, both capable of 4× magnification or greater. This requires further study, of which the outcomes could greatly affect training time and costs associated with marksmen.

4) **Shooting Model.** A shooting model such as a multiple regression model or structural equation model of shooting data should be created to examine the multiple connections among different variables in the shooting process. While not significant in this study, other individual differences such as visual acuity should be checked as an important component of marksmanship performance (Daniels 1981).

10. References

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Appendix A. Demographic Data

Table A-1 Demographic data

Subject	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Handedness	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Left or right eye to aim weapon	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
M4Carbine/M16 rifle qualification	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Difficulties seeing objects in daytime	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Optical or thermal sights ease of use	2	1	0	2	1	0	2	3	1	2	4	2	0	1	3	3
Iron sights ease of use	3	1	1	2	4	3	1	2	1	3	4	2	1	2	2	5
M68 reflex sight ease of use	1	1	1	1	2	2	1	0	1	1	2	2	1	0	2	2
ACOG ease of use	1	1	1	1	1	1	1	1	1	1	1	4	1	2	2	1
Vortex ease of use	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0

Notes: R = right; L = left; Y = yes; N = no
Ease of use: 0 = no experience; 5 = very difficult; 4 = difficult; 3 = neutral; 2 = easy; 1 = very easy

Appendix B. Visual Acuity Data

Table B-1 Eye sight

TP	Right eye	Left eye	Both eyes
1	20/20	20/25	20/25
2	20/20	20/20	20/13
3	20/15	20/15	20/13
4	20/20	20/20	20/20
5	20/40	20/30	20/25
6	20/13	20/13	20/13
7	20/25	20/25	20/20
8	20/20	20/20	20/20
9	20/15	20/25	20/20
10	20/20	20/15	20/15
11	20/25	20/25	20/20
12	20/13	20/13	20/13
13*	20/100	20/50	20/50
14	20/20	20/25	20/15
15	20/15	20/15	20/20
16	20/15	20/15	20/15

* Did not have glasses

Appendix C. Assignment Order of Zero Type and Weapon Sight/Optics for Each Test Participant

Table C-1 Assignment order of zero type and weapon sight/optics for each test participant

Participant	Scenario order							
1	A-1	A-2	C-2	C-1	B-2	B-1	D-1	D-2
2	C-1	C-2	A-2	A-1	D-2	D-1	B-1	B-2
3	B-2	B-1	D-1	D-2	A-1	A-2	C-2	C-1
4	D-2	D-1	B-1	B-2	C-1	C-2	A-2	A-1
5	B-1	B-2	C-1	C-2	D-1	D-2	A-1	A-2
6	C-2	C-1	D-2	D-1	A-2	A-1	B-2	B-1
7	D-1	D-2	A-1	A-2	B-1	B-2	C-1	C-2
8	A-2	A-1	B-2	B-1	C-2	C-1	D-2	D-1
9	A-2	A-1	D-2	D-1	C-2	C-1	B-2	B-1
10	D-1	D-2	C-1	C-2	B-1	B-2	A-1	A-2
11	B-1	B-2	A-1	A-2	D-1	D-2	C-1	C-2
12	C-2	C-1	B-2	B-1	A-2	A-1	D-2	D-1
13	A-1	A-2	C-2	C-1	D-2	D-1	B-1	B-2
14	D-2	D-1	B-1	B-2	A-1	A-2	C-2	C-1
15	C-1	C-2	A-2	A-1	B-2	B-1	D-1	D-2
16	B-2	B-1	D-1	D-2	C-1	C-2	A-2	A-1

Notes: A = iron; B = M68; C = vortex; D = ACOG; 1 = individual zero; 2 = universal zero

Appendix D. F_{max} Variance Ratios of Dependent Variables for ANCOVA Analyses

Table D-1 F_{max} variance ratios of dependent variables by sight type (n = 16)

Dependent variables	Independent variable level (Sight type)	Variance		
		Variance	High/low	F_{max} ratio
Hit percentage	Iron	0.158	High	1.858
Hit percentage	M688	0.116	…	…
Hit percentage	M150	0.101	…	…
Hit percentage	Vortex	0.085	Low	…
Radial error	Iron	54.370	High	1.797
Radial error	M688	30.250	Low	…
Radial error	M150	31.174	…	…
Radial error	Vortex	35.630	…	…
Time to shoot	M688	1.059	…	…
Time to shoot	M150	0.923	…	…
Time to shoot	Moderate	1.145	High	1.305
Time to shoot	Vortex	0.877	Low	…

** Using variances from Explore function in SPSS V22.0.

Table D-2 F_{max} variance ratios of dependent variables (n = 16)

Dependent variables	Independent variable level (Zero method)	Variance		
		Variance	High/low	F_{max} ratio
Hit percentage	Universal	0.126	High	1.067
Hit percentage	Individual	0.118	Low	…
Radial error	Individual	48.769	Low	…
Radial error	Universal	36.166	High	1.348
Time to shoot	Universal	1.031	Low	…
Time to shoot	Individual	1.033	High	1.001

Table D-3 F_{max} variance ratios of dependent variables by target distance (n = 16)

Dependent variables	Independent variable level (Target distance)	Variance		
		Variance	High/low	F_{max} ratio
Hit percentage	100 m	0.008	High	16.125
Hit percentage	200 m	0.104	…	…
Hit percentage	300 m	0.134	…	…
Hit percentage	400 m	0.129	Low	…
Radial error	100 m	14.726	Low	…
Radial error	200 m	38.891	…	…
Radial error	300 m	19.368	…	…
Radial error	400 m	56.119	High	3.810
Time to shoot	100 m	0.728	…	…
Time to shoot	200 m	0.705	Low	…
Time to shoot	300 m	0.809	…	…
Time to shoot	400 m	0.924	High	1.310

*Using variances from Explore function in SPSS V22.0.
** Exceeds F_{max} recommended ratio of 10:1. Due to high number of hit percentage at 100 m.

List of Symbols, Abbreviations, and Acronyms

3-D	3-dimensional
ACOG	Advanced Combat Optical Gunsight
ANCOVAs	Analyses of Covariance
ARL	US Army Research Laboratory
CCO	Close Combat Optic
DV	dependent variable
HRED	Human Research and Engineering Directorate
MANCOVAs	Multivariate Analyses of Covariance
SD	standard deviation
SME	subject matter expert
SPSS	Statistical Package for Social Sciences

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