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Analysis of Pellet Patterns and GSR Produced from Judge Taurus Revolvers

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Copyright Statement

ANALYSIS OF PELLET PATTERNS AND GSR PRODUCED FROM JUDGE TAURUS REVOLVERS

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Forensic Science at Virginia Commonwealth University

by

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Abstract

ANALYSIS OF PELLET PATTERNS AND GSR PRODUCED FROM JUDGE TAURUS REVOLVERS

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The Taurus Judge is a five-shot revolver designed to fire both 410 Bore shotshells and caliber 45 (Long) Colt cartridges. It is marketed as a self-defense firearm by Taurus. As of 2010, the Taurus Judge was "quickly becoming a popular personal defense firearm".[1] Although it has become somewhat popular, the Taurus Judge and its various models have not had many distance determination studies completed and there is still a dearth of information on how these handguns compare with shotguns when looking at range of fire determinations. This study focused on: how barrel length affected pellet spread patterns produced by the Taurus Judge, how patterns produced by the Judge revolvers compared with traditional smoothbore shotgun patterns, and if GSR analysis would aid in distance determination for handguns firing shotshells.

First, test ammunition was selected from common types observed in casework. Fifteen birdshot and two buckshot shotshell types were tested. The birdshot pattern measurements were analyzed and using one-way ANOVA; buckshot measurements were compared using a Welch two-sample t-test and a boxplot. From these comparisons, a single birdshot load (Winchester AA Target Load 410 2.5in Max ½oz 9 Shot) and a single buckshot load (Remington HD Ultimate Home Defense 410 2.5in 1225 FPS 4 Pellet 000BK) were selected.

Each of the nine firearms was fired five times into blotter paper, both birdshot and buckshot loads, at the following muzzle-to-target distances: 1ft, 2ft, 4ft, 8ft, and 16ft. GSR testing patterns were made by firing each firearm three times into 12in square cotton twill, using both shotshell loads, at: 0.5ft (6 in), 1ft (12 in), 1.5ft (18 in), and 2ft (24 in). Only two sets of GSR patterns, produced by the A1 (Taurus Judge, 2in barrel) and B1 (Taurus Judge, 3in barrel) firearms using the birdshot load, were processed with only the Modified Griess test. All data was analyzed using two-way ANOVA with interaction, to determine if firearm type (barrel length) and distance significantly affected diameter. This analysis was followed by a comparison of Least Square Means (lsmeans) to ascertain where statistical differences lay.

A review of the data suggests that there is no relationship between barrel length and pellet spread size in regards to the Taurus Judge. It was also determined that there is indeed a statistical difference in pellet pattern spread between the shotguns and revolvers beginning at the 4ft range and that GSR could prospectively further differentiate between patterns.

Introduction

The Taurus Judge is a five-shot revolver designed to fire both 410 Bore shotshells and caliber 45 (Long) Colt cartridges. It is marketed as a self-defense firearm by Taurus. As of 2010, the Taurus Judge was "quickly becoming a popular personal defense firearm".[1] The concept of this research project originated with a case investigation at the Virginia Department of Forensic Science (DFS) involving a distance determination examination using the Taurus Judge revolver and both birdshot and buckshot patterns. A literature review performed by the DFS examiner found a lack of studies regarding pellet patterns fired from a handgun. Although it has become somewhat popular, the Taurus Judge and its various models have not had many distance determination studies completed and there is still a dearth of information on how these handguns compare with shotguns when looking at range of fire determinations.

The first area that will be considered in this research is how barrel length affects pellet spread patterns produced by the Taurus Judge revolver. Taurus produces the Judge in several barrel lengths (2in – Public Defender, 3in, and 6.5in), two cylinder lengths (2.5in and 3in), and two finishes (Matte Stainless and Matte Black Oxide). Judge revolvers of differing barrel length will be compared with each other to determine if the shorter revolver barrels reflect the same results as observed in previous research conducted on smoothbore barrel shortening effects on shotgun pellet patterns. It has long been established in the field of firearms examination that shorter shotgun barrels produce larger, more dispersed patterns than longer barrels at the same distance due to "blast effects at the muzzle [which] accelerate the lateral spread of the pellets".[4]

Besant et al. and Gibson and Glass have also addressed the effect of rifled shotgun barrels on pellet spread patterns, finding that the centrifugal forces acting on the shot column by the rifling causes larger, wider patterns at equivalent distances compared to their smoothbore

counterparts.[2,3] It has not yet been established if this principle carries over for handguns designed to fire shotshells. Part of this study will focus on patterns produced by the Judge revolvers, which are rifled, compared with traditional smoothbore shotgun pellet patterns to see how significant a difference is observed at the same distances. Minorly, Besant and Gibson/Glass have also described a phenomenon of rifled shotgun barrels referred to as the "doughnut pattern" effect, the distribution of the shot pellets in either circular pattern with a hollow center or a circular pattern with a cluster of pellets in the center of the pattern.[2,3] It would be interesting to note any observations of this patterning effect resulting from the rifled barrel of the Judge revolvers. It is possible that this phenomenon may not be observed due to the shortness of the barrels. The centrifugal forces observed in the longer rifled shotgun barrels may be minimized due to the plastic shot protectors not significantly engaging with the rifling.

Finally, gunshot residue (GSR) from each firearm was to be analyzed using the Modified Griess test and sodium rhodizonate test at: 0.5ft (6in), 1ft (12in), 1.5ft (18in), and 2ft (24in) range distances. Due to limitations discussed later, only two revolvers were able to be fully processed with the Modified Griess test and sodium rhodizonate testing was not done. Shot pellet patterns are not normally subjected to GSR analysis due to the nature of the shotshell components and the typical longer range at which a shotgun would normally be used. Muzzle-to-target distance determination would generally be based on the pellet spread/dispersion. However, a handgun like the Taurus Judge may be used at ranges close enough to produce GSR patterns significant enough for distance determination, similar to the traditional distance determination exams associated with handgun and rifle ammunition (i.e. single projectile ammunition). Considering both GSR and pellet spread may be beneficial for distance determination when dealing with a case involving shotshell ammunition fired from a handgun.

Materials and Methods

The test firearms were provided by the various regional laboratories within the Virginia DFS. Six Taurus Judge Revolvers and three 410 Bore shotguns of varying barrel length were provided for study. Their designation, respective brand, model, serial number, barrel length, and cylinder length are described in Table 1. All test fires were completed in the Virginia DFS Central Laboratory firing range using a remote firing device. All statistics were completed at 95% confidence interval. All of the pattern measurements and chemical processing was completed at Virginia Commonwealth University.

Ammunition Selection

The test ammunition was selected from the variety of common types observed in casework and also provided by the Virginia DFS. The list of ammunition tested for selectivity is listed in Table 2. Firearm A1 was mounted to a remote firing device, and test fired five times into blotter paper at a muzzle-to-target distance of eight feet using shotshells pulled from five separate boxes of ammunition. In total, 85 patterns were created. After every shot, the distance was re-measured and confirmed by two examiners using a standard calibrated laboratory tape measure. Once a set of five patterns was completed, the firearm bore was cleaned with a cloth patch. Pellet spread from the resulting patterns were measured using a yardstick and recorded, focusing on the largest distance observed between pellets on the outer edge of the patterns. Fifteen birdshot and two buckshot shotshell types were tested. The birdshot pattern measurements were analyzed utilizing R and using one-way ANOVA; buckshot measurements were compared using a Welch two-sample t-test and a boxplot. From these comparisons, a single birdshot load (Winchester AA Target Load 410 2.5in Max ½oz 9 Shot) and a single buckshot load (Remington HD Ultimate Home Defense 410 2.5in 1225 FPS 4 Pellet 000BK) were

selected for testing. This decision was based on how representative the ammunition was compared to the other ammunition types (the Winchester No. 9 shared the most groups) and by the distribution of data (the Remington 000BK did not exhibit outliers).

Distance Determination

Upon choosing the shotshell loads, fresh boxes of ammunition were purchased, and the lot numbers for each are described in Table 3. One random shotshell per box was preserved for disassembly, to ensure consistency of weight/amount of the shot pellet and powder load between boxes of ammunition. Each of the nine firearms was fired five times into blotter paper, using each of the selected birdshot and buckshot loads, at the following muzzle-to-target distances: 1ft, 2ft, 4ft, 8ft, and 16ft. In total, 450 patterns were created. Each set of five shotshells described above was selected by removing one shotshell randomly from five separate boxes of ammunition. The remote firing device was used for the test firing of the weapons, and the distance was measured using a standard calibrated laboratory tape measure. The distance was re-measured between shots and each firearm bore was cleaned using a cloth patch after each set of five patterns.

Each blotter paper target was preserved and the diameter for each pattern was measured using a yardstick and recorded. This data was analyzed using two-way ANOVA with interaction in R, to determine if firearm type (barrel length) and distance significantly affected pellet spread diameter. This analysis was followed by a comparison of Least Square Means (lsmeans) to ascertain which patterns were statistically similar or different. Line graphs were created for both sets of data by plotting the diameter means of each range for every firearm.

Modified Griess Test

GSR testing patterns were made for each firearm. All nine weapons were fired three times into 12-in square cotton twill, using each of the birdshot and buckshot loads, at each of the following muzzle-to-target distances: 0.5ft (6 in), 1ft (12 in), 1.5ft (18 in), and 2ft (24 in). In total, 216 patterns were created. As stated previously, the remote firing device was used for test firing of the weapons. The distance was measured from muzzle to target material using a standard calibrated laboratory tape measure and re-measured between shots. Each firearm bore was cleaned using a cloth patch after each set of three patterns.

Only two sets of GSR patterns, produced by the A1 (Taurus Judge, 2in barrel) and B1 (Taurus Judge, 3in barrel) firearms using the birdshot load, were processed with only the Modified Griess test. Scaled photographs were taken of the original patterns and the resulting Modified Griess test patterns. HP Glossy Advanced Photo Paper for Inkjet (8.5 x 11 inches) was used instead of the traditional desensitized emulsion-based photographic paper, as it was found to be an effective and affordable alternative.[5,6] A solution that contained 0.75g of sulfanilic acid to every 150mL of deionized water was created and designated “Solution 1”. Another solution that contained 0.42g of alpha-naphthyl for every 150mL of methanol was created and designated “Solution 2”. Each sheet of photo paper was submerged in a bath containing equal parts of Solution 1 and 2. They were then removed, hung by binder clips on a wooden drying rack, and allowed to dry for approximately thirty minutes. Only one sheet of treated photo paper was necessary to process the 0.5ft (6in) test patterns. Two sheets were taped together for processing 1ft (12in) test patterns and four sheets were taped together to process the 1.5ft (18in) and 2ft (24in) test patterns.

The treated photo papers were placed into a fume hood and tested on each corner with a positive control nitrite swab dampened with 15% glacial acetic acid solution. Once the orange

positive reaction was noted, the corresponding test pattern was placed on top of the treated photo paper for processing. A piece of cheese cloth of corresponding size to the test pattern was saturated with the 15% glacial acetic acid solution and then squeezed to remove excess solution. Finally, an iron on the max heat setting was applied to the entirety of the test pattern, producing an orange nitrite (Modified Griess) pattern on the treated photo paper.

Each Modified Griess pattern was measured at both the outer-most and inner-most diameters. The outer-most diameter was defined as the largest distance between the positive reactions on the outer edge of the pattern. The inner-most diameter was defined as the largest distance containing the core of the pattern (i.e. the highest density area of the pattern). Both sets of data were analyzed using two-way ANOVA with interaction in R, to determine if firearm type (barrel length) and distance significantly affected the size of the nitrite (Modified Griess) pattern diameter. Once again, this analysis was followed by a comparison of lsmeans to ascertain which patterns were statistically similar or different.

Results

Ammunition Selection

The one-way ANOVA was used in order to detect any significant differences in pellet pattern diameters between the different varieties of shotshells tested, Table 4. Since the p-value returned was $3.62e^{-11}$, which is less than α: 0.05, it can be confirmed that there is a significant difference. Least square means for multiple comparisons was subsequently used afterwards, as shown in Table 5 and Figure 1. The Winchester AA Target Load 410 2.5in Max ½oz 9 Shot shotshell was found to be the least significantly different from the other test ammunition loads, being the only one to share four groups. The buckshot loads were compared via a Welch two-sample t-test to determine if there was a statistically significant difference between the two types.

The p-value was found to be 0.03036, which is less than α: 0.05, confirming that there is a significant difference. This difference was further investigated by creating boxplots for each shotshell type, as seen in Figure 2. The Remington 000 Buck load exhibited evenly distributed data that fell within the inner and outer fences, whereas the Federal did not and exhibited an outlier as its max value.

Distance Determination

A line graph plotting the diameter means was first created in Excel to visualize the pellet pattern trends, Figure 3. Two-way ANOVA was completed to determine if distance, firearm type, or a combination of both factors had a significant effect on the diameter of pellet spread for the birdshot patterns, Table 6. This table indicates that both the main effects (firearm type and distance) and the interaction effect (joint effect of both) were significant, as the p-value was less than α: 0.05. The comparison of lsmeans was completed afterwards, shown in Tables 7 and 8 and Figure 4. This analysis revealed that the Judge Taurus revolvers were not significantly different up to the 4ft range. Once the 8ft and 16ft ranges are reached however, the revolvers become more divergent and are significantly different from their lower range patterns but still overlap with each other in respect to firearm type (barrel length).

At low muzzle-to-target distance ranges, 1ft to 2ft, the shotguns were not able to be differentiated from the Judge revolvers. Upon reaching 4ft, the shotgun pellet spread patterns are significantly different from those of revolvers at 4ft, but not significantly different from revolver patterns at 1ft and 2ft. This trend continues at 8ft and 16ft distances. The shotgun patterns are significantly different from the revolver patterns at those ranges, but are still not significantly different from revolver patterns at lower muzzle-to-target distance ranges.

The same procedure, described previously, was used to analyze the buckshot distance patterns. A line graph was created (Figure 5) and as shown by the two-way ANOVA with interaction in Table 9, both the main effects and the interaction effect were significant at α: 0.05. The comparison of lsmeans was completed as described by Tables 10 and 11 and Figure 6. Similar to the birdshot comparison, shotguns and revolvers were indistinguishable at the lower distance ranges of 1ft and 2ft and began to separate at the 4ft range. By the 8ft and 16ft distance ranges, the shotguns were significantly different again. One trend that was only seen in the buckshot, was that the revolvers were essentially not significantly different from one another at 16ft, except for one outlier, B2 (Taurus Judge, 3in barrel).

Modified Griess Test

Again, two-way ANOVA was used to determine if distance, firearm type, or a combination of both factors, had a significant effect on the outer-most diameter of the Modified Griess patterns, Table 12. While the main effects were significant at p-values less than α: 0.05, the interaction effect was not, with a p-value of 0.1736. A comparison of the lsmeans was completed and recorded in Tables 13 and 14. A1 (Taurus Judge, 2in barrel) was significantly different from B1 (Taurus Judge, 3in barrel) at the 0.5ft (6in) range but was indistinguishable at every range following that.

This analysis was also applied to the inner-most diameter of the Modified Griess patterns, which found that the main effects and the interaction effect were all significant, Table 15. The comparison of the lsmeans (Tables 16 and 17) revealed that while not significantly different at the 0.5ft (6in) range, A1 and B1 were significantly different at each respective range beyond.

Limitations

Several limitations were noted due to schedule changes and laboratory closures related to the coronavirus pandemic. First, the shotshells that were reserved for disassembly were unable to be disassembled, thus we are unable to confirm that the weight/amount of the shot pellet and powder load were consistent between boxes of ammunition; however, a significant difference was not expected, especially for boxes of ammunition sharing the same lot number from the manufacturer. This quality check step will be completed in the near future.

Second, the majority of the GSR patterns were unable to be processed using the Modified Griess test, and as a result, sodium rhodizonate processing for lead residues was not completed. Without a full GSR analysis, only partial conclusions can be drawn from the limited Modified Griess data currently available.

Third, the test pattern measurements were not verified by a second examiner, which was originally intended as a quality control check. This step will also be completed as soon as possible, since having the second examiner verify the data would add to the reliability of the data.

Finally, it was discovered during Modified Griess processing that a batch of cotton twill used to produce the GSR patterns was found to contain an interfering substrate, most likely due to treatment during manufacture. As a result, the treated photo paper would exhibit a light orange haze after processing the test pattern. The issue was isolated to the cotton twill using negative and positive controls. While it was still possible to distinguish the positive nitrite point reactions on the treated photo paper and measure the inner and outer diameters of patterns, this interference may have obscured some data points.

Conclusion

One of the main objectives of this study was to determine if barrel length in Taurus Judge revolvers significantly affected pellet spread and, if so, at what distance ranges. A review of the data suggests that there is no clear proven relationship between barrel length and pellet spread size in regards to the Taurus Judge. The "C" set of Judge revolvers have the longest barrel (6.5in), yet they did not consistently produce the smallest mean diameter patterns among the revolvers. This can be seen in Figures 3 and 5, as well as any of the lsmeans tables. C1 did, however, create smaller patterns when compared to C2. Similarly, B1 (3in) created smaller patterns than B2 (3in). This is likely due to the difference in cylinder length (3in vs. 2.5in), allowing the shot to stay together for slightly longer before engaging the barrel.

Alternatively, the "A" set of revolvers had the shortest barrels (2in), but simultaneously had A1 produce the smallest patterns and A2 produce the largest patterns at 16ft when firing birdshot. A1 and A2 were the same in regards to barrel and cylinder length. While a numerical relationship between barrel length and pellet spread diameter was unable to be generated, these observations do support current distance determination methodology. The specific suspect firearm must be used in distance determination for accurate results, as all guns are unique, even the same make and model. Minorly, no "doughnut pattern" effects as described by Besant and Gibson/Glass were observed.[2,3]

Another objective was to determine if Judge revolvers could be differentiated from shotguns and, if so, at what ranges. It has been determined that there is indeed a statistical difference in pellet pattern spread between the shotguns and revolvers beginning at the 4ft range. This separation was more delineated in the birdshot patterns, but still visible in the buckshot patterns. This culminated in full divergence once the 8ft range was reached. However, long range

shotgun patterns can still be mistaken for short range revolver patterns, as they are not significantly different.

Finally, the last objective was to identify if GSR analysis would be useful in providing a more accurate distance determination for the Taurus Judge. While the GSR analysis cannot be considered complete in this study, the inner-diameter Modified Griess test pattern comparisons show promise. Past the 0.5ft (6in) range, A1 (Taurus Judge, 2in barrel) can be statistically differentiated from B1 (Taurus Judge, 3in barrel) when firing birdshot.

Being able to differentiate shotguns and the Taurus Judge pellet patterns starting from 4ft ranges just by pellet pattern spread/dispersion could potentially be directly applied at a crime scene. Knowing what size patterns could be formed in fixed distances, like within the confined space of a bedroom, could help direct the police search towards a handgun or a shotgun. Currently however, this procedure is flawed in that it cannot determine significant difference between the different revolvers themselves, or between short-range revolver patterns and long-range shotgun patterns. This is where GSR analysis could provide insight, establishing more accurate results. From just one small set of Modified Griess results, it can be suggested that a full GSR analysis could significantly differentiate these subsets.

Future directions of this work would assuredly include an in-depth analysis of Modified Griess and sodium rhodizonate processing of all of the test patterns. Further analysis using more firearms and a similar procedure would be beneficial in validating this study. Each firearm is unique in its wear and tear and brand-new firearms could possibly perform significantly differently than those that have been used. Finally, utilizing known patterns to create statistical models for more accurate distance determinations of unknown patterns would be a future goal.

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Tables and Figures

Table 1. Descriptions of Firearms provided by the Virginia DFS

Designation	**Brand**	**Model**	**Serial Number**	**Barrel Length**	**Cylinder Length**
A1	Taurus	Judge/Public Defender	CT833429	2in	2.5in
A2	Taurus	Judge/Public Defender	ES441742	2in	2.5in
B1	Taurus	Judge	FS619726	3in	3
B2	Taurus	Judge	BR616183	3in	2.5in
C1	Taurus	Judge	DX313644	6.5in	3in
C2	Taurus	Judge	ZH415624	6.5in	2.5in
D1	H&R	Topper Jr. Model 490	AP280954	13.625in	N/A
D2	H. Koon Inc	Snake Charmer	73230	18.125in	N/A
D3	H&R	Model 088	A2449831	25.125in	N/A

Table 2. Test Ammunition Descriptions

#	**Ammunition Details**	**Box#**	**Lot#**
1	Winchester AA Target Load 410 2.5in Max ½oz 9 Shot	980	G2PK22
2	Remington Tournament Skeet Load No.9	805	BE18A512
3	Federal 410 2.5in ½oz 9 shot	1082	73 V076
4	Winchester Super X HS High Brass Game Load 410 2.5in 1245 FPS ½oz 6 shot	1065	D1CA28
5	Winchester Super X HS High Brass Game Load 410 2.5in 1245 FPS ½oz 7.5 shot	1069	HIYC24
6	Winchester Super X HS High Brass Game Load 410 2.5in 1245 FPS ½oz 4 shot	1087	H1CA19
7	Federal Premium 410 Handgun 2.5in 7/16oz 4 Shot 950 FPS	1083	35VM048
8	Federal Premium 410 Handgun 2.5in 7/16oz 4 Shot 1200 FPS	1083	35UX512
9	Remington Express Long Range 410 2.5in Max ½oz 4 Shot	367	CS19G512
10	Remington Express Long Range 410 2.5in Max ½oz 6 Shot	1080	AU19U512
11	Remington Express Long Range 410 2.5in Max ½oz 7.5 Shot	368	CC26P512
12	Winchester AA Target Load 410 2.5in Max ½oz 8.5 Shot	1037	G1ED04
13	Federal Gold Medal 410 ½oz 2.5in Max No. 8.5	80	74 Y236
14	Remington Target Load 410 2.5in Max ½oz 8.5 Shot	806	BD29K512
15	Winchester AA Super Sport 410 2.5in 1300 Velocity ½oz 8 Shot	N/A	D3GH20
16	Remington HD Ultimate Home Defense 410 2.5in 1225 FPS 4 Pellet 000BK	1090	S22NB523
17	Federal Premium 410 Handgun 2.5in 4 Pellets 000BK 850 FPS	1088	34UJ648

Table 3. Birdshot and Buckshot Box Numbers and Lot Numbers

Brand	**Box#**	**Lot#**
Winchester No. 9	1 – 10	D2MK15
Winchester No. 9	11, 12	D2NI17
Winchester No. 9	13 – 17	D1NE25
Remington 000BK	1 – 10	A15OC523
Remington 000BK	11 – 27	A25RB523

Table 4. One-way ANOVA Birdshot Ammunition Selection

```
             Df Sum Sq Mean Sq F value   Pr(>F)
ammo$Brand   14 237.43  16.959   10.18 3.62e-11 ***
Residuals    60  99.93   1.666
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Table 5. Birdshot Ammunition Selection lsmeans for Multiple Comparison. Groups sharing a letter are not significantly different at α: 0.05, Tukey adjusted.

Brand	lsmean	SE	df	lower.CL	upper.CL	.group
Winchester 1087	8.62	0.577	60	6.87	10.4	a
Remington 805	9.35	0.577	60	7.59	11.1	ab
Remington 367	10.32	0.577	60	8.57	12.1	abc
Remington 1080	10.57	0.577	60	8.82	12.3	abc
Federal 1083 950	10.85	0.577	60	9.09	12.6	abc
Federal 1083 1200	11.15	0.577	60	9.39	12.9	abc
Winchester 980	11.50	0.577	60	9.74	13.3	abcd
Winchester 1065	11.55	0.577	60	9.79	13.3	bcd
Remington 368	11.88	0.577	60	10.12	13.6	bcd
Winchester 1069	12.18	0.577	60	10.42	13.9	bcd
Winchester 1037	12.47	0.577	60	10.72	14.2	cd
Federal 1082	12.72	0.577	60	10.97	14.5	cde
Federal 80	14.05	0.577	60	12.29	15.8	de
Winchester No.8	14.10	0.577	60	12.34	15.9	de
Remington 806	15.60	0.577	60	13.84	17.4	e

Confidence level used: 0.95
Conf-level adjustment: sidak method for 15 estimates
P value adjustment: tukey method for comparing a family of 15 estimates
significance level used: alpha = 0.05

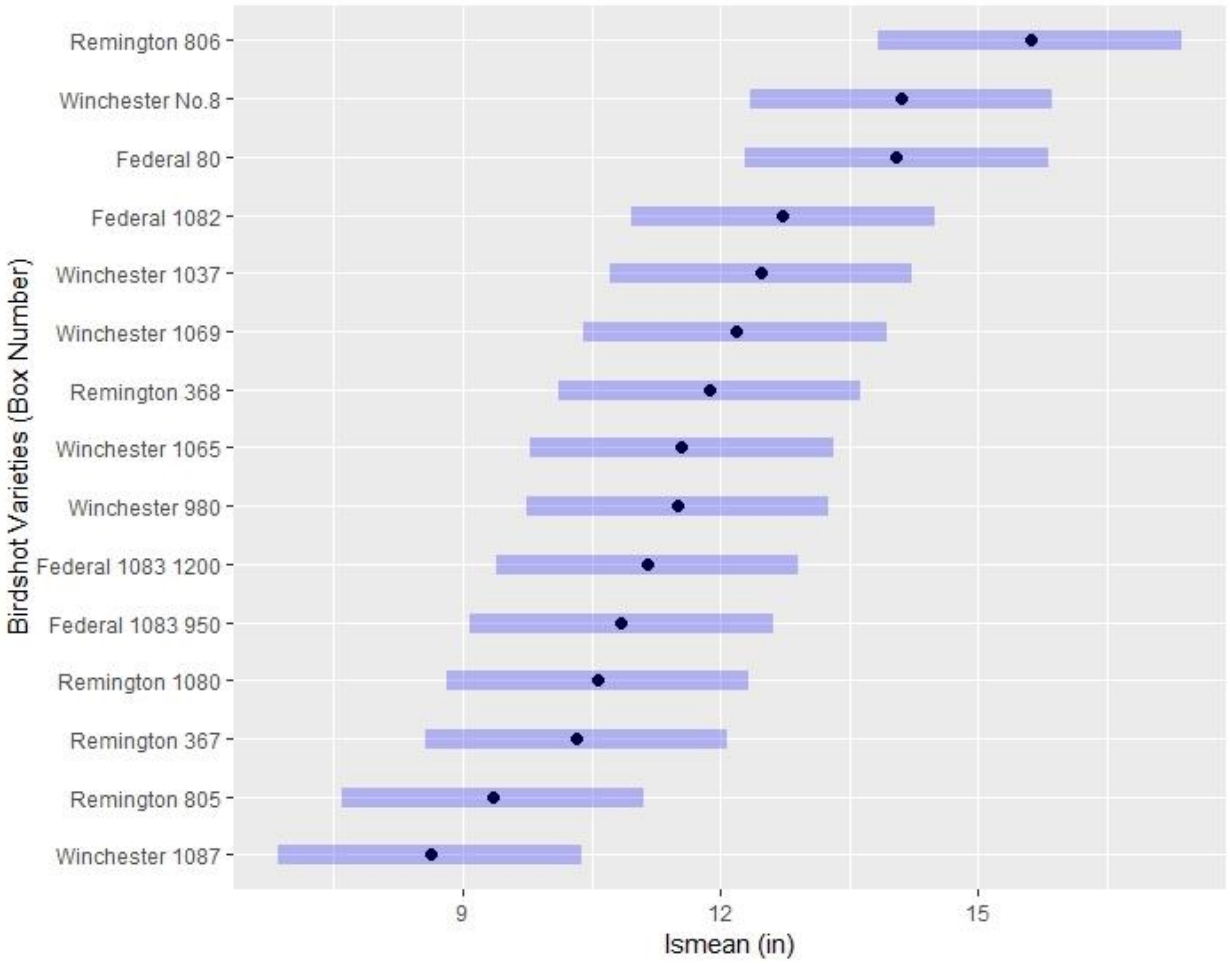

Figure 1. Birdshot Ammunition Selection lsmeans for Multiple Comparison. Overlapping bars indicate no significant difference at α: 0.05, Tukey adjusted.

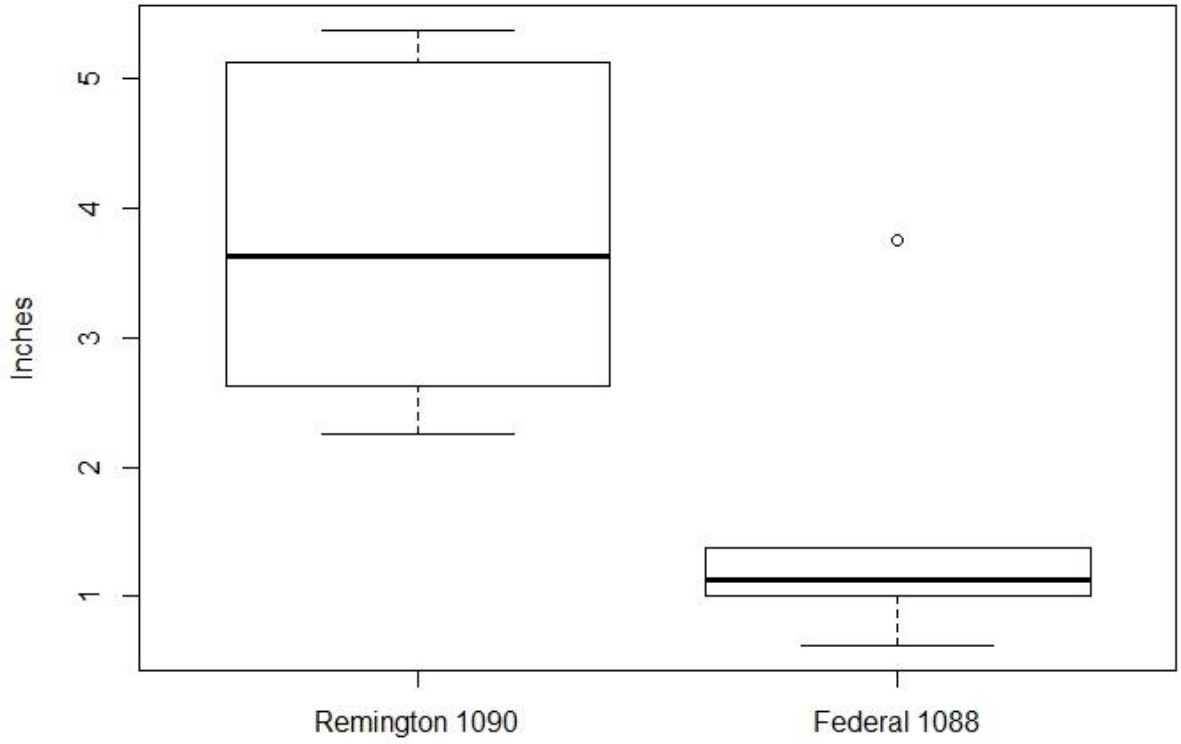

Figure 2. Buckshot Ammunition Selection Boxplot: minimum value, Q_1, median, Q_2, maximum value.

Table 6. Two-way ANOVA for Birdshot Distance Determination

Anova Table (Type II tests)

Response: birdshot$Diameter

	Sum Sq	Df	F value	Pr(>F)	
birdshot$Distance	20579.7	4	2404.457	< 2.2e-16	***
birdshot$Firearm	6441.6	8	376.308	< 2.2e-16	***
birdshot$Distance:birdshot$Firearm	4687.1	32	68.453	< 2.2e-16	***
Residuals	385.2	180			

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table 7. Birdshot Distance Determination lsmeans for Multiple Comparison. Groups sharing a letter are not significantly different at α: 0.05, Tukey adjusted.

Distance	Firearm	lsmean	SE	df	lower.CL	upper.CL	.group
1ft	D3	0.525	0.654	180	-1.6382	2.69	a
2ft	D2	0.575	0.654	180	-1.5882	2.74	a
1ft	D2	0.600	0.654	180	-1.5633	2.76	a
1ft	D1	0.775	0.654	180	-1.3882	2.94	ab
2ft	D3	0.800	0.654	180	-1.3633	2.96	ab
2ft	D1	1.025	0.654	180	-1.1382	3.19	abc
4ft	D3	1.375	0.654	180	-0.7883	3.54	abc
4ft	D2	1.600	0.654	180	-0.5633	3.76	abcd
4ft	D1	1.850	0.654	180	-0.3132	4.01	abcde
1ft	C1	1.925	0.654	180	-0.2382	4.09	abcde
1ft	B1	2.200	0.654	180	0.0367	4.36	abcde
1ft	C2	2.200	0.654	180	0.0367	4.36	abcde
1ft	A1	2.250	0.654	180	0.0867	4.41	abcde
1ft	A2	2.450	0.654	180	0.2868	4.61	abcde
1ft	B2	2.650	0.654	180	0.4868	4.81	abcdef
8ft	D3	2.950	0.654	180	0.7867	5.11	abcdefg
2ft	C1	3.800	0.654	180	1.6367	5.96	abcdefg
2ft	A1	4.175	0.654	180	2.0118	6.34	abcdefg
2ft	C2	4.475	0.654	180	2.3117	6.64	bcdefg
2ft	B1	4.525	0.654	180	2.3617	6.69	cdefgh
8ft	D2	4.550	0.654	180	2.3868	6.71	cdefghi
2ft	A2	5.250	0.654	180	3.0867	7.41	defghij
2ft	B2	5.400	0.654	180	3.2367	7.56	efghijk
8ft	D1	6.325	0.654	180	4.1617	8.49	fghijk
16ft	D3	6.575	0.654	180	4.4117	8.74	ghijk
4ft	B1	8.200	0.654	180	6.0367	10.36	hijkl
4ft	C1	8.262	0.654	180	6.0992	10.43	ijkl
4ft	A1	8.625	0.654	180	6.4618	10.79	jklm
4ft	C2	8.975	0.654	180	6.8117	11.14	klm
4ft	B2	10.625	0.654	180	8.4618	12.79	lm
16ft	D2	10.800	0.654	180	8.6367	12.96	lm
4ft	A2	10.900	0.654	180	8.7368	13.06	lm
16ft	D1	12.150	0.654	180	9.9868	14.31	m
8ft	C1	15.900	0.654	180	13.7368	18.06	n
8ft	A1	17.600	0.654	180	15.4367	19.76	n
8ft	C2	18.075	0.654	180	15.9117	20.24	n
8ft	B1	18.650	0.654	180	16.4868	20.81	no
8ft	A2	21.800	0.654	180	19.6367	23.96	o
8ft	B2	21.850	0.654	180	19.6867	24.01	o
16ft	A1	30.575	0.654	180	28.4118	32.74	p
16ft	C1	32.375	0.654	180	30.2117	34.54	pq
16ft	B1	35.500	0.654	180	33.3368	37.66	qr
16ft	C2	36.650	0.654	180	34.4868	38.81	r
16ft	A2	43.075	0.654	180	40.9117	45.24	s
16ft	B2	43.075	0.654	180	40.9117	45.24	s

Confidence level used: 0.95
Conf-level adjustment: sidak method for 45 estimates
P value adjustment: tukey method for comparing a family of 45 estimates
significance level used: alpha = 0.05

Table 8. Sorted Birdshot Distance Determination lsmeans for Multiple Comparison. Groups sharing a letter are not significantly different at α: 0.05, Tukey adjusted.

	A1	A2	B1	B2	C1	C2	D1	D2	D3
1ft	ABCDE	ABCDE	ABCDE	ABCDEF	ABCDE	ABCDE	AB	A	A
2ft	ABCDEFG	DEFGHIJ	CDEFGH	EFGHIJK	ABCDEFG	BCDEFG	ABC	A	AB
4ft	JKLM	LM	HIJKL	LM	IJKL	KLM	ABCDE	ABCD	ABC
8ft	N	O	NO	O	N	N	FGHIJK	CDEFGHI	ABCDEFG
16 ft	P	S	QR	S	PQ	R	M	LM	GHIJK

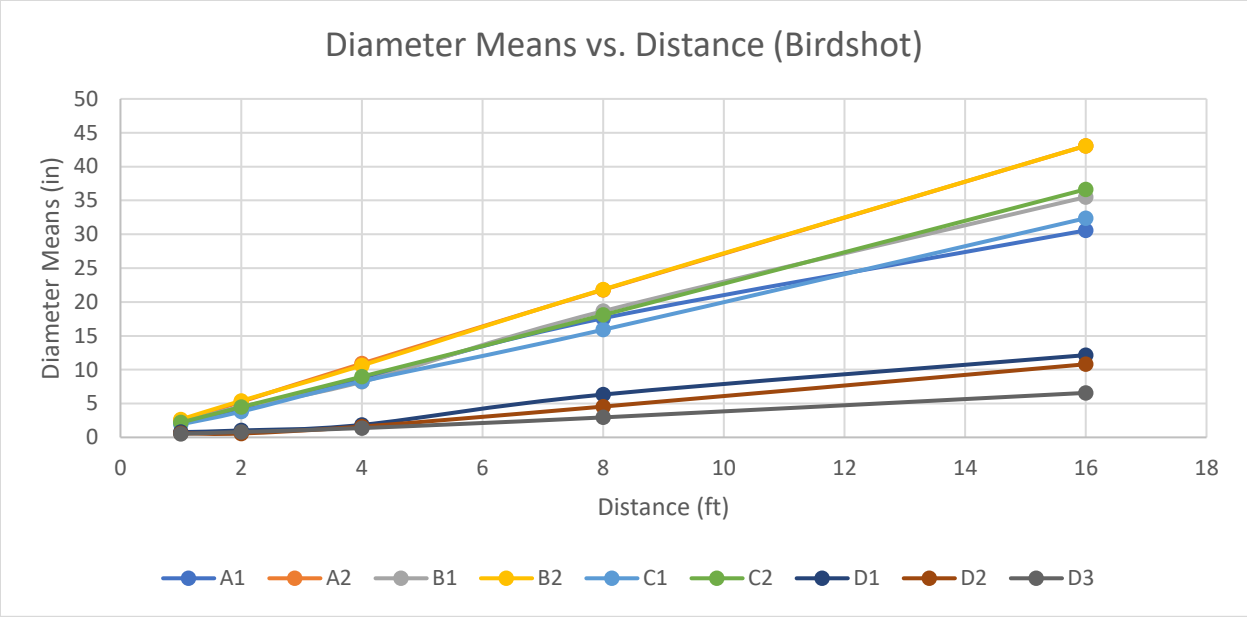

Figure 3. Diameter Means of Birdshot Distance Determination

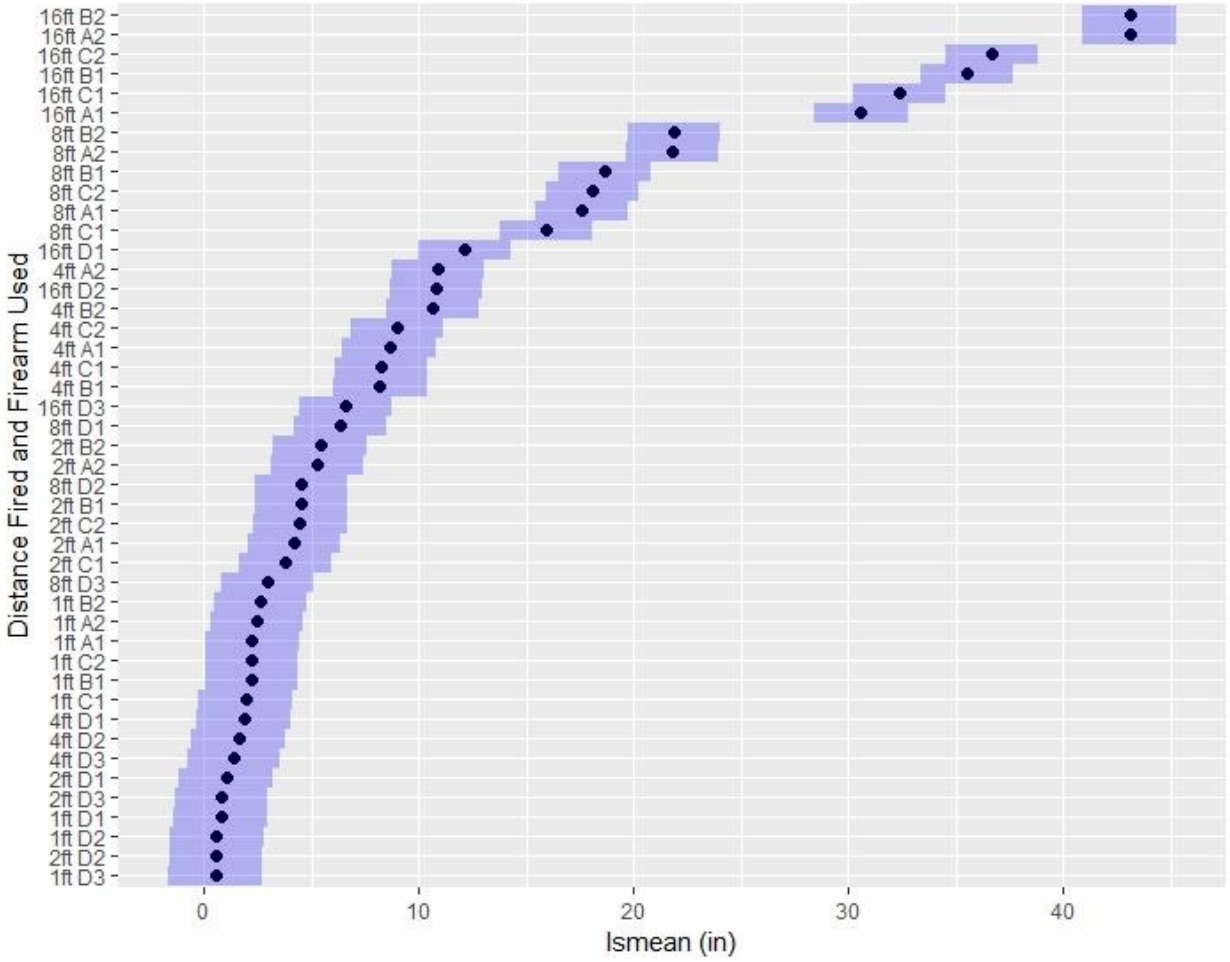

Figure 4. Birdshot Distance Determination lsmeans for Multiple Comparison. Overlapping bars indicate no significant difference at α: 0.05, Tukey adjusted.

Table 9. Two-way ANOVA for Buckshot Distance Determination

Anova Table (Type II tests)

Response: buckshot$Diameter

	Sum Sq	Df	F value	Pr(>F)	
buckshot$Distance	1404.38	4	687.207	< 2.2e-16	***
buckshot$Firearm	468.10	8	114.528	< 2.2e-16	***
buckshot$Distance:buckshot$Firearm	375.40	32	22.962	< 2.2e-16	***
Residuals	91.96	180			

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table 10. Buckshot Distance Determination lsmeans for Multiple Comparison. Groups sharing a letter are not significantly different at α: 0.05, Tukey adjusted.

Distance	Firearm	lsmean	SE	df	lower.CL	upper.CL	.group
2ft	D2	0.275	0.32	180	-0.782	1.33	a
1ft	D2	0.300	0.32	180	-0.757	1.36	a
1ft	D1	0.350	0.32	180	-0.707	1.41	a
2ft	D1	0.400	0.32	180	-0.657	1.46	a
4ft	D2	0.450	0.32	180	-0.607	1.51	a
1ft	D3	0.450	0.32	180	-0.607	1.51	a
4ft	D1	0.650	0.32	180	-0.407	1.71	a
1ft	B1	0.700	0.32	180	-0.357	1.76	a
2ft	D3	0.725	0.32	180	-0.332	1.78	a
1ft	A1	0.800	0.32	180	-0.257	1.86	ab
1ft	C1	0.825	0.32	180	-0.232	1.88	ab
8ft	D2	0.850	0.32	180	-0.207	1.91	ab
1ft	A2	0.875	0.32	180	-0.182	1.93	ab
1ft	C2	0.925	0.32	180	-0.132	1.98	ab
1ft	B2	1.000	0.32	180	-0.057	2.06	abc
8ft	D1	1.200	0.32	180	0.143	2.26	abcd
4ft	D3	1.225	0.32	180	0.168	2.28	abcd
2ft	A1	1.225	0.32	180	0.168	2.28	abcd
2ft	B1	1.300	0.32	180	0.243	2.36	abcd
2ft	C1	1.325	0.32	180	0.268	2.38	abcd
2ft	A2	1.450	0.32	180	0.393	2.51	abcd
2ft	B2	1.525	0.32	180	0.468	2.58	abcd
2ft	C2	1.525	0.32	180	0.468	2.58	abcd
16ft	D2	1.675	0.32	180	0.618	2.73	abcd
16ft	D1	1.750	0.32	180	0.693	2.81	abcd
8ft	D3	2.000	0.32	180	0.943	3.06	abcd
4ft	B1	2.575	0.32	180	1.518	3.63	bcde
4ft	A2	2.750	0.32	180	1.693	3.81	cde
4ft	C1	2.825	0.32	180	1.768	3.88	def
4ft	C2	2.925	0.32	180	1.868	3.98	defg
4ft	B2	2.950	0.32	180	1.893	4.01	defg
4ft	A1	2.950	0.32	180	1.893	4.01	defg
8ft	A1	3.925	0.32	180	2.868	4.98	efgh
16ft	D3	4.000	0.32	180	2.943	5.06	efgh
8ft	B1	4.600	0.32	180	3.543	5.66	fghi
8ft	C1	4.650	0.32	180	3.593	5.71	ghi
8ft	C2	4.875	0.32	180	3.818	5.93	hi
8ft	A2	5.025	0.32	180	3.968	6.08	hi
8ft	B2	6.250	0.32	180	5.193	7.31	i
16ft	C1	8.900	0.32	180	7.843	9.96	j
16ft	A1	8.950	0.32	180	7.893	10.01	j
16ft	B1	9.950	0.32	180	8.893	11.01	j
16ft	A2	10.125	0.32	180	9.068	11.18	j
16ft	C2	10.550	0.32	180	9.493	11.61	jk
16ft	B2	12.325	0.32	180	11.268	13.38	k

Confidence level used: 0.95
Conf-level adjustment: sidak method for 45 estimates
P value adjustment: tukey method for comparing a family of 45 estimates
significance level used: alpha = 0.05

Table 11. Sorted Buckshot Distance Determination lsmeans for Multiple Comparison. Groups sharing a letter are not significantly different at α: 0.05, Tukey adjusted.

	A1	A2	B1	B2	C1	C2	D1	D2	D3
1ft	AB	AB	A	ABC	AB	AB	A	A	A
2ft	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	A	A	A
4ft	DEFG	CDE	BCDE	DEFG	DEF	DEFG	A	A	ABCD
8ft	EFGH	HI	FGHI	I	GHI	HI	ABCD	AB	ABCD
16ft	J	J	J	K	J	JK	ABCD	ABCD	EFGH

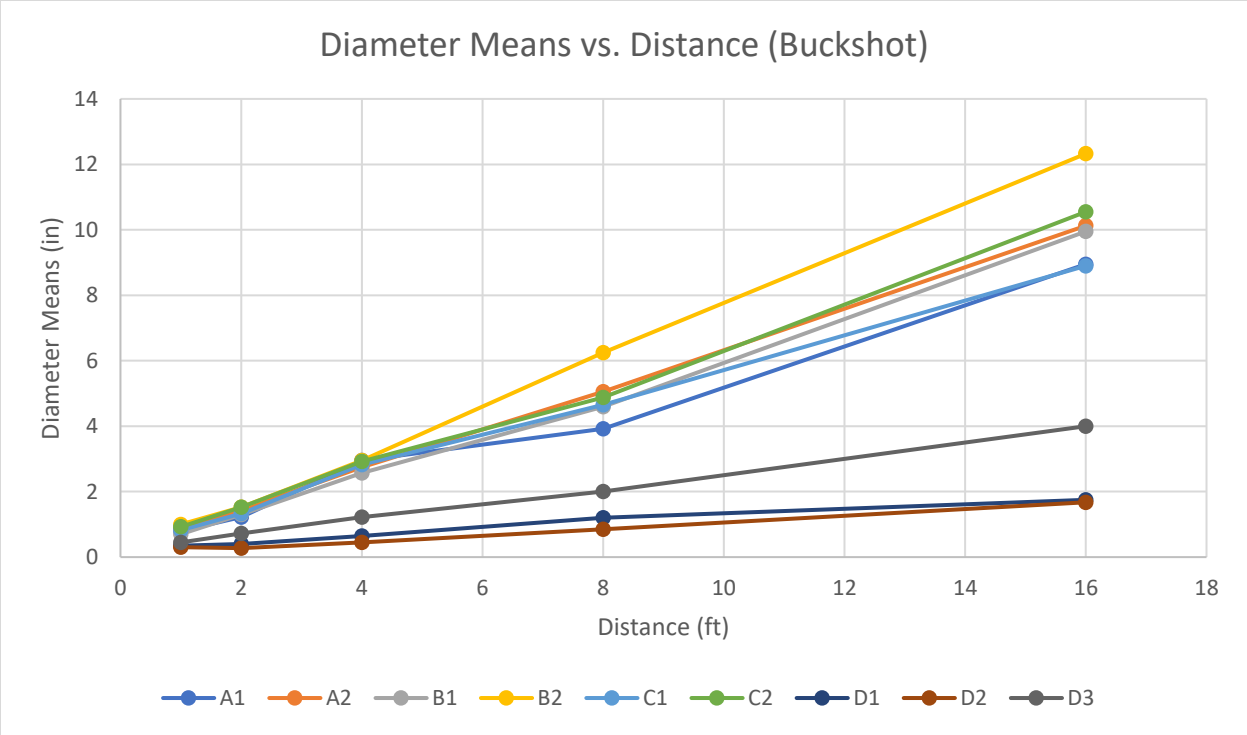

Figure 5. Diameter Means of Buckshot Distance Determination

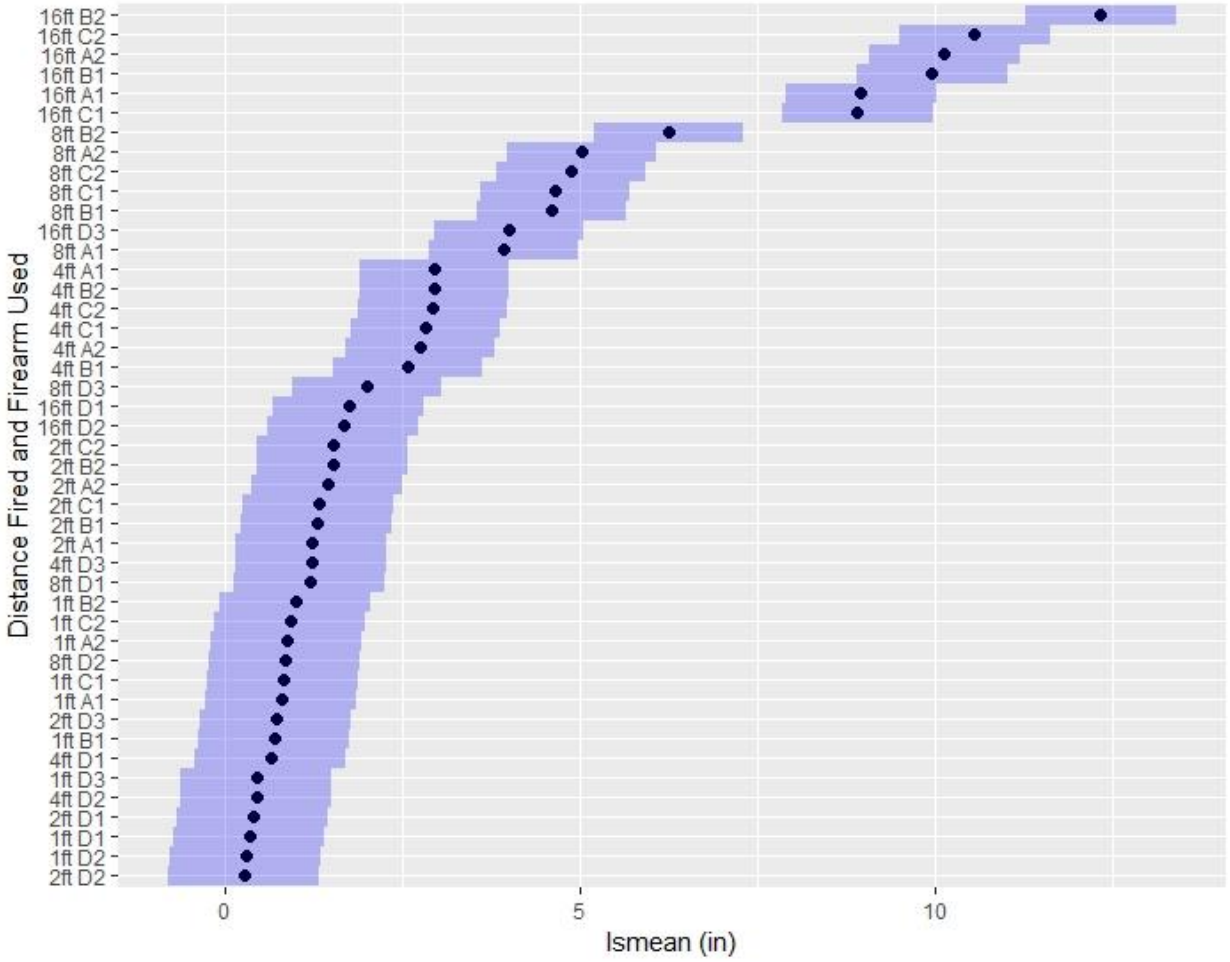

Figure 6. Buckshot Distance Determination lsmeans for Multiple Comparison. Overlapping bars indicate no significant difference at α: 0.05, Tukey adjusted.

Table 12. Two-way ANOVA for Griess Outer Diameter

Anova Table (Type II tests)

Response: griess$Outer

	Sum Sq	Df	F value	Pr(>F)	
griess$Distance	165.663	3	46.4257	4.044e-08	***
griess$Firearm	39.719	1	33.3930	2.824e-05	***
griess$Distance:griess$Firearm	6.710	3	1.8805	0.1736	
Residuals	19.031	16			

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table 13. Griess Outer Diameter lsmeans for Multiple Comparison. Groups sharing a letter are not significantly different at α: 0.05, Tukey adjusted.

Distance	Firearm	lsmean	SE	df	lower.CL	upper.CL	.group
0.5ft	A1	4.38	0.63	16	2.40	6.35	a
1ft	A1	7.75	0.63	16	5.78	9.72	b
0.5ft	B1	8.58	0.63	16	6.61	10.56	bc
1ft	B1	9.67	0.63	16	7.69	11.64	bcd
1.5ft	A1	11.12	0.63	16	9.15	13.10	cde
2ft	A1	12.00	0.63	16	10.03	13.97	de
2ft	B1	13.42	0.63	16	11.44	15.39	e
1.5ft	B1	13.88	0.63	16	11.90	15.85	e

Confidence level used: 0.95
Conf-level adjustment: sidak method for 8 estimates
P value adjustment: tukey method for comparing a family of 8 estimates
significance level used: alpha = 0.05

Table 14. Sorted Griess Outer Diameter lsmeans for Multiple Comparison. Groups sharing a letter are not significantly different at α: 0.05, Tukey adjusted.

Distance	**A1**	**B1**
0.5ft	A	BC
1ft	B	BCD
1.5ft	CDE	E
2ft	DE	E

Table 15. Griess Inner Diameter lsmeans for Multiple Comparison. Groups sharing a letter are not significantly different at α: 0.05, Tukey adjusted.

Anova Table (Type II tests)

Response: griess$Inner

	Sum Sq	Df	F value	Pr(>F)	
griess$Distance	28.101	3	27.4051	1.531e-06	***
griess$Firearm	41.016	1	120.0019	7.616e-09	***
griess$Distance:griess$Firearm	7.585	3	7.3975	0.002508	**
Residuals	5.469	16			

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table 16. Griess Inner Diameter lsmeans for Multiple Comparison. Groups sharing a letter are not significantly different at α: 0.05, Tukey adjusted.

Distance	Firearm	lsmean	SE	df	lower.CL	upper.CL	.group
0.5ft	A1	3.29	0.338	16	2.23	4.35	a
1ft	A1	3.58	0.338	16	2.53	4.64	a
0.5ft	B1	4.71	0.338	16	3.65	5.77	ab
1.5ft	A1	4.79	0.338	16	3.73	5.85	ab
2ft	A1	5.25	0.338	16	4.19	6.31	bc
1ft	B1	6.71	0.338	16	5.65	7.77	cd
2ft	B1	6.96	0.338	16	5.90	8.02	d
1.5ft	B1	9.00	0.338	16	7.94	10.06	e

Confidence level used: 0.95
Conf-level adjustment: sidak method for 8 estimates
P value adjustment: tukey method for comparing a family of 8 estimates
significance level used: alpha = 0.05

Table 17. Sorted Griess Inner Diameter lsmeans for Multiple Comparison. Groups sharing a letter are not significantly different at α: 0.05, Tukey adjusted.

Distance	**A1**	**B1**
0.5ft	A	AB
1ft	A	CD
1.5ft	AB	D
2ft	BC	E

Vita

Donald Chunlong Poon was born on December 3rd, 1995, in New York, NY. He graduated from Brooklyn Technical High School, Brooklyn, NY in 2013. He received his Bachelor of Arts in Biological Sciences with a Minor in General Anthropology from the State University of New York Binghamton, Vestal, NY in 2017. Subsequently, he engaged in research under the SUNY Binghamton Department of Anthropology for a year.