Frank Horvath,[1] Ph.D.; Kent Gardner,[2] M.S.; and Jay Siegel,[1] Ph.D.

Range of Fire Estimates from Shotgun Pellet Patterns: The Effect of Shell and Barrel Temperature

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ABSTRACT: The purpose of this study was to determine the accuracy of range-of-fire estimates in shotgun pellet patterns at fixed intervals. It was also of interest to investigate the effect of barrel and shell temperature changes on the diameter of pellet patterns. One hundred shots were fired from a .12 gauge shotgun though a series of 5 in-line paper targets positioned at 5-foot intervals between 15 and 35 feet from the muzzle. A series of confidence intervals was calculated to determine the error in range-of-fire estimates. Statistical analysis of the data revealed that shell but not barrel temperature significantly reduced pattern diameter.

KEYWORDS: forensic science, range of fire, shotgun patterns, firearms, ballistics

Estimates of the firing distance of shotguns by examination of the size of pellet pattern dispersion is a common forensic technique. In most cases these estimates are made by using a weapon and ammunition as similar as possible to those used in a crime to fire test patterns at targets placed at measured distances. Usually only a few shots are fired at selected distances. The distance producing the pellet pattern closest in size to that in question indicates the approximate firing distance. However, since these patterns are known to have some variability, it is typical to find that distance determinations are established with upper and lower bounds; the former is ascertained by selection of a test distance with a pattern larger in size from that of the questioned pattern whereas the latter is determined by selection of a test distance producing a pattern smaller in size than the evidence pattern. The examiner's experience and observations made during the test firings play a pivotal role in the selection of the upper and lower boundaries.

Because range of fire estimates depend somewhat on examiner experience, it is sometimes the case that firearms examiners disagree. Such a disagreement in an actual case led to the present research. In this case two firearms examiners were called upon to testify as to whether shotgun pellet patterns in the wall of a home were fired at more or less than a distance of 30 feet. One examiner testified that the patterns indicated a firing distance of about 25 feet but less than 30 feet; the other stated that the firing distance had been greater than 30 but less than 35 feet. In both cases the actual sample data produced by the examiners supported the opinions offered. The two examiners reportedly conducted their tests in a similar way except that the test firings that produced the lower estimate were made at an ambient temperature of about 70° F while those of the other

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[1]Professors, School of Criminal Justice, Michigan State University, East Lansing, MI.
[2]Firearms Unit Supervisor, Bridgeport Laboratory, Michigan State Police, Bridgeport, MI.

expert were made at about 50°. Since these temperature differences might have influenced the test results it was of interest in this study to investigate temperature effects on shotgun pellet patterns. It appeared likely, however, that the conditions in which shotgun shells and the weapon itself have been stored may affect pellet patterns more directly than ambient air temperature; therefore, those factors were of primary interest.

There are several reports in the literature in which range of-fire estimates of shotgun pellet patterns were investigated. In 1984, for instance, Alfonsi et al. reported that when there is only a partial pellet pattern and the shotgun choke is not known, range of fire estimates for 00 buck and 0 buck shells can be considerably in error; thus, it is necessary to control for these variables in test firings [*1*]. Rowe and Hanson investigated the degree to which standard statistical analysis could be used to derive estimates of the range of fire of questioned patterns with two different 12 gauge shotguns, each firing a different type of shell. Their results showed that in all cases .99 confidence intervals encompassed the actual range-of-fire of questioned patterns [*2*]. These results were essentially similar to those reported earlier by Heaney and Rowe [*3*], Wray et al. [*4*], Jauhari et al. [*5,6*].

In the available studies the primary issue investigated was the utility of statistical methods for determination of range-of-fire estimates. The effect, if any, of temperature differences, such as shotgun barrel and shell temperature on pellet patterns were not at issue; these were the variables of interest here. Because, it was anticipated that temperature effects would be likely to be quite small it was decided to use much larger samples than would be done in an actual case to dramatically alter the effects at issue. If under such conditions no effects were observed, it would be reasonable to assume that that would also obtain in less severe conditions.

Method

Procedure

All test firings were made with a Remington model 870, 12 gauge pump action shotgun. The barrel of this firearm was 22 inches in length with a cylinder bore measuring .729 inches. (This is usually referred to as a "standard bore"). In all cases the ammunition used was commercially available 12 gauge Winchester-Western, 00 Buck, shot shells. Each shell contained the equivalent of 3¾ drams of black powder and 9 lead pellets, each measuring approximately .33 in. in diameter and weighing 51 grains. All shotshells were from the same production run and lot number.

The firearm was held in a stationary fixture when it was fired. The fixture was set so that the muzzle of the gun could be vertically adjusted in order to align properly the elevation with the target. Windage alignment was accomplished by movement of the entire support structure on a horizontal plane. In order to position the shotgun properly, it was test fired before each data collection period. The test firing was done by shooting at a single target at 35 feet distant from the muzzle such that proper alignment of targets for the test firings was ensured. The barrel of the gun was cleaned after each test firing.

An in-line array of five paper targets, each made of brown paper of .007 in. thickness, was set such that the targets were placed at five foot intervals from the muzzle of the shotgun. Each of the five targets was supported by a wire hanger suspended along a 20 foot long wooden structure. The first target was placed 15 feet from the muzzle; the last at 35 feet.

Data Collection

A total of 100 firings of the shotgun was made. Twenty of these, the low barrel temperature group, were made with a shotgun barrel temperature that had been lowered to 0 +/− 5° F. Twenty other shots, the low shell temperature group, were made with a shell temperature that had been decreased to 5 +/− 7° F. Sixty of the firings were made with the barrel and shell temperature at ambient values. Thus, there were three categories established for the temperature manipulations: low barrel, low shell and ambient temperature. In all firings, except for the first 15 carried out in the "ambient temperature" grouping, air temperature was ascertained in Fahrenheit by a commercial thermometer placed near the testing site.

The low barrel temperature was accomplished by placing liquid nitrogen into the barrel before firing until the temperature of the barrel, measured by a calibrated secondary nitrogen-above-mercury thermometer suspended midway into the gun barrel with the breech closed, showed the desired temperature. The decreased shell temperature was obtained by placing the selected shotshells into a freezer until the desired air temperature in the freezer was obtained. The air temperature of the freezer was measured by suspending the bulb end of a calibrated thermometer, as used for measurement of barrel temperature, into the freezer into which the shotshells had been placed.

After each of the 100 firings the pellet pattern dispersion was measured by placing a clear plastic overlay over each target. The diameter of the smallest circle (indicated on the overlay) that encompassed all nine pellets served as the dependent variable. In all cases measurements to the nearest .25 in. were made since that was the approximate size of each of the pellet holes. Hence, for each of the 100 shots fired, there were 5 pellet patterns collected, each at a different 5-foot interval from a 15 to 35 foot distance from the muzzle. In all, therefore, the diameter of 500 pellet patterns was ascertained.

Although Jauhari et al. [5] have demonstrated that the resistance of paper screen targets, such as that used here, do not affect the size of pellet pattern diameter at long distances, it was of interest, nevertheless, to investigate that issue, particularly so since in the Jauhari et al. study the targets were placed at 3 foot intervals with a maximum distance of only 18 feet (5.46 m). To assess the effect of the target penetration on pattern diameter ten shots were fired at a target placed 35 feet from the muzzle of the shotgun. The mean diameter of these shots was compared to that obtained from 10 targets randomly selected from the 100 obtained in the test firings at the 35 foot interval.

Results

Table 1 shows the mean and standard deviation for each of the two groups of ten shots that were compared to assess the effect of the paper targets on pattern diameter. As can be seen, in the group without intervening targets the mean diameter was 9.42 in. (s = .61) whereas in the randomly drawn group the mean diameter was 9.10 in. (s = .54). This difference was not statistically significant [t(correlated means, 9 df) = 1.1; $P > .10$];

TABLE 1—*Descriptive statistics (inches) for test shot patterns fired with and without intervening targets at 35 feet.*[a]

	Intervening Targets	
Statistic	Without (n = 10)	With (n = 10)
Mean	9.42	9.10[b]
SD	0.61	0.54
Range	8.50–10.25	7.75–9.50

[a] 1 ft = 0.3048 m; 1 in = 2.54 cm.
[b] t (df = 9) = 1.1; $P > .10$.

therefore, the intervening targets did not have a significant effect on the pattern diameter even at the 35 foot distance.

Because ambient air temperature was not controlled, initial statistical analysis was carried out to assess if this variable affected pattern diameters of the test firings. This was done by categorizing all shots as either "high" (above the median of 70° F) or "low" (below 69° F) air temperature. It should be noted here, however, that air temperature was not determined for the first 15 shots in the "Ambient" grouping; for that reason, the mean air temperature for the 45 firings in that group was assigned to the 15 cases with missing data. The temperature factor was then used in an Analysis of Variance (Anova) in which the diameters in each of the five test firing distances served as a repeated measures (within subjects) variable (Distance). This Anova did not reveal a statistically significant effect for Air Temperature [$F(1,98) = 2.25$, $P > .10$] or for the temperature by Distance interaction [$F(4,392) = .342$, $P > .10$]. Thus, whether or not ambient air temperature was above or below 70 degrees F did not have a statistically significant effect on the diameters of the test firings.

Displayed in Table 2 are the means, standard deviations and actual minimum and maximum measurements of the pattern diameters at each of the five measured distances and for each of the three groups of test firings, Low Barrel Temperature, Low Shell Temperature and Ambient Temperature. The first two groups consisted of 20 shots each; the third group of 60 shots. It can be seen in Table 2 that the mean diameters at all test firing distances for the Low Shell temperature groups were consistently lower than those for the others. For that reason, these groups were treated as three levels of a Temperature factor in calculation of a two-way Anova in which the diameters of the test firings at the five distances served as the second factor (Distance). This Anova revealed that there

TABLE 2—*Descriptive statistics (inches) for the groupings of test shots at varying distances.*[a]

Shot Group Statistic	Target Distance from Muzzle (feet)				
	15	20	25	30	35
Ambient (N = 60)					
Mean	3.69	5.03	6.44	7.91	9.37
SD	.372	.446	.543	.699	.842
Range (inches)					
Low	3.00	4.25	5.25	6.50	7.75
High	4.75	6.25	7.75	9.75	11.50
Low barrel temp (N = 20)					
Mean	3.68	5.05	6.34	7.76	9.14
SD	.313	.449	.534	.700	.776
Range					
Low	3.25	4.25	5.50	6.50	7.75
High	4.50	6.00	7.75	9.50	11.20
Low shell temp (N = 20)					
Mean	3.45	4.67	6.05	7.45	9.00
SD	.208	.305	.410	.657	.896
Range					
Low	3.00	4.00	5.00	6.25	7.25
High	3.75	5.25	7.00	9.00	11.50
Combined (ambient and low barrel) (N = 80)					
Mean	3.69	5.03	6.41	7.87	9.31
SD	.356	.444	.539	.698	.827
Range					
Low	3.00	4.25	5.25	6.50	9.75
High	4.75	6.25	7.75	9.75	11.50

[a] 1 ft = 0.3048 m; 1 in = 2.54 cm.

was a statistically significant effect for Temperature [$F(2,97) = 3.67$, $P < .03$] and for Distance, but the Distance by Temperature interaction was not significant. Post hoc analysis of the Temperature effect was made by calculation of Scheffe's S test; this showed that the mean diameter for the Low Shell group was significantly different only from that of the Ambient temperature group. Hence, lowering the shell temperature but not the barrel temperature decreased the average diameters of the pellet patterns relative to those obtained in the Ambient temperature firings.

Because of the significant statistical effect of the Low Shell temperature on pattern diameter it was necessary to treat separately the data collected in that grouping. Since, however, the Low Barrel temperature did not have a significant effect on pattern diameters, the 20 shots from that grouping were merged with those of the 60 shots in the Ambient temperature group into a "Combined" group. (The merged statistical data for the "Combined" group are shown in Table 2.) Then, 99% confidence intervals at each of the five varying distances of fire were calculated for the pattern diameters for each of these groups of shots. These are shown in Table 3, where it can be seen that there is no overlap from one test distance to another at the .99 level for either grouping of shots. However, it can be also be observed that the bounds established for the Low Shell Temperature group generally were considerably lower than those in the other group; hence, it is clear that shell temperature variations may alter the degree of confidence with which the estimate of the range of fire can be expressed within five-foot intervals. In other words, the Low Shell temperature produced more restricted pattern diameters making those shots appear to have been fired at a shorter distance than would be the case for "normal" shots, yielding general underestimates of the range of fire of the former group.

Based on the data shown in Table 2 it can be seen that, in general, the actual range of measured diameters for each group of test firings yielded considerable overlap between the five-foot distances. That is, the upper bound, for example at 15 feet, was greater than the lower measurement at 20 feet and so forth. Hence, the determination of firing distance within five feet would not be possible with any degree of certainty unless the number of shots (sample size) equalled or exceeded a specified value. For instance, if a relatively large number of shots were fired, say 20, then the confidence interval results shown in Table 3 (for the "low shell temperature" group $n = 20$) indicate that distance determinations could be made within five-foot intervals at .99 confidence. In real-life situations, however, it is seldom the case that distance determinations are made with samples as large as 20 shots. Given this limitation, it was of interest here to determine the sample size necessary to produce a given result at a particular level of probability.

TABLE 3—*Ninety-nine percent confidence intervals for the low shell temperature and combined test firings at varying distances.*

	Target Distance from Muzzle (feet)[a]				
Group	15	20	25	30	35
Low shell temp ($N = 20$)					
Lower	3.31	4.48	5.78	7.02	8.42
Upper	3.58	4.86	6.31	7.87	9.57
Combined ambient and low barrel ($N = 80$)					
Lower	3.58	4.93	6.26	7.67	9.07
Upper	3.79	5.13	6.57	8.07	9.55

[a]Mean values are displayed in Table 2; the T distribution, df = 19, was used to establish the confidence intervals for the Low Shell Temp Group; the Z distribution was used for the combined group. 1 ft = 0.3048 m.

TABLE 4—*Sample size necessary at varying distances to estimate mean pattern diameter to within .33 inches accuracy at .95 and .99 confidence level.*[a]

Group distance (ft.)	Confidence Level .95	.99
Combined		
15	5	7
20	7	10
25	11	14
30	18	24
35	25	33
Low Shell Temp		
15	2	2
20	4	5
25	6	8
30	16	21
35	29	39

[a]1 in = 2.54 cm; 1 ft = 0.3048 m.

Specifically, since the pellet size in the shotshells used in this study was approximately .33 inches in diameter, it was decided to calculate the sample size that would be necessary to estimate the mean diameters to an accuracy of .33 inches at both .95 and .99 levels of confidence. These results are shown in Table 4, where, for example, it can be seen that with a sample of 5 shots one could estimate with .95 confidence the mean pattern diameter of shots fired at 15 feet within .33 inch accuracy. More shots, of course, would be required at greater distances and at higher levels of confidence. In other words, it would be necessary to fire at least 5 shots at 15 feet to estimate with .95 certainty the

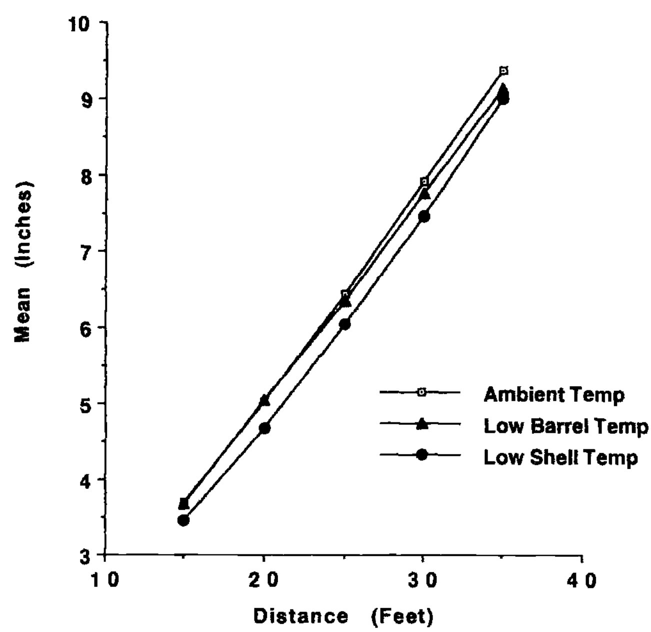

FIG. 1—*Mean pattern diameters (inches) by distance for the three test firing conditions.*

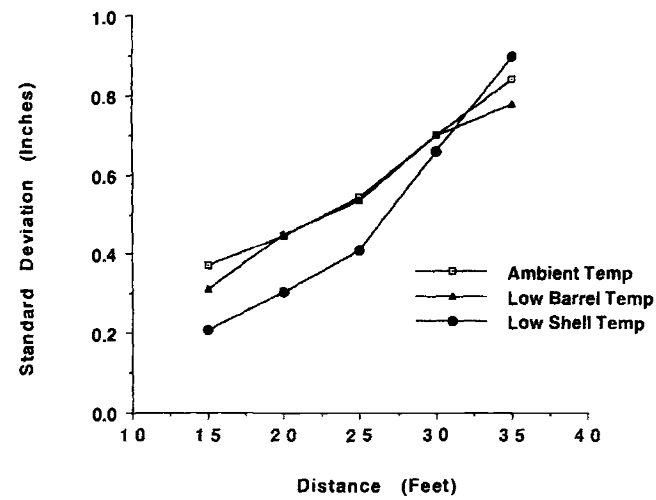

FIG. 2—*Standard deviations (inches) of pattern diameters by distance in the three test firing conditions.*

actual mean pattern diameter with the given accuracy; fewer shots would produce misleading results.

It has been established that there is a strong linear relationship between shotgun pellet pattern dispersion at varying distances such as that used in this study [*1–3*]. Although that issue was not of special interest here, calculation of an ordinary regression coefficient between pattern diameter and distance across all shots excluding those in the Low Shell Temperature group ($n = 400$) showed an r of .958. A similar calculation on the Low Shell Temperature group ($n = 100$) produced an r of .963. This linearity is further illustrated in Fig. 1 in which the mean diameters at the five distances for each of the three temperature groups are displayed. Figure 2 displays the dispersion (standard deviations) of the pellet patterns over the five distances. In both of these figures the effect of the "low shell" temperature is evident, the mean diameter and the amount of the pattern spread were clearly suppressed (at least out to 30 feet) relative to "normal" firings.

Discussion

These results make clear that temperature effects may have undesirable consequences on estimation of range-of-fire of shotgun pellet patterns. Specifically, the condition in which shotgun shells have been stored may seriously compromise the determination of distance of fire from the pellet pattern; shells that have been stored in cold weather, such as in a garage or automobile in the winter months in the northern latitudes, may produce pellet patterns on a much more restricted range than those stored under more "normal" conditions. The reduced temperature produces a slowing of the burn time of the gun powder in the shotshell which, in turn, reduces the pressure in the barrel chamber and lowers the velocity of the shot. Consequently, there is less natural deformation of the pellets, referred to as "setback," which results in less air resistance, and smaller dispersion of the pellets, at least at close distances. In short, estimation of range-of-fire of shotgun pellet patterns must not only be done with a gun and shells similar to those used in a crime but must be carried out in climatic conditions as close as possible to those prevalent during the firing of the crime-scene weapon. To report range-of-fire estimates for shotgun pellet patterns without knowledge of the condition in which the shells have been stored could produce quite misleading indications.

In actual cases it would be impractical to estimate range-of-fire from shotgun pellet patterns with samples of test firings as large as those used here. The use of in-line targets, however, seems to be a productive and effective method of reducing the need for large samples at specified distances. Yet, it is also the case that these findings show that shotgun pellet patterns produce enough variation, at least at the distances employed in this study, to make the calculation of range-of-fire estimates from small samples less precise than might be desired. For example, it was observed here that at each of the five distances from which shots were fired, there was overlap in the actual measurements of the pellet patterns between the lower and upper range bounds at adjacent distances. Hence, with small samples of test shots, one could reliably estimate range-of-fire within only a ten foot range, in most situations, perhaps, a result not of sufficient probative interest.

Estimates of range-of-fire that could be expressed with a reasonable degree of scientific certainty require samples of at least moderate size. These findings (Table 4) show, for instance, that the firing of only two or three test shots at varying distances would not allow one to calculate range-of-fire from pellet patterns with a .95 degree of certainty. Of course, such a conclusion is based on a number of assumptions about the degree of confidence of interest as well as the accuracy of the calculation that is desired. Nevertheless, there will always be a balance between the degree of certainty and the number of test shots. In that sense, these findings reinforce the position of Rowe and Hanson [*2*] and Heaney and Rowe [*3*] and Jauhari et al. [*5,6*] that statistical treatment of shotgun pellet patterns is a desired method of analysis. In addition, however, even when properly treated, shotgun pellet pattern measurements can produce misleading indications if analysis is carried out without concern for a number of ecological factors. It is usually the case that there is an attempt to match the firearm and the ammunition that was used in a crime; our findings are clear that it is also important to ensure that the test ammunition had been stored in the same conditions as that used in the crime. In situations when that cannot be done, inferences drawn from test findings must be done with extreme caution.

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Address requests for reprints or additional information to
Frank Horvath, Ph.D.
512 Baker Hall
School of Criminal Justice
Michigan State University
East Lansing, MI 48824