Influence of the Length of Homemade Shotgun Barrels on Accuracy and Shot Patterns at Different Firing Distances

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Received August 9, 2021; **Revised** September 8, 2021; **Accepted** February 15, 2022

Abstract

Every year, gun violence results in thousands of deaths and injuries globally. Firearms-related violent crime is a serious social concern. Various types of guns are used in crimes, but many such incidents involve the use of shotguns. A shotgun is a weapon that fires using the energy of the explosive within a fixed shotgun shell for firing either several ball shots, referred to as pellets, or one projectile, for each pull of the trigger. This study was designed to investigate the correlation between the length of homemade shotgun barrels, shot patterns, the number of pellets hitting the target and firing distance in an outdoor shooting range in the Chaengwattana area of Bangkok, Thailand. The experiments were performed using an improvised 12-gauge (0.729-inch) single-barrel, break-action shotgun with five different barrel lengths (4, 6, 10, 16 and 28 inches) loaded with 12-gauge 2 3/4" OO 9 pellet buckshot. The data were analyzed by analysis of covariance and correlation. The results showed that the number of shots hitting the target was positively correlated with the length of the barrel, whereas the diameter of the shot pattern was negatively correlated with the length of the barrel, as an increase in length reduced shot pattern diameter. It was concluded that there is a nonlinear relationship between barrel length, firing distance and shot pattern. The results of our study can be used to estimate the distance at which a shotgun has been fired in a crime scene.

Keywords: firearms, pellets, dispersion pattern, gun barrel, shooting distance, distance estimation

Introduction

Gun violence is a contemporary human rights issue affecting the lives of individuals around the world. Every 4 minutes and 44 seconds, one person is injured by gunshot in the United States, and one person dies as a result every 16 minutes (Fowler et al., 2015). At a global scale, >500 people die every day because of violence committed with firearms (Punkaew, 2020). Shotguns account for a considerable percentage of gun violence, and it is important for forensic experts to investigate cases in which a shotgun has left a shot pattern at the crime scene (Dresang, 2001; Kahan & Braman, 2003; Kellermann & Rivara, 2012). There have been many research studies and hypotheses about the underlying causes of gun violence and its growth pattern. For example, children might be influenced by movies or the media, or individuals with a mental disease might be responsible for mass shootings (Cook & Ludwig, 2002; Dillon & Bushman, 2017; Gold, 2013; Graziano & Pulcini, 2013). Governments have employed a variety of methods to lower gun violence, and some have been successful to a certain extent. A focus on point-of-sale background checks in the United States is regarded as a necessity to prevent at-risk persons from obtaining firearms. In Indiana, police officers have the authority to confiscate guns from persons who are likely to injure others or themselves, now or in the future. The same regulations apply in that state to a person who has the potential of being emotionally unstable or displaying violent behaviour. In such cases, a court session is called in which a judge determines if the seized firearms can be returned to their owner after a period of 5 years or if they are to be retained. (Burruss & Decker, 2002; Sherman & Rogan, 2006; Swanson et al., 2019).

Many incidents of gun violence in Thailand are committed with illegal firearms, including stolen firearms, firearms obtained from the black market and homemade firearms (improvised firearms). Illegal firearms that are not registered are not traceable. The Office of Police Forensic Science oversees the Central Police Forensic Science Division in Bangkok and 10 regional Police Forensic Science Centres (PFSCs) across the country: PFSC 1 in Pathum Thani, PFSC 2 in Chon Buri, PFSC 3 in Nakhon Ratchasima, PFSC 4 in Khon Kaen, PFSC 5 in Lampang, PFSC 6 in Phitsanulok, PFSC 7 in Nakhon Pathom, PFSC 8 in Surat Thani, PFSC 9 in Songkhla and PFSC 10 in Yala. The centres oversee all firearms cases in Thailand (Office of Police forensic science, n.d.). According to statistical data collected in 2013 and 2014 by PFSC 6 in Phitsanulok Province, 50 of 110 firearms-related crimes (45.45%) were committed with shotguns, and > 60% of those shotguns were homemade (Ordog, Wasserberger & Balasubramaniam, 1988). The rate of shotgun ownership is high due to their affordable price and distribution channels that are accessible to target buyers.

Although there are a variety of shotguns on the market, the 12-gauge homemade shotgun is the most common shotgun owned by teenage groups and local people in the lower part of northern Thailand. (Punkaew, 2020)

The Firearms Control Act of Thailand imposes rigorous regulations on the possession of firearms, especially homemade shotguns. It is against the law for civilians to possess any of the following weapons. Currently, firearms investigators have to perform crime scene reconstruction for many fatal cases involving homemade shotguns, as there are no official data comparing the results between manufactured and homemade shotguns. The present study will begin to fill this research gap in Thailand by obtaining data on the diameter of pellet dispersion or shot patterns and muzzle velocity in relation to the barrel lengths of homemade shotguns and firing distances. The results were analyzed by analysis of covariance (ANCOVA). The results will be made available to the Firearms and Ammunition Subdivision of the Central Police Forensic Science Division of Thailand. This pilot study will bring new findings to light with empirical data about homemade guns to support criminal investigations related to homemade shotguns. Moreover, police investigations supported by relevant empirical data may have a positive influence on court hearings, because judges can rely on forensic knowledge applied to homemade shotguns. This improved judicial step, combined with acceleration of the investigation process, may result in the perpetrators being sentenced with less delay.

Objective of Research

1. To study shooting accuracy and states that there is a nonlinear relationship between firing distance and the number of pellets hitting the target: when the firing distance increases, fewer pellets will hit the target.

2. To study verify that there is a nonlinear relationship between firing distance and shot pattern: the greater the firing distance, the larger the shot pattern.

Literature review

Shot patterns in forensic investigations

In cases of firearms injuries, and especially, in those causing death, estimation of the shot distance is important in forensic investigations. To estimate shot distance, gunshot pellets on the victim's body or on the wall may yield valuable clues that can help distinguish a murder from a suicide (Berg, 1997; Di-Miao; 1999). When there has been an injury due to a shotgun, the shot pattern of pellets on the target may also allow estimation of the shot distance. When investigating the wounds on a victim's body, the number of pellets that hit the victim and the diameter of the shot pattern can be used to estimate the distance between the shooter and the victim. (Di-Miao, 1999; Breitenecker, 1969; Fann et al., 1986; Thube & Chikhalka, 2017)

The shotgun projectile is a cluster of pellets in front of expanding wadding such that the hot gases produced by the burning propellant do not leak past the pellets. There have been many modifications in shotguns and cartridges to minimize or maximize the scatter pattern of the pellets, known as the shotgun pattern. For instance, in some cartridges, the pellets are placed in a plastic cup to reduce barrel wear and minimize distortion of pellet shape. (Bonfanti & Kinder, 2013; Weaver, 2020) Different manufacturers also produce shotguns in different lengths, which means that not every shotgun maker produces the same length of shotgun. These differences stem from the distribution market but also from a country's legislation, since the maximum length of the barrel depends on national laws. The effect of barrel length on muzzle velocity is a controversial subject. Some studies investigated shot patterns of sawed-off shotguns and found that as the barrel was shortened, the pressure and velocity in the barrel remained unaffected, but the pressure at the muzzle of the shorter barrels was higher because less propellant was burned and the muzzle velocity was accordingly reduced. In addition, the higher pressure and incomplete burning of the propellant in sawed-off shotguns resulted in higher noise levels and greater muzzle flash on firing (Weaver, 2020; Kumral, Aslan & Buyuk, 2013; Sahu, Lal & Gupta, 2018). Considering the dramatic effect of barrel length, it seems logical to study how barrel length affects the shot pattern. In our study, we therefore selected different barrel lengths in order to investigate their influence on shot patterns at different firing distances.

A study by Moreau et al. addressed the shot patterns of sawed-off shotguns using three different 12-gauge shotguns. As expected, they found that the shot pattern was correlated with distance and to some extent with pellet size. Interestingly, they found that sawing off the choke resulted in a considerable increase in the diameter of the shot pattern, but continuing to shorten the barrel down to 12 inches had little effect. Nevertheless, when the barrel was shortened from 12 to 6 inches, a notable increase in shot pattern diameter became evident. However, since 12-gauge shotgun cartridges are typically about 3 inches long, a 6-inch barrel is not appreciably longer than the cartridge (Moreau, Nickels & Wray, 1985).

Research Conceptual framework

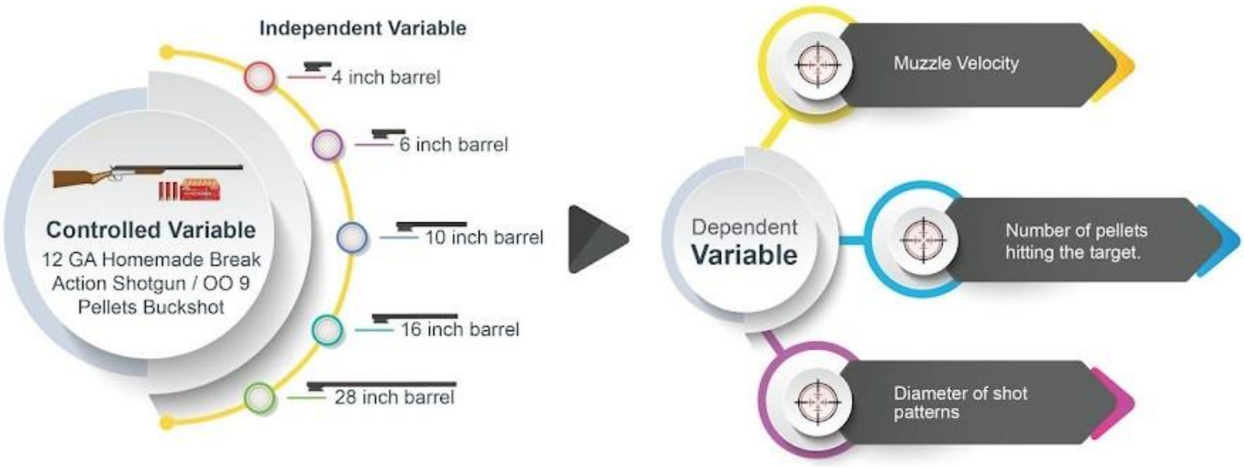

Fig 1. Research Conceptual framework

Methods

Homemade shotgun with different barrel lengths

A 12-gauge (0.729-inch) single-barrel, break-action shotgun was used. Five different barrel lengths (4, 6, 10, 16 and 28 inches) were used. The barrels were made of steel pipe with no choke. The barrels were installed on Steven 12GA Single Shot Shotgun Stock. The shotgun was fixed by a clamp mounted on a table. The table was fixed to the floor to ensure that the firing distance remained the same after shots were fired. Homemade shotguns do not have the same standards as company-manufactured shotguns, and there was a concern about explosion of the shotgun barrel after multiple shots. To prevent explosion and for additional safety measures, the shotgun was fired from a distance of 5 feet by pulling a plastic rope tied to the trigger.

Ammunition: Throughout the experiments, 12-gauge 2 3/4" OO 9 pellet buckshot from Bullet Master was used. Different brands of ammunition, such as Sellier and Bellot, Bullet Master and CCI, yield different results. In order to maintain the consistency of the results, the ammunition manufacturer remained the same throughout the study.

Paper target and firing distances: A rectangular paper target with a 15-inch circle drawn in the centre was used. A circle with a diameter of 15 inches was judged to be comparable with the human inner body area and is commonly used in similar studies. Two portable posts with concrete bases were moved closer to or farther from the clamp table to set the desired firing distance. The paper target was held between the two portable posts by fold-back clips. Firing distances are different according to the barrel length, because with longer barrels, an increase of 3 feet in the firing distance would not have any effect on the result. The longer the barrel, the longer the firing distance that had to be chosen. Longer firing distance was performed for the 28-inch barrel until 7 pellets hit the target as per our objective.

Table 1. Distances at which shots were fired using different barrel lengths (n = 53)

4-Inch Barrel	6-Inch Barrel	10-Inch Barrel	16-Inch Barrel	28-Inch Barrel
5 feet	5 feet	5 feet	5 feet	5 feet
8 feet	8 feet	8 feet	8 feet	8 feet
11 feet	11 feet	11 feet	11 feet	11 feet
14 feet	14 feet	14 feet	14 feet	14 feet
17 feet	17 feet	17 feet	17 feet	17 feet
21 feet	21 feet	21 feet	21 feet	21 feet
23 feet	23 feet	23 feet	23 feet	23 feet
40 feet	45 feet	45 feet	45 feet	45 feet
45 feet	48 feet	48 feet	48 feet	48 feet
		62 feet	62 feet	62 feet
			76 feet	76 feet
				83 feet
				87 feet
				90 feet
9 shots	**9 shots**	**10 shots**	**11 shots**	**14 shots**

Table 1 shows all distances tested while firing the shotgun (n = 53). The shortest firing distance was 5 feet, and the longest was 90 feet. The longer the distance, the harder it was for shots from the shorter barrels to hit the target, and therefore, longer distances, such as 90 feet, were only tested using long barrels.

Tape measure: Firing distance, shot barrel length and shot pattern diameter were measured with a tape measure marked in centimeters, feet and inches.

Measurement rod: To ensure that the measurements were taken accurately, a measurement rod was used to keep the shotgun muzzle fixed at the desired position. As barrels with different lengths were replaced, the distance between the muzzle of the shotgun and the paper target was altered. The rod was placed by the exit point of the shotgun barrel before and after each shot. The distance between the rod and the target was measured using a tape measure.

Chronograph: A Caldwell® Ballistic Precision Chronograph was used to measure the muzzle velocity of the shotgun. The chronograph was placed 4 feet from the shotgun barrel so that the fired pellets could pass through the sensor rods. The distance of the sensor rods was determined to ensure that the pellets still had their initial velocity before they had been significantly dispersed.

Experimental setup: The study was carried out in the outdoor shooting range in the Chaengwattana area of Bangkok. The experimental setup is illustrated in Figure 1. The shotgun was fixed on a table by a clamp. The chronograph was placed on a table between the gun and the target. The mobile board target was placed at different distances according to the experimental requirement. All experiments were performed on sunny days because environmental factors could influence the trajectory of the pellets and thus the shooting pattern on the target. To avoid the impact of wind on the shot pattern, we made sure that at the time of the experiments there was no wind. In addition, no experiments were conducted on foggy or humid days. An increase in density of the air increases resistance to the pellets as they fly through the air, so that the pellets move more slowly and thus have a lower impact on the target (Cleckner, 2018)

Data analysis: Four shots were fired for each firing distance and barrel length, for a total of 53 shots. Each combination of distance and barrel length, as presented in Table 1, was tested with one shot. The independent variables were the length of the shotgun barrel (4, 6, 10, 16 and 28 inches) and the firing distance, as shown above. The independent variables were shot pattern diameter, the number of shots hitting the target and muzzle velocity. The data were analyzed by the Statistical Package for the Social Sciences, version 17, to evaluate the relationships between variables by Pearson correlation and ANCOVA.

Results

The length of shotgun barrels has been a subject of controversy. Some studies have found that a longer barrel significantly improves accuracy, and others have not found any significant correlation between barrel length and shot accuracy (Moreau et al., 1985; Ward, Kujala & Coltri, 2013). Unless the barrel length is reduced by <50% of the original length, shortening it has no impact on the diameter of the shot pattern (also referred to as gun or shot accuracy). The main factor determining the diameter of this area is the choke, the type of cartridge that is fired or the constriction typically located at the muzzle of the shotgun barrel. Cutting off the end of the barrel changes its diameter and moves the choke (normally 2 inches or 5 cm in diameter) inward from the muzzle; this produces a cylinder bore that results in the widest shot pattern shotgun barrels generally found (Moreau et al., 1985). These observations prompted us to investigate the impact of shotgun barrel length on accuracy and shot patterns in addition to determining the distances each barrel length can be used until the pellets are dispersed too widely to hit the target.

Correlation between firing distance and shot accuracy

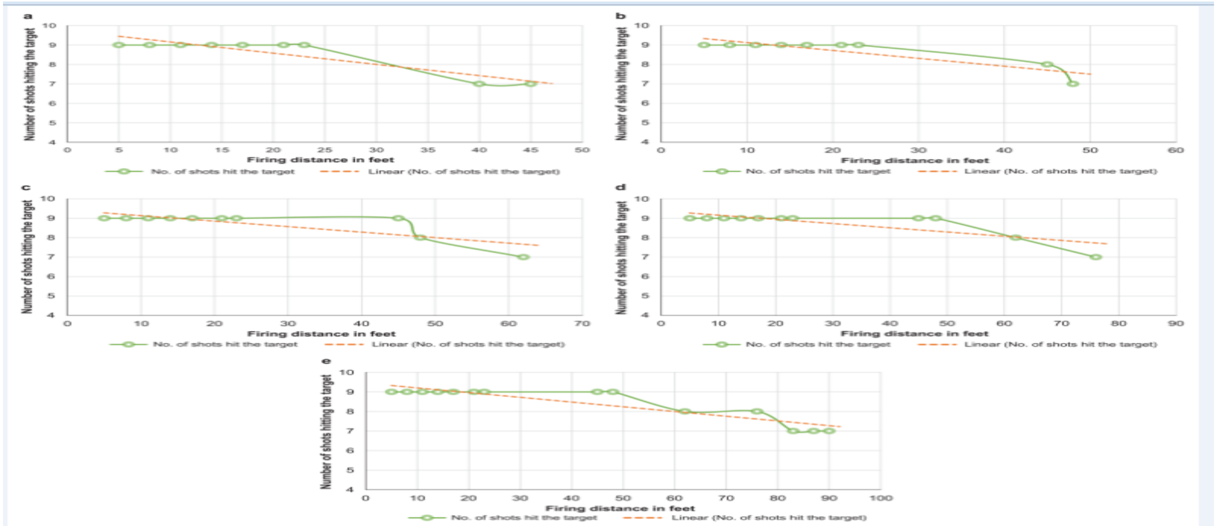

Fig 2. Correlation between firing distance and numbers of pellets hitting the target

(a) Firing distance and number of shots hitting the target with a 4-inch barrel shotgun (b) a 6-inch (c) a 10-inch (d) a 16-inch (e) a 28-inch. First, we examined whether the firing distance can affect the accuracy of the shotgun. Each shot contained nine pellets, so any shot that landed all nine pellets on the target was considered a perfect hit. We designed the experiment to determine the maximum distance at which 75% of the pellets would hit the target. Thus, any shot in which fewer than seven pellets hit the target was considered a miss. For instance, shots from the 4-inch barrel at distances of 5, 8, 11, 14, 17, 21 and 23 feet landed all nine pellets on the target (Fig. 2a). At 40 and 45 feet, only seven pellets hit the target. Shots from longer distances that resulted in fewer than seven pellets hitting the target were not recorded or indicated in the results. The following figures show the firing distances and the number of pellets that hit the target for each length of the shotgun barrel.

With the use of the 6-inch barrel, all nine of the pellets hit the target except for shots fired at 45 and 48 feet, in which eight and seven pellets, respectively, hit the target (Fig. 2b).

For the 10-inch barrel, firing distances from 5 to 62 feet were used (Fig. 2c). Nine pellets hit the target for all firing distances with the exception of 48 and 62 feet, in which 8 and 7 pellets, respectively, hit the target. The improvement in the firing distance for the 10-inch barrel was great enough that it could be tested at 62 feet.

Shots from the 16-inch barrel showed better accuracy and could hit the target at 76 feet (Fig. 2d). The shortest firing distance at which the 16-inch barrel was tested was 5 feet, and the longest was 76 feet. The number of pellets that hit the target was nine for all firing distances except for 62 and 76 feet, where 8 and 7 pellets, respectively, hit the target.

For the 28-inch barrel, the shortest firing distance was 5 feet and the longest firing distance was 90 feet (Fig. 2e). Eight or more pellets hit the target for all firing distances except for distances of 83, 87 and 90 feet, for which only 7 pellets hit the target.

Overall, our descriptive results show that shooting with longer barrels results in higher accuracy at longer distances, which supports the common assumption that longer barrels provide improved accuracy. ANCOVA indicated that there was a relationship between the number of shots hitting the target and the length of the barrel ($F(1,4) = 2.008$, $p = .109$). The greater the barrel length, the greater is the shot accuracy. Further, there was a significant relationship between the number of shots hitting the target and the firing distance ($F(1,4) = 104.849$, $p = .00$). Thus, greater firing distances will result in a higher number of shots hitting the target.

Correlation between firing distance and shot patterns

It is often assumed that using a shotgun with a shorter barrel will result in wider shot patterns. This assumption, however, has not been scientifically challenged. We therefore examined the effect of the length of the shotgun barrel on the shot pattern at various firing distances. In addition to barrel length as an independent variable or predictor, we fired the shots at different distances, as shown in Table 1, in order to examine the effect of distance on pellet dispersion or shot pattern. The results of this experiment are shown in the following figures for each barrel length.

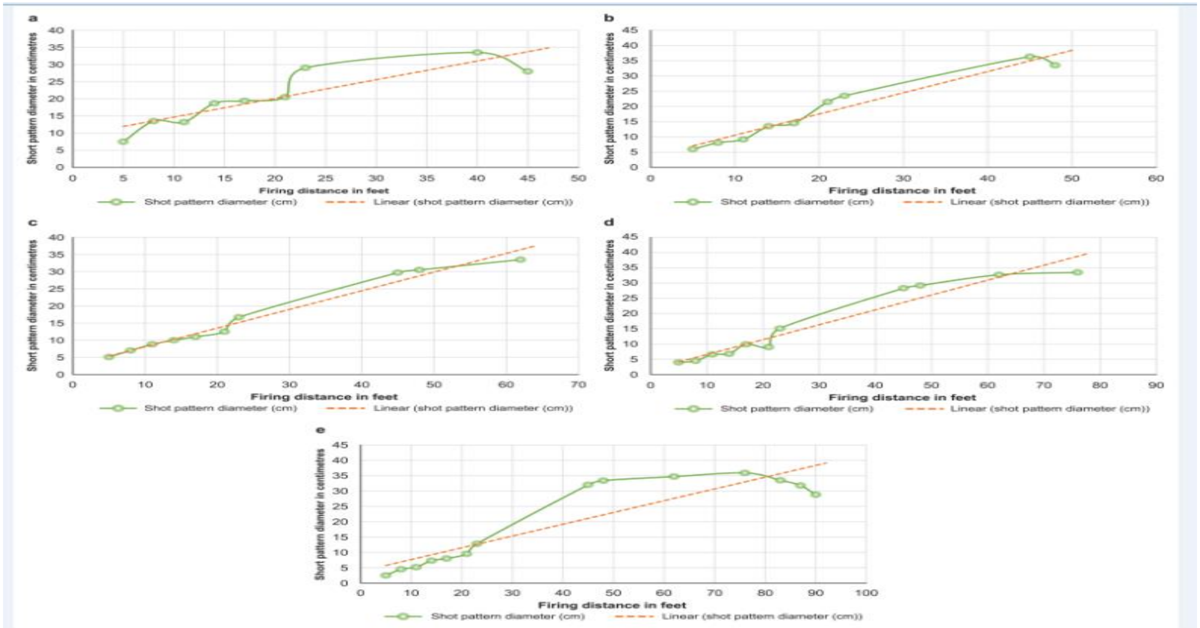

Fig 3 Shot pattern also increased

(a) Firing distance and shot pattern diameter with a 4-inch (b) a 6-inch (c) a 10-inch (d) a 16-inch (e) a 28-inch. For the 4-inch barrel, as the firing distance increased, the diameter of the shot pattern also increased, with the exception of shots fired at 11 and 45 feet, where the diameter decreased from 13.5 cm at 8 feet to 13.2 cm at 11 feet and from 33.5 cm at 40 feet to 28.0 cm at 45 feet (Fig. 3a).

For the 6-inch barrel, as the firing distance increased, the diameter of the shot pattern also increased, with the exception of the shot fired at 48 feet, where the diameter slightly decreased from 36.3 cm at 45 feet to 33.5 cm at 48 feet (Fig. 3b).

For the 10-inch barrel, as the firing distance increased, the diameter of the shot pattern also systematically increased from 5.1 cm at 5 feet to 33.5 cm at 62 feet (Fig. 3c).

We were able to test the 16-inch barrel at a greater range of firing distances, from 5 to 76 feet (Fig. 3d). As the firing distance increased, the diameter of the shot pattern also increased, with the exception of the shot fired at 21 feet, where the diameter was decreased from 9.9 cm at 17 feet to 9.0 cm at 21 feet.

We were able to test the longest barrel (28 inches) at firing distances ranging from 5 to 90 feet (Fig. 3e). As the firing distance increased, the diameter of the shot pattern also increased, with the exception of shots fired at 83, 87 and 90 feet, where the diameter slightly decreased from 35.9 cm at 87 feet to 33.5 cm at 83 feet, from 33.5 cm at 83 feet to 31.8 cm at 87 feet and from 31.8 cm at 87 feet to 28.8 cm at 90 feet. The unexpected reduction in the number of pellets hitting the target may have resulted not from an actual reduction in the shot pattern but from a greater dispersion of the pellets such that a lower number of the pellets hit the target.

Overall, our results show that the greater the firing distance, the greater the diameter of the shot pattern. Some exceptions were observed where the number of pellets hitting the target decreased, which resulted in a decrease in the diameter of the shot pattern. In fact, the smaller diameters of the shot patterns that did not follow the trend cannot be strictly interpreted as a decrease in shot pattern, as dispersion of the pellets may have resulted in losing the pellets. This hypothesis was tested with ANCOVA and Pearson correlation analysis. The results showed $F(1, 4) = 8.224$ ($p < 0.05$), and since the p-value was <.05, there was a significant nonlinear relationship between the firing distance and the number of pellets hitting the target. When the firing distance increased, fewer pellets hit the target. The Pearson correlation coefficient ($r = -0.682$, $p = 0.000$) indicates that there was a significant negative relationship between the number of pellets hitting the target and shot pattern diameter. An increase in the number of pellets hitting the target will decrease the shot pattern diameter and vice versa, when the number of pellets hitting the target decreases, the shot pattern diameter will increase.

Regarding our second hypothesis, ANCOVA resulted in $F(1, 4) = 422.841$ ($p < .05$). Since the p-value was <.05, the null hypothesis was rejected. Hence, there was a nonlinear relationship between firing distance and shot pattern diameter. Therefore, the second hypothesis was confirmed, and we can conclude that the greater the firing distance, the greater the shot pattern diameter, even though the relation is not constant.

Discussion

We tested shotgun barrels of different lengths (4, 6, 10, 16 and 28 inches) at different firing distances (Table 1). The shortest barrel was 4 inches long. Since the 12-gauge 2 3/4" OO 9 pellet buckshot used in this study was 3 inches long, this barrel was only 1 inch longer than the pellet buckshot. This significantly reduced the impact of barrel length on the fired pellets, as the pellets did not travel far in the barrel before exiting the barrel. In addition, before the ammunition gas transferred its maximum energy to the pellets, the barrel restriction was removed and the pellets had already left the barrel. It is widely assumed that longer barrels restrict pellet dispersion and yield smaller shot patterns. It is also believed that longer barrels have higher accuracy (Çelikel et al., 2012; Khudbudin et al., 2016; Nag, & Sinha, 1992; Rios et al., 1986)

We found that shots from the shortest barrel were indeed very inaccurate, since they did not hit targets farther away than 45 feet. Shots from the 6-inch barrel showed a slight improvement by hitting targets at 48 feet. This could be due to the long distance travelled by the pellets in the barrel, which further restricted dispersion of the pellets. With the use of longer barrels (10 and 16 inches), the shotgun hit targets up to 62 and 76 feet, respectively. The farthest target examined was at 90 feet, which was hit by shots from the 28-inch barrel. Our results indicate a clear tendency towards an improvement of shooting accuracy with the use of longer barrels.

A study conducted using the 16-inch barrel recorded shot patterns of #2 and #5 shots at firing distances between 75 and 1000 cm. The findings indicated that the radii of the shot pattern were 2.0, 2.3, 5.0, 8.2 and 15.6 cm for #2 shot and 2.1, 2.3, 5.4, 11.2 and 18.4 cm for #5 shot at firing distances of 75 cm (2.4 feet), 100 cm (3.2 feet), 300 cm (9.8 feet), 500 cm (16.4 feet) and 1000 cm (32 feet), respectively (38). Our results support these findings, with a significant positive correlation between firing distance and shot pattern diameter. With regard to the methodology of the study, (Arslan et al., 2011). used test runs for initial firing and applied linear regression to the results. Our study utilised a different methodology because the results were analyzed using ANCOVA and correlation. Although the methodologies of these studies varied, the results are comparable, with the same results obtained for the 16-inch barrel shotgun used at similar distances.

Meric et al. conducted a study to investigate the shotgun's range (Meric, Polat & Altun, 2020). The study analyzed how grain-loaded cartridges cause injury by studying the shot pattern from firing distances of 50, 100, 200, 300 and 500 cm (1.6, 3.2, 6.5, 9.8 and 16.4 feet). A Cifsan 12-gauge, 70 mm shotgun was used with a barrel length of 71 cm, with the over-barrel modified and the under-barrel having an improved cylinder choke.

The constriction of a modified cylinder is less than that of a full choke, and it delivers about 60% of a shell's total pellets within a 30-inch circle at 40 yards. An improved cylinder is less constricted than a modified one and delivers about 50% of a shell's total pellets at the same distance. A graph of the results shows shot pattern diameter on the y-axis and different brands, namely, Ozkursan, Zuber, Yaf, Makarov, Yeni-Tur, Mesco, Bombastic and Momento, with various grains on the x-axis. The data indicated that increasing the firing distance increased pellet dispersion on the target. The shot patterns of 10- and 16-inch barrels were similar to those in our study. For other barrel sizes, the largest shot patterns were observed at firing distances of 40 and 45 feet. Based on these results, it can be argued that for lead cartridge pellet shotguns, the shot pattern diameter is optimal at firing distances of 40 to 50 feet, whereas for grain-loaded shotguns, the diameter of the shot pattern increases when the firing distance is increased. Further tests with greater firing distances should be performed to fully analyze different types of shotguns and their firing distances, barrel lengths and diameter of shot patterns on the target. Meric et al. also analyzed the effects of modified choke on grain-loaded cartridges and found that modified chokes with an improved cylinder created larger shot patterns, with diameters of >123 cm at a firing distance of 500 cm (Meric et al., 2020). In our study, we used a cylinder as a choke tube; it was not modified or improved. A cylinder distributes about 40% of a shell's total pellets in a 30-inch circle at 40 yards when there is no constriction. Cylinder choke is most frequently utilized by law enforcement services for service shotguns (Sutton, 2019) Modified and improved chokes were mentioned in the study by Moreau et al. (1985). We did not use a modified choke or an improved cylinder in our study; therefore, this factor could not be included in the outcome.

Karapirli et al., (2015) positioned intermediate objects such as glass (30 × 30 × 0.6 cm), tempered auto glass (30 × 30 × 0.6 cm), mica auto glass (30 × 30 × 0.63 cm), flat iron (30 × 30 × 0.05 cm), fibreboard (30 × 30 × 0.8 cm), aluminium (30 × 30 × 0.05 cm) and grey cotton fabric in front of the shotgun (Fowler et al., 2015). All material was bought from a fabric dealer except for the auto glass, which was made in Ankara, Turkey in a glass factory. A white sheet of A4 paper, placed on cardboard and fixed to a target board, was the principal target. Two wooden target boards of the same size were used, supported by two holders. Pellet dispersion on the main target was measured. The methodology of the study included categorization of the different materials used, followed by calculation of coefficients of variation and standard deviations. The results showed that increasing the density of the intermediate objects increased the dispersion of pellets on the main target from shots with a Turkish-made Sen-Mak automatic 12-gauge, choke less licensed shotgun with a 70-cm barrel length and a capacity of 8+1 cartridges using cartridges number 0 and 9 (Karapirli et al., 2015). We used a slightly different shotgun in our study, a 12-gauge cylinder shotgun break-action single-barrel with barrels of 4, 6, 10, 16 and 28 inches. Moreover, we used a 270-g rectangular paper on which a circle with a diameter of 15 inches was drawn to fix the area of the shotgun patterns. A circle with a diameter of 15 inches was considered to be comparable to the human inner body area. We did not have an intermediate target. However, similar to their results, increasing the firing distance increased the shot pattern diameter, and increasing the density of an intermediary target also increased the shot pattern diameter. Both studies showed that increasing the firing distance increased the shot pattern diameter; this relationship can be used to determine the distance of a perpetrator in the criminal investigation.

New knowledge from research

This research has brought to light the new data of shot patterns and numbers of shot hitting the target at different firing distance when the 12GA homemade break-action shotgun used. This new knowledge obtained from this research can be used in comparison with the 12GA manufactured break-action shotgun when the same length of shotgun barrel and firing distance applied.

Conclusion

The length of the shotgun barrel was positively correlated with muzzle velocity and negatively correlated with the diameter of the shot pattern. These findings can be used in forensic investigations to help determine the distance of the shooter from the victim and to distinguish crimes from suicides and accidents.

Recommendation

Future research should investigate more firing distances with more shots for each distance, recording the number of pellets from 0 to 9 landing on the target. These additional findings would extend our results and help to address the subject of homemade shotguns. The results could in turn help the police and the criminal justice system to solve cases involving this type of weapon.

Acknowledgements

We thank the Office of Police Forensic Science for their collaboration and the provisions of firearm forensic specialists: Chaiyong Promchiang and Sichon Pinijchai, to support this study. This study was supported by a research grant from Thammasat University Research Fund under the TU Research Scholar, Contract No. 33/2018.

References

Arslan, M. M., Kar, H., Üner, B., & Çetin, G. (2011). Firing distance estimates with pellet dispersion from shotgun with various chokes: An experimental, comparative study. *Journal of Forensic Sciences,* 56(4), 988–992. https://doi.org/10.1111/j.1556-4029.2011.01761

Burruss, J. W., & Decker, S. H. (2002) Gun violence and police problem solving: A research note examining alternative data source. *Journal of Criminal Justice*, *30*(6), 567-574. https://doi.org/10.1016/S0047-2352(02)00190-3

Breitenecker, R. (1969). Shotgun wound patterns. *American Journal of Clinical Pathology*, *52*(3), 258–269.

Berg, S. O. (1997). *The Forensic Ballistics Laboratory*, In C.G. Tedeschi, W.G. Ecket, Tedeschi G.L. (Eds.), Forensic Medicine, Section 2, W.B. Saunders.

Bonfanti, M. S., & Kinder, J. D. (2013). *Firearm and Toolmark Examination and Identification*(Houck M. M, Ed.). Elsevier.

Cook, P. J., & Ludwig, J. (2002). The costs of gun violence against children. *The Future of Children*, *12*(2), 86–99. https://doi.org/10.2307/1602740

Çelikel, A., Balcı, Y, Üner, B., & Bal, C. (2012). The effect of barrel length on pellet dispersion and its importance in determination of range of fire. *Turkish Journal of Forensic Medicine*, 26(2), 115-123.

Cleckner, R. (2018, January 15). *Bullet trajectory: The effects of humidity*. Gun Digest. https://gundigest.com/more/how-to/firearm-training/humidity-effects-bullet-trajectory

Dillon, K. P., & Bushman, B. J. (2017). Effects of exposure to gun violence in movies on children's interest in real guns. *JAMA Pediatrics, 171*(11), 1057–1062. https://doi.org/10.1001/jamapediatrics.2017.2229

Di-Miao, V. J. M. (1999). *Gunshot wounds: Practical aspects of firearms, ballistics, and forensic techniques*. CRC Press.

Dresang, L. T. (2001). Gun deaths in rural and urban settings: Recommendations for prevention. *The Journal of the American Board of Family Practice*, *14*(2), 107–115.

Fowler, K. A., Dahlberg, L. L., Haileyesus, T., & Annest, J. L. (2015). Firearm injuries in the United States. *Preventive medicine, 79, 5–14.* https://doi.org/10.1016/j.ypmed.2015.06.002

Fann, C., Ritter, W., Watts, R., & Rowe, W. (1986). Regression analysis applied to shotgun range-of-fire estimations: results of a blind study. *Journal of Forensic Sciences, 31*(3), 840-854. https://doi.org/10.1520/JFS11094J

Gold, L. H. (2013). Gun violence: psychiatry, risk assessment, and social policy. *Journal of the American Academy of Psychiatry and the Law*, *41*(3), 337–343.

Graziano, M., & Pulcini, J. (2013). Gun violence and the role of health care: a confusing state of affairs. *The American journal of nursing, 113*(9), 23–25.

Kahan, D. M, & Braman, D. (2003). More statistics, less persuasion: a cultural theory of gun-risk perceptions. *University of Pennsylvania Law Review*, *151*(4), 1291–1327. https://doi.org/10.2139/SSRN.286205

Kellermann, A. L., & Rivara, F. P. (2012). Silencing the science on gun research. *JAMA*, *309*(6), 549–550. https://doi.org/10.1001/jama.2012.208207

Khudbudin, M., Mahesh, K., Gautam, G., & Jagtap, R. (2016). Study of estimating firing distance based on pellets distribution on targets from country made pipegun. *Research Journal of Forensic Sciences, 4*(3), 1–5.

Karapirli, M., Uysal, C., Akcan, R., & Aksoy, M. E. (2015). The effect of intermediate targets on the spread of pellets from shotguns. *Australian Journal of Forensic Sciences*, *47*(3), 355-362 https://doi.org/10.1080/00450618.2014.982181

Kumral, B., Aslan, E., Buyuk, Y. (2013). Ballistic examination findings of sawed-off shotguns referred to council of forensic medicine. *Journal of Animal and Veterinary Advances, 12*(10), 977-981. https://doi.org/10.3923/javaa.2013.977.981

Meric, C. Ç, Polat, M. Ö, & Altun, G. (2020). Shot range estimation of shotgun grain-loaded cartridges. *Forensic science international, 314*, 110375. https://doi.org/10.1016/j.forsciint.2020.110375

Moreau, T. S., Nickels, M. L., & Wray, J. L. (1985). Pellet patterns fired by sawed-off shotguns. *Journal Forensic Science*, *30*(1), 137–149. https://doi.org/10.1520/JFS10974J

Nag, N. K., & Sinha, P. (1992). An investigation into pellet dispersion ballistics. *Forensic science international*, *55*(2), 105–130. https://doi.org/10.1016/0379-0738(92)90118-g

Office of Police forensic science. (n.d.). *Office of Police Forensic Science's Organization Structure.* Office of Police forensic science. http://www.forensic.police.go.th/FS/html/structurenew.php

Ordog, G. J., Wasserberger, J., & Balasubramaniam, S. (1988). Shotgun Wound Ballistics. *The Journal of Trauma: Injury, Infection, and Critical Care*, *5*, 624–631. https://doi.org/10.1097/00005373-198805000-00011

Punkaew, W. (2020, August 18). *The study of shot patterns, shot holes of shotgun, and visible Gun Shot Residue (GSR) from firing a customized 12 gauge shotgun detected in lower northern part of Thailand.* Police Forensic Science Center 6. http://www.scdc6.forensic.police.go.th/images/file/web.pdf

Rios, F.G., Thornton, J. I., & Guarino, K. (1986). Multivariate statistical analysis of shotgun pellet dispersion. *Forensic Science International*, *32*, 21-28. https://doi.org/10.1016/0379-0738(86)90154-4

Sahu, K. I, Lal A, & Gupta, A. K. (2018). Comparative study of gunshot residue and gunshot pattern of 12 bore standard and country made firearm. *IAETSD Journal for Advanced Research in Applied Sciences*, *5*(5), 18–36.

Sherman, L. W., & Rogan, D. P. (2006). Effects of gun seizures on gun violence: "Hot spots" patrol in Kansas City. *Justice Quarterly*, *12*(4), 673–693. https://doi.org/10.1080/07418829500096241

Sutton, K. (2019, February 5). *Guide to Shotgun Choke Tubes.* BassProShops1Source. https://1source.basspro.com/news-tips/hunting-gear/7692/guide-shotgun-choke-tubes

Swanson, J. W. et al. (2019). Criminal justice and suicide outcomes with Indiana's risk-based gun seizure law. *Journal of the American Academy of Psychiatry and the Law, 47*(1), 188–197. https://doi.org/10.29158/JAAPL.00 3835-19

Thube, H. R., & Chikhalkar, B. G. (2017). A study of fatal gunshot injuries over two years in Mumbai, India. *Indian Journal of Forensic and Community Medicine, 4*(3), 154–157. https://doi.org/10.18231/2394-6776.2017.0033

Ward, M. S., Kujala. V., & Coltri, A. (2013). Sawed-off shotgun, the effect of barrel length on shot pattern size. *AFTE Journal, 45*(1), 37–41.

Weaver, D. S. (2020) The English blunderbuss and its ballistics. *Arms & Armour*, *17*(2), 122–156. https://doi.org/10.1080/17416124.2020.1727630.