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Impacts of Supersonic and Subsonic Ammunition on Gunshot Residues Distribution

Süpersonik ve Subsonik Mühimmatin Atış Artıklarının Dağılımı Üzerindeki Etkileri

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IMPACTS OF SUPERSONIC AND SUBSONIC AMMUNITION ON GUNSHOT RESIDUES DISTRIBUTION

Abstract

In incidents involving firearms, determining the firing distance is one of the basic steps of the analysis aimed at determining the origin of the incident with Forensic Shot Analysis studies. Shot residues consist of partially burned and unburnt powder grains, gunpowder gas, capsule residues and inorganic and organic residues. As a result of determining the presence and density of shot residues on the target, the distance from which the shot was fired can be determined. The pattern and density of shot residues directly correlate with the specifications of firearms and ammunition. The weapon's intended use and traits affect the ammunition's properties. An instance of specialised ammunition is subsonic cartridges, which have lower powder burn rates and amounts compared to supersonic cartridges. To ensure accurate gunshot residue analysis, gunshot residue density and pattern from reference test fires are necessary. The key factors affecting the GSR analysis are the type of weapon and ammunition used during test fires, which should closely match those used in the incident. Any variation in these variables can reduce the precision of the residue analysis. In the study, an independent T-test was applied to determine whether there is a significant difference between the gunshot residue density on the target during test firing of 9×19mm diameter and type Supersonic and Subsonic cartridges with semi-automatic pistols at distances of 0cm, 15cm, 30cm, 60cm and 100cm. It was determined that a significant difference existed between supersonic and subsonic cartridges in the density and patterns of gunshot residue on the target resulting from shots fired at the mentioned distances.

Keywords: *Gunshot Residues, Supersonic Ammunition, Subsonic Ammunition, Forensic Shooting Analysis.*

SÜPERSONİK VE SUBSONİK MÜHİMMATIN ATIŞ ARTIKLARININ DAĞILIMI ÜZERİNDEKİ ETKİLERİ

Öz

Ateşli silahların kullanıldığı olaylarda atış mesafesinin tespit edilmesi, "Adli Atış Analizi" çalışmaları ile olayın orijinin tespit edilmesine yönelik analizlerin temel adımlarından biridir. Atış artıkları, kısmen yanmış ve yanmamış barut taneleri, barut gazı, kapsül eczası artıkları ile inorganik ve organik kalıntılardan oluşmaktadır. Hedef üzerinde atış artıklarının varlığının ve yoğunluğunun tespit edilmesi neticesinde atışın hangi mesafeden yapıldığı belirlenmektedir.

Atış artıklarının yoğunluğu ve dağılımı doğrudan ateşli silah ve mühimmat özellikleriyle ilgilidir. Mühimmat özellikleri, kullanım amacına ve silaha göre değişmektedir. Ses üstü fişeklere kıyasla daha düşük barut yanma oranlarına ve miktarlarına sahip olan ses altı fişekler, özel amaçlı mühimmatlara örnek olarak verilebilir. Atış artığı analizinin doğru şekilde yapılabilmesi için referans test atışlarından elde edilen atış artığı yoğunluğu ve dağılımı gereklidir. GSR analizini etkileyen kilit faktörler, olayda kullanılanlarla yakından eşleşmesi gereken test atışları sırasında kullanılan silah ve mühimmat türüdür. Bu değişkenlerdeki herhangi bir farklılık kalıntı analizinin hassasiyetini azaltabilir. Çalışmada, 9×19mm çap ve tipindeki Süpersonik ve Subsonik fişeklerin yarı otomatik tabancalarla 0 cm, 15cm, 30 cm, 60 cm ve 100 cm mesafelerde test atışları sırasında hedef üzerindeki atış artığı yoğunluğu arasında anlamlı bir fark olup olmadığını belirlemek için bağımsız T-testi uygulanmıştır. Test sonucunda süpersonik ve subsonik fişekler arasında söz konusu mesafelerde yapılan atışlar sonucunda hedef üzerinde oluşan barut artığı yoğunluğu ve desenlerinde önemli bir fark olduğu tespit edilmiştir.

Anahtar Kelimeler: *Atış Artığı, Süpersonik Fişek, Subsonik Fişek, Adli Atış Analizi.*

INTRODUCTION

Shooting reconstruction studies have been extensively utilised in criminal investigations for years to determine various factors in a shooting incident. The analysis of gunshot residue results can identify the shooter's position, distance, bullet trajectory, and ricochets and ascertain the nature of the event, whether it is a homicide, suicide or accident (Hueske, 2016).

Gunshot residues consist of burned and unburned gunpowder particles, gunpowder gas, and inorganic and organic residue components from the primer material (lead styphnate-$C_6HN_3O_8Pb$, as an oxidiser; barium nitrate, Ba $(NO_3)_2$ and as a primer fuel; antimony sulphide, Sb_2S_3) metals from the bullet core and jacket, the cartridge case, and the firearm itself (Mozayani and Noziglia, 2006). When gunpowder ignites, it releases a vapour cloud of organic and inorganic gunshot residues and unburnt powder grains from the muzzle under the influence of the gunpowder gas. As a result, gunshot residue dispersion patterns form on the nearby target. By analysing the density and presence of gunshot residue and unburnt gunpowder grains on the target, it becomes possible to determine the distance from which the shot was fired (Fisher et al., 2009).

After the firing pin strikes the primer container, the primer material trapped between the anvil and the primer container catches fire. It ignites the lead styphnate, considered the primer's primary explosive. The barium nitrate then begins to release its oxygen quickly to raise the temperature of the chemical reaction. When a high temperature is reached, the antimony sulphur ignites. This reaction ignites the gunpowder in the cartridge, and the pressure of the burning gunpowder gas pushes the bullet core along the barrel to the target (Schwoeble and Exline, 2000). Lead, barium, and antimony are frequently present in the residues produced by firing and many modern residue detection tests rely on detecting these elements. Alongside these fundamental components, the GSR also contains minute quantities of calcium, silicon, sulfur, copper, and zinc (Feeney et al., 2020; Pyl et al., 2019).

The smokeless powder used today contains nitrocellulose (NC), nitro-glycerine (NG) and nitroguanidine (NGu), stabilisers such as diphenylamine and ethyl centralite methyl centralite, and sensitisers such as nitrotoluenes and dinitrotoluenes (Yüksel et al., 2023).

Completely burned organic gunshot residues (GSR) appear as soot stains on the target. However, 20-25% of the gunpowder in small arms cartridges is expected to leave the barrel without burning (Akçay, 2017). In this context, unburnt or partially burned organic gunshot residue particles form a phenomenon called "gunpowder tattoo", which is visible on the target (DiMaio, 2016).

In forensic science, the GSR tests are performed for two purposes: the first is the detection of GSR particles on the shooter's hands or objects, and the second is estimating the shooting distance (muzzle to target) (Barry et al., 2009) using physical and chemical methods. In conjunction with x-ray spectrometry (SEM-EDX), scanning electron microscopy is the most common gunshot residue examination method for detecting the GSR (William J. Tilstone, 2006). Colourimetric tests such as the modified Griess and sodium rhodizonate tests estimate the shooting distance (Yüksel et al., 2019; Barry et al., 2009).

The physical examination of the suspected bullet entrance hole is the first step of the GSR examination. The position, shape, diameter, deposit (soot) ring of the hole and the direction and pattern of the fibres around the hole are examined. If the hole is defined as a bullet entrance, the second step, "chemical examination," is performed to determine (estimate) the shooting distance. In order to determine the bullet impact and shooting distance, the sodium rhodizonate test is the most common chemical GSR examination method (Wallace, 2008). The target surfaces are contaminated with lead residues by the high-velocity lead vapours from the muzzle at contact or close distance (John H. DILLON, July 1990). The sodium rhodizonate colour tests, which are the reagents for detecting lead residues, change the colour of the surface to "bright pink" (Fisher et al., 2009) or a "violent" colour. The colour changes depending on the lead residues' pH level (pH 7: blue to violet; pH 28: bright red colour; and other pH levels: red-brown) (Shrivastava, Jain, ve Nagpal, 2021).

According to the colourimetric test results, the shooting distance estimates can be classified into three distance categories: contact, close, and long distance.

The main problem of GSR examination is that the compositions of GSR can be variable, according to the type of weapon, the barrel length, the types and brands, and the amount of ammunition (Ditrich, 2012; Heard, 2008). Additionally, the gunshot residues are easily removed by washing the shooter's hands or changing the shooter's clothes, and they are contaminated by environmental changes (Schwoeble and Exline, 2000).

As mentioned in the previous paragraph, ammunition characteristics are one of the main factors affecting GSR intensity and distribution. Regarding muzzle velocity, cartridges can be categorised into two main classes: supersonic/transonic and subsonic. This study aimed to determine the GSR distribution of subsonic ammunition, which is preferred by the armed forces and law enforcement units for tactical use due to its low muzzle velocity (less than 343 meters per second at sea level and room temperature), low kinetic energy, low recoil energy, and high accuracy at short ranges, and which has been preferred for self-defence situations and hunting in recent years, and to determine whether there is any difference between the GSR distribution of supersonic cartridges.

Note: *This study was supported by the Gendarmerie and Coast Guard Academy Scientific Research Project No. 22B4*

*(**Not:** Bu çalışma, Jandarma ve Sahil Güvenlik Akademisi Bilimsel Araştırma Projesi No. 22B4 tarafından desteklenmiştir.)*

MATERIAL AND METHODS

The test firings were performed with a 9×19mm TP9 Elite Combat model Canik semi-automatic handgun, and muzzle velocity was measured by LabRadar® v.1.3 velocity radar (± 0.1% accuracy). The technical specifications of the test handgun, which are related to the study, are mentioned in Table 1.

Table-1. The Technical Specifications of the 9×19mm TP9 Elite Combat Model Canik Semi-Automatic Handgun.

Caliber	9×19mm
Barrel Length	127mm
Muzzle Velocity with Supersonic Ammunition	380±10m/sn
Muzzle Velocity with Subsonic Ammunition	305±10m/sn

In the test firings, Sterling® brand 9×19 mm diameter supersonic and subsonic ammunition produced by Turaç Company were used. The technical specifications of the cartridges related to the tests are stated in Table 2 and Table 3.

Table-2. The Technical Specifications of Sterling® Brand 9×19 mm Diameter Supersonic Ammunition Produced by Turaç Company.

Caliber	9×19mm Supersonic
Bullet Type	FMJ Lead Core
Bullet Weight	8 grams
Max Pressure	2850 bar
Test Barrel Muzzle Velocity	370±10m/sn

Table-3. The Technical Specifications of Sterling® Brand 9×19 mm Diameter Subsonic Ammunition Produced by Turaç Company.

Caliber	9×19mm Subsonic
Bullet Type	FMJ Lead Core
Bullet Weight	9,5 grams
Max Pressure	1500 bar
Test Barrel Muzzle Velocity	290±10m/sn

In this study, 30 test fires were performed with each cartridge type to targets made of dye-free cotton fabric with dimensions of 210mm×297mm from 0cm, 15cm, 30cm, 60cm and 100cm distances. (Figure 1), (Table 4).

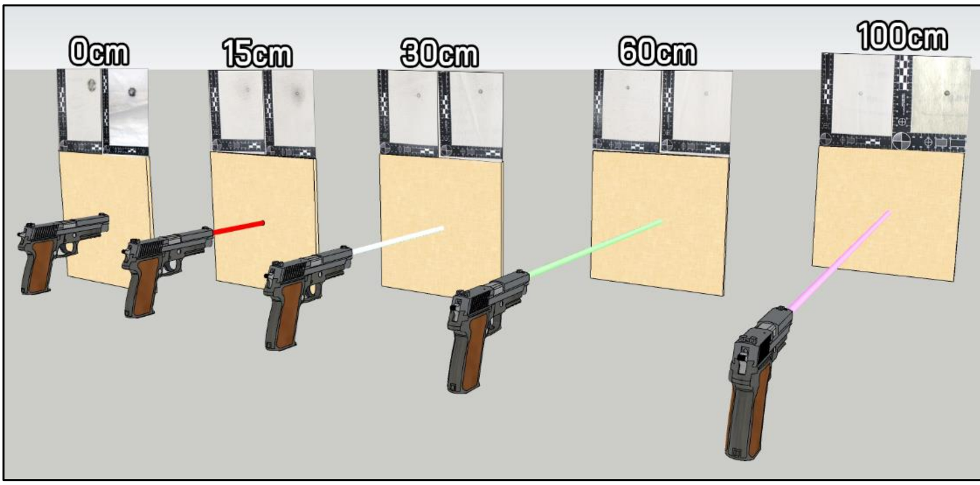


Figure-1. The GSR Test Setup.

Table-4. The Test Fire Ammunition Planning.

Ammunition Types	0cm	15cm	30cm	60cm	100cm	Total Test Shots
Supersonic Cartridge	30 Rounds	30 Rounds	30 Rounds	30 Rounds	30 Rounds	150 Rounds
Subsonic Cartridge	30 Rounds	30 Rounds	30 Rounds	30 Rounds	30 Rounds	150 Rounds

During the tests, the barrel and slide group were cleaned with pressurised dry air and acetone cotton wool after each test fire to prevent contamination between shots and memory effects due to the accumulation of gunshot residues (Burnett and Nunziata, 2023).

In order to detect the gunshot residues, the Sodium Rhodizonate Test (SRT) was used, which is a colour test that reacts with the element lead from the residues of the capsule (lead styphnate or lead azide) and the materials used in the manufacture of the bullet core (Feigl and Suter, 1942; Schwoeble and Exline, 2000).

The gunshot residue area detected as a result of the test was measured using ImageJ® software, and the data was subjected to a T-test in SPSS® software (Version 20th) to analyse whether there was a significant difference between the gunshot residue patterns formed as a result of firing supersonic and subsonic cartridges at five different distances.

The test firings were conducted at Samsun Yurt Savunma Canik firm's outdoor firing range facilities, whilst STR analyses were performed at the Samsun Criminal Police Laboratory Directorate of the Turkish National Police.

RESULTS

1. 0 cm DISTANCE (CONTACT SHOT) TEST FIRES

Thirty shots were fired with both supersonic (Figure 2) and subsonic (Figure 3) cartridges at a dye-free cotton fabric target at a distance of 0 cm. Sodium Rhodizonate solution was applied to the area of the bullet entry hole. The bright pink colour formation was observed due to a reaction with lead, lead styphnate, or lead azide around the bullet entry hole.

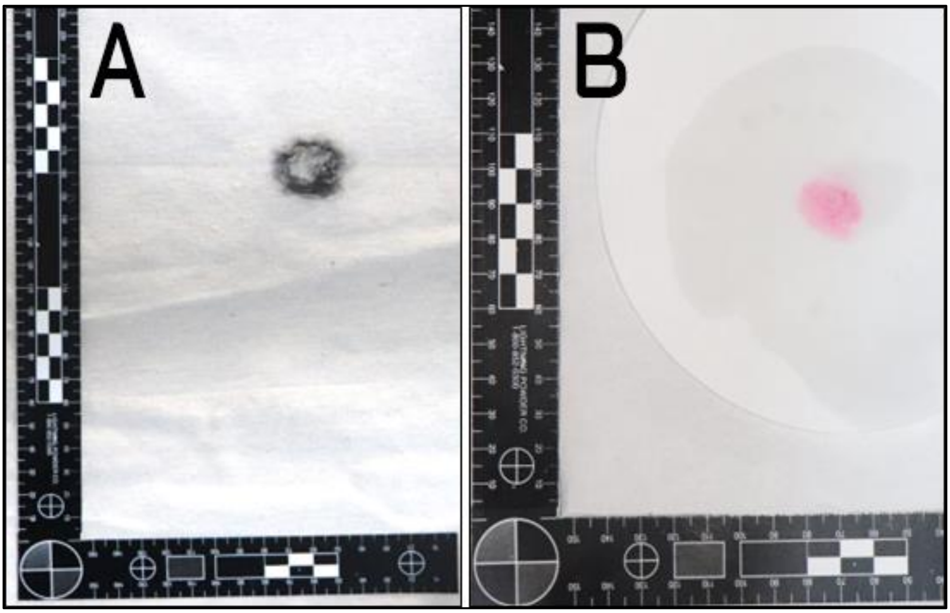


Figure-2. The Gunshot Residue Distribution Around the Bullet Entry Hole of 9×19mm Supersonic Cartridges **A.** Original Bullet Entry Hole View **B.** The Gunshot Residue Distribution View After Sodium Rhodizonate Solution Application.

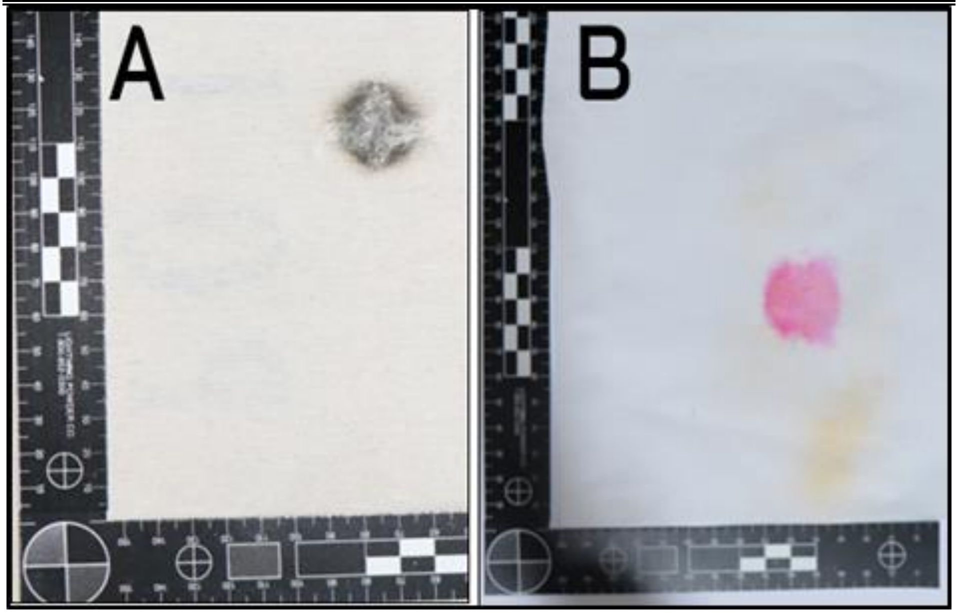


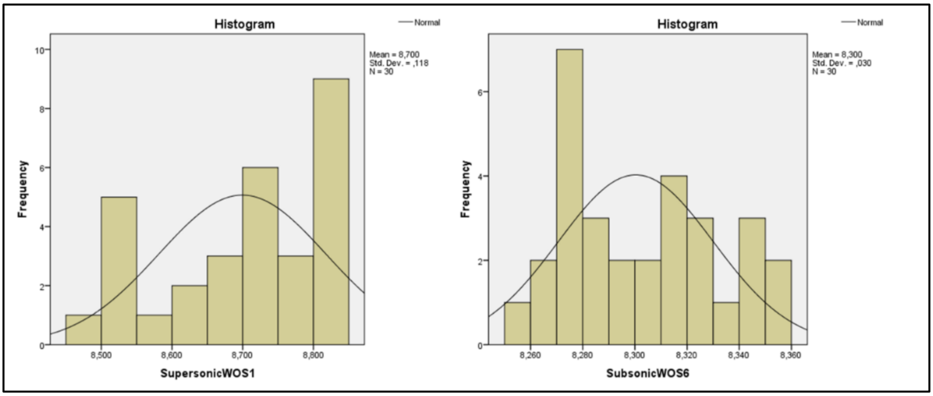
Figure-3. The Gunshot Residue Distribution Around the Bullet Entry Hole of 9×19mm Subsonic Cartridges **A.** Original Bullet Entry Hole View **B.** The Gunshot Residue Distribution View After Sodium Rhodizonate Solution Application.

The pink-coloured gunshot residue distribution area (mm^2) on the target due to the shooting of supersonic and subsonic cartridges was measured using ImageJ® software. The values of the measured shot residue area on the target of thirty shots fired with each type of cartridge were analysed with SPSS® software, and it was determined that they showed a normal distribution (Table 5) (Graphic 1).

Table-5. Descriptive Analysis of the Supersonic and Subsonic Cartridges Test Fires in the 0 cm Range.

Descriptives

			Statistic	Std. Error
SupersonicWOS1	Mean		8,69950	,021568
	95% Confidence Interval for Mean	Lower Bound	8,65539	
		Upper Bound	8,74361	
	5% Trimmed Mean		8,70250	
	Median		8,72000	
	Variance		,014	
	Std. Deviation		,118132	
	Minimum		8,496	
	Maximum		8,845	
	Range		,349	
	Interquartile Range		,212	
	Skewness		-,493	,427
	Kurtosis		-1,168	,833
SubsonicWOS6	Mean		8,30033	,005429
	95% Confidence Interval for Mean	Lower Bound	8,28923	
		Upper Bound	8,31144	
	5% Trimmed Mean		8,29970	
	Median		8,29650	
	Variance		,001	
	Std. Deviation		,029736	
	Minimum		8,257	
	Maximum		8,356	
	Range		,099	
	Interquartile Range		,048	
	Skewness		,326	,427
	Kurtosis		-1,134	,833



Graphic-1. The Average Distribution Histogram of the Gunshot Residues of Supersonic and Subsonic Cartridges Test Fires in the 0cm Range.

Evaluation: According to the results of the T-test, it was determined that there was a **significant difference** between the shot residue distribution area (mm^2) created on the target by the supersonic and subsonic cartridges of 9×19mm diameter and type produced by the same company (Turaç) when fired from a distance of 0cm with the TP9 Elite Combat model Canik semi-automatic pistol (Table 6).

Table-6. T-test Results of the Gunshot Residues of Supersonic and Subsonic Cartridges Test Fires in the 0cm Range.

T-Test

Group Statistics

	Silencer	N	Mean	Std. Deviation	Std. Error Mean
GSR	SPS_WoS-0cm	30	8,69950	,118132	,021568
	SBS_WoS-0cm	30	8,30033	,029736	,005429

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
GSR	Equal variances assumed	41,378	,000	17,948	58	,000	,399167	,022241	,354647	,443686
	Equal variances not assumed			17,948	32,660	,000	,399167	,022241	,353900	,444434

2. 15 cm DISTANCE TEST FIRES

Thirty shots were fired with both supersonic (Figure 4) and subsonic (Figure 5) cartridges at a dye-free cotton fabric target at a distance of 15 cm. Sodium rhodizonate solution was applied to the area of the bullet entry hole. The bright pink colour formation was observed due to a reaction with lead, lead styphnate, or lead azide around the bullet entry hole.

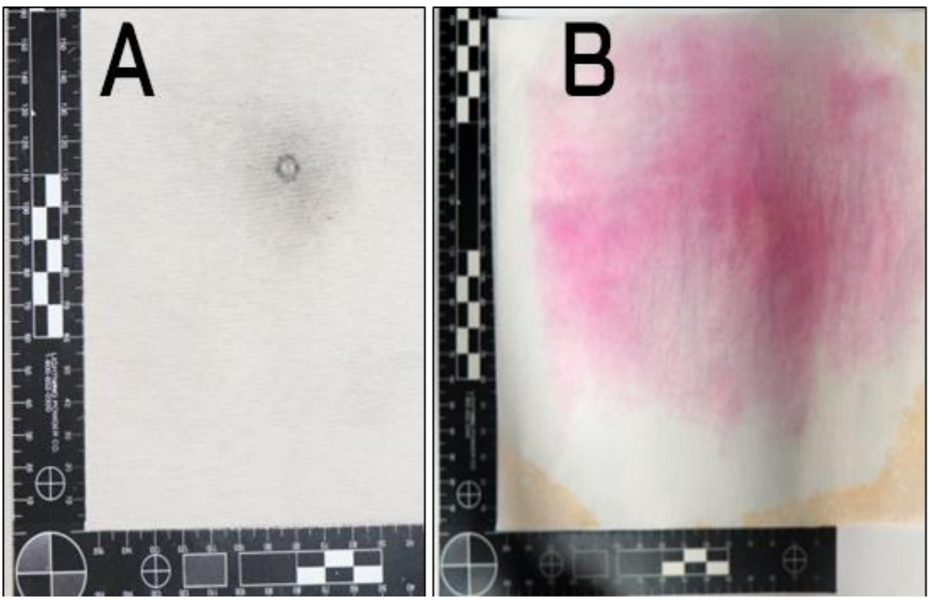


Figure-4. The Gunshot Residue Distribution Around the Bullet Entry Hole of 9×19mm Supersonic Cartridges **A.** Original Bullet Entry Hole View **B.** The Gunshot Residue Distribution View After Sodium Rhodizonate Solution Application.

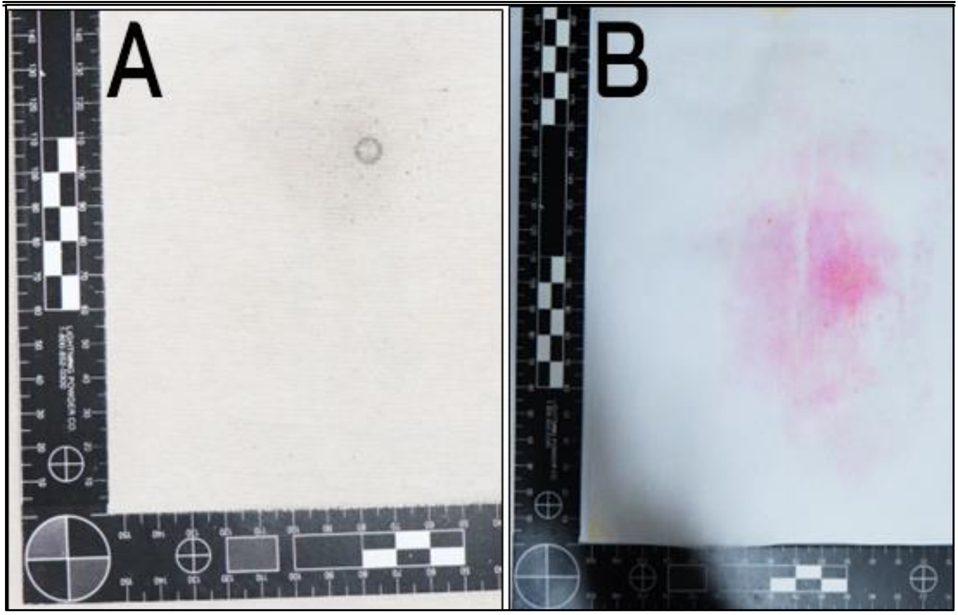


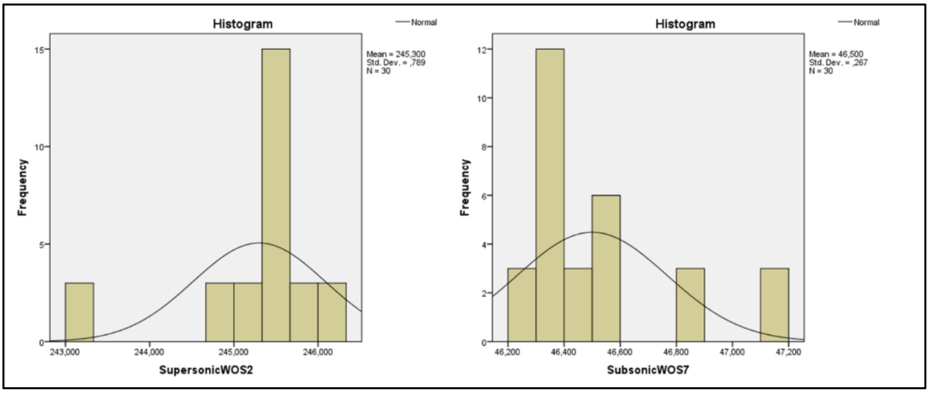
Figure-5. The Gunshot Residue Distribution Around the Bullet Entry Hole of 9×19mm Subsonic Cartridges **A.** Original Bullet Entry Hole View **B.** The Gunshot Residue Distribution View After Sodium Rhodizonate Solution Application.

The pink-coloured gunshot residue distribution area (mm^2) on the target due to the shooting of supersonic and subsonic cartridges was measured using ImageJ® software. The values of the measured shot residue area on the target of thirty shots fired with each type of cartridge were analysed with SPSS® software, and it was determined that they showed a normal distribution (Table 7) (Graphic 2).

Table-7. Descriptive Analysis of the Supersonic and Subsonic Cartridges Test Fires in the 15 cm Range.

Descriptives

			Statistic	Std. Error
SupersonicWOS2	Mean		245,30020	,144026
	95% Confidence Interval for Mean	Lower Bound	245,00563	
		Upper Bound	245,59477	
	5% Trimmed Mean		245,36720	
	Median		245,59300	
	Variance		,622	
	Std. Deviation		,788865	
	Minimum		243,238	
	Maximum		246,156	
	Range		2,918	
	Interquartile Range		,326	
	Skewness		-1,828	,427
	Kurtosis		2,842	,833
SubsonicWOS7	Mean		46,49987	,048715
	95% Confidence Interval for Mean	Lower Bound	46,40023	
		Upper Bound	46,59950	
	5% Trimmed Mean		46,48063	
	Median		46,41800	
	Variance		,071	
	Std. Deviation		,266824	
	Minimum		46,221	
	Maximum		47,126	
	Range		,905	
	Interquartile Range		,219	
	Skewness		1,364	,427
	Kurtosis		,965	,833



Graphic-2. The Average Distribution Histogram of the Gunshot Residues of Supersonic and Subsonic Cartridges Test Fires in the 15 cm Range.

Evaluation: According to the results of the T-test, it was determined that there was a **significant difference** between the gunshot residue distribution area (mm^2) created on the target by the supersonic and subsonic cartridges of 9×19mm diameter and type produced by the same company (Turaç) when fired from a distance of 15cm with the TP9 Elite Combat model Canik semi-automatic pistol (Table 8).

Table-8. T-test Results of the Gunshot Residues of Supersonic and Subsonic Cartridges Test Fires in 15 cm Range.

T-Test

Group Statistics

	Silencer	N	Mean	Std. Deviation	Std. Error Mean
GSR	SPS_WoS-15cm	30	245,30020	,788865	,144026
	SBS_WoS-15cm	30	46,49987	,266824	,048715

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
GSR	Equal variances assumed	9,617	,003	1307,537	58	,000	198,800333	,152042	198,495988	199,104678
	Equal variances not assumed			1307,537	35,550	,000	198,800333	,152042	198,491842	199,108824

3. 30 cm DISTANCE TEST FIRES

Thirty shots were fired with both supersonic (Figure 6) and subsonic (Figure 7) cartridges at a dye-free cotton fabric target at a distance of 30cm. Sodium Rhodizonate solution was applied to the area of the bullet entry hole. The bright pink colour formation was observed due to a reaction with lead, lead styphnate, or lead azide around the bullet entry hole.

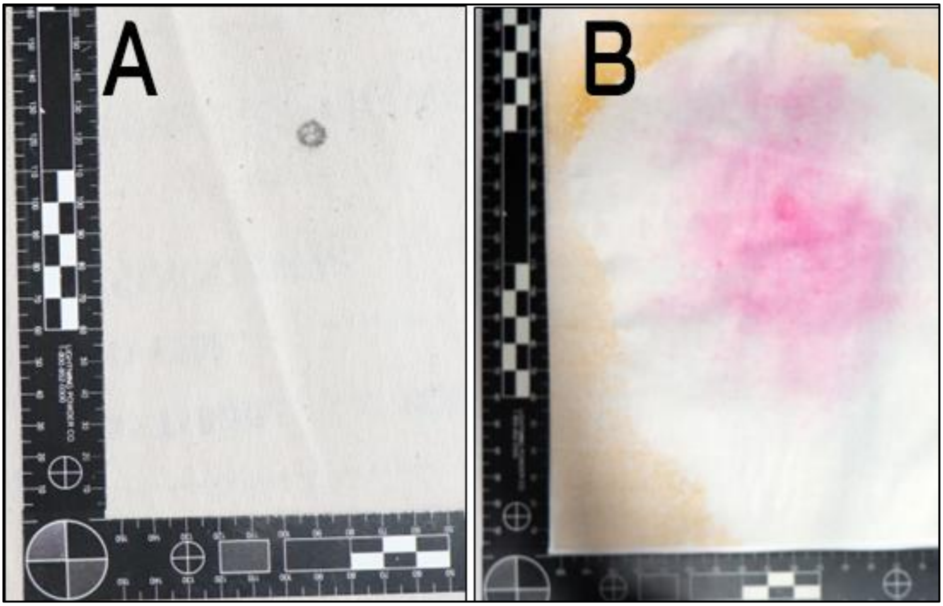


Figure-6. The Gunshot Residue Distribution Around the Bullet Entry Hole of 9×19mm Supersonic Cartridges **A.** Original Bullet Entry Hole View **B.** The Gunshot Residue Distribution View After Sodium Rhodizonate Solution Application.

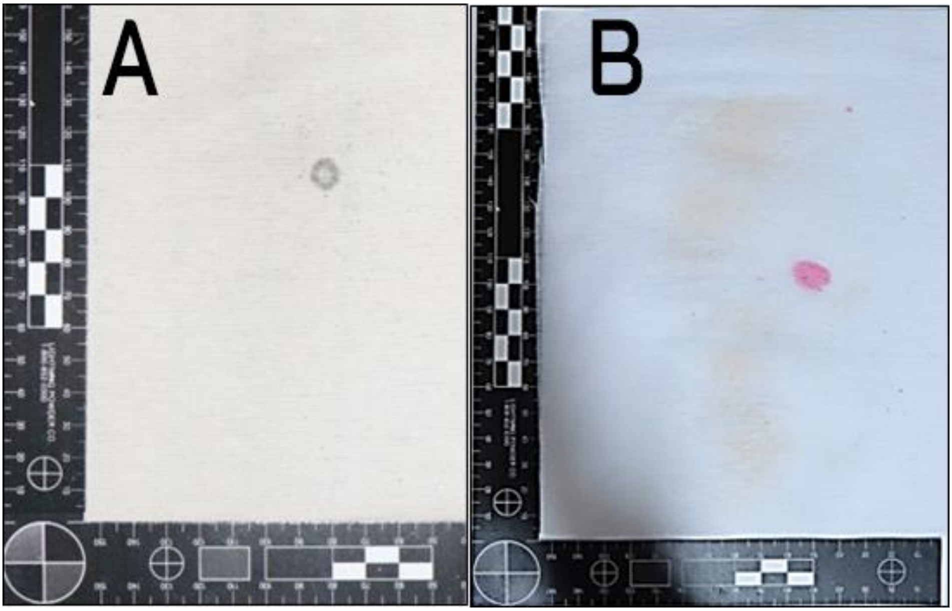


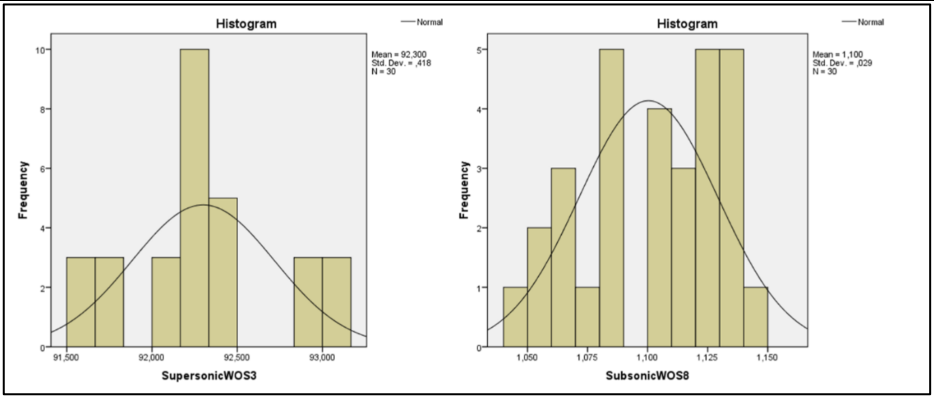
Figure-7. The Gunshot Residue Distribution Around the Bullet Entry Hole of 9×19mm Subsonic Cartridges **A.** Original Bullet Entry Hole View **B.** The Gunshot Residue Distribution View After Sodium Rhodizonate Solution Application.

The pink-coloured gunshot residue distribution area (mm^2) on the target due to the shooting of supersonic and subsonic cartridges was measured using ImageJ® software. The values of the measured shot residue area on the target of thirty shots fired with each type of cartridge were analysed with SPSS® software, and it was determined that they showed a normal distribution (Table 9) (Graphic 3).

Table-9. Descriptive Analysis of the Supersonic and Subsonic Cartridges Test Fires in the 30 cm Range.

Descriptives

			Statistic	Std. Error
SupersonicWOS3	Mean		92,30043	,076345
	95% Confidence Interval for Mean	Lower Bound	92,14429	
		Upper Bound	92,45658	
	5% Trimmed Mean		92,30322	
	Median		92,32050	
	Variance		,175	
	Std. Deviation		,418160	
	Minimum		91,537	
	Maximum		93,013	
	Range		1,476	
	Interquartile Range		,299	
	Skewness		-,085	,427
	Kurtosis		-,224	,833
SubsonicWOS8	Mean		1,10037	,005283
	95% Confidence Interval for Mean	Lower Bound	1,08956	
		Upper Bound	1,11117	
	5% Trimmed Mean		1,10109	
	Median		1,10800	
	Variance		,001	
	Std. Deviation		,028935	
	Minimum		1,046	
	Maximum		1,141	
	Range		,095	
	Interquartile Range		,044	
	Skewness		-,417	,427
	Kurtosis		-1,060	,833



Graphic-3. The Average Distribution Histogram of the Gunshot Residues of Supersonic and Subsonic Cartridges Test Fires in the 30cm Range.

Evaluation: According to the results of the T-test, it was determined that there was a **significant difference** between the gunshot residue distribution area (mm^2) created on the target by the supersonic and subsonic cartridges of 9×19mm diameter and type produced by the same company (Turaç) when fired from a distance of 30cm with the TP9 Elite Combat model Canik semi-automatic pistol (Table 10).

Table-10. T-test results of the gunshot residues of supersonic and subsonic cartridges test fires in a 30 cm range.

T-Test

Group Statistics

	Silencer	N	Mean	Std. Deviation	Std. Error Mean
GSR	SPS_WoS-30cm	30	92,30043	,418160	,076345
	SBS_WoS-30cm	30	1,10037	,028935	,005283

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
GSR	Equal variances assumed	24,165	,000	1191,726	58	,000	91,200067	,076528	91,046880	91,353254
	Equal variances not assumed			1191,726	29,278	,000	91,200067	,076528	91,043614	91,356519

4. 60 cm DISTANCE TEST FIRES

Thirty shots were fired with both supersonic (Figure 8) and subsonic (Figure 9) cartridges at a dye-free cotton fabric target at a distance of 60cm. Sodium rhodizonate solution was applied to the area of the bullet entry hole. The bright pink colour formation was observed due to a reaction with lead, lead styphnate, or lead azide around the bullet entry hole.

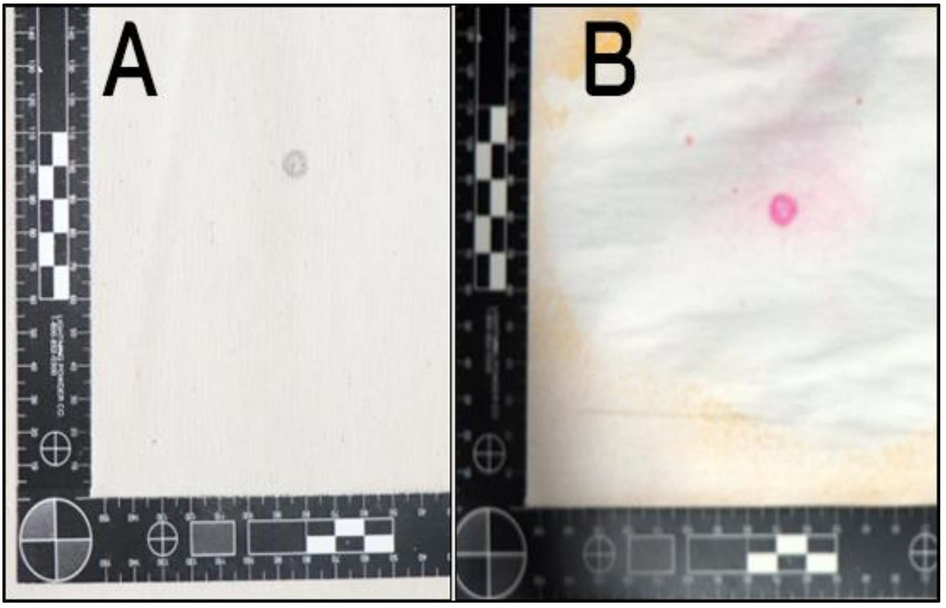


Figure-8. The Gunshot Residue Distribution Around the Bullet Entry Hole of 9×19mm Supersonic Cartridges **A.** Original Bullet Entry Hole View **B.** The Gunshot Residue Distribution View After sodium Rhodizonate Solution Application.

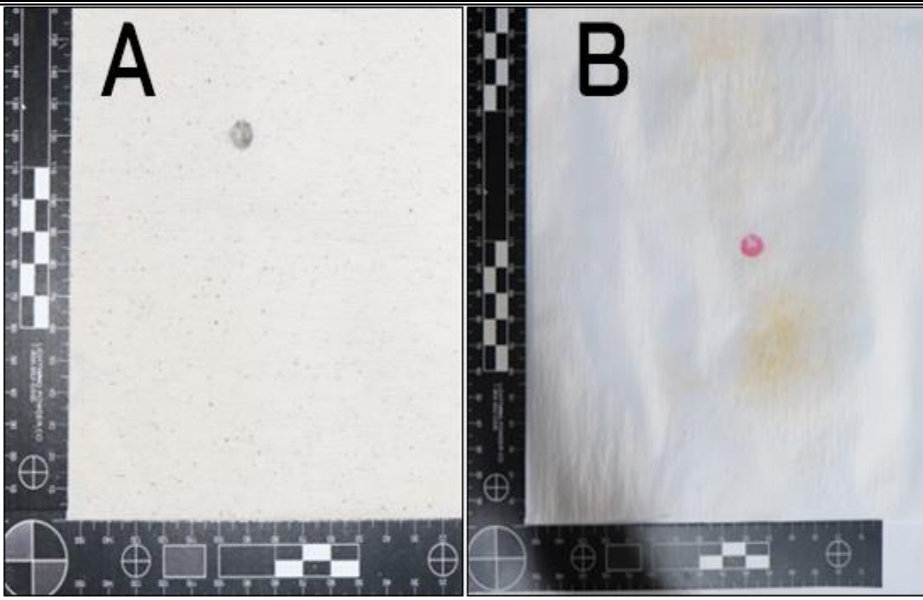


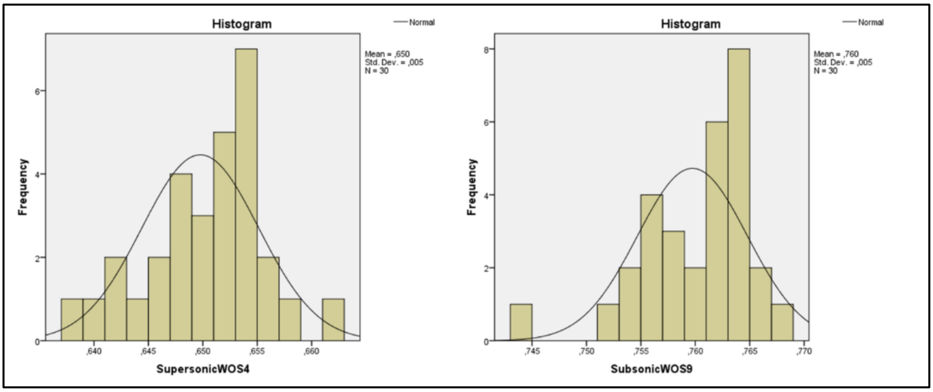
Figure-9. The Gunshot Residue Distribution Around the Bullet Entry Hole of 9×19mm Subsonic Cartridges **A.** Original Bullet Entry Hole View **B.** The Gunshot Residue Distribution View After Sodium Rhodizonate Solution Application.

The pink-coloured gunshot residue distribution area (mm^2) on the target due to the shooting of supersonic and subsonic cartridges was measured using ImageJ® software. The values of the measured shot residue area on the target of thirty shots fired with each type of cartridge were analysed with SPSS® software, and it was determined that they showed a normal distribution (Table 11) (Graphic 4).

Table-11. Descriptive Analysis of the Supersonic and Subsonic Cartridges Test Fires in the 60 cm Range.

Descriptives

			Statistic	Std. Error
SupersonicWOS4	Mean		,64977	,000980
	95% Confidence Interval for Mean	Lower Bound	,64776	
		Upper Bound	,65177	
	5% Trimmed Mean		,64985	
	Median		,65100	
	Variance		,000	
	Std. Deviation		,005367	
	Minimum		,638	
	Maximum		,661	
	Range		,023	
	Interquartile Range		,006	
	Skewness		-,451	,427
	Kurtosis		,052	,833
SubsonicWOS9	Mean		,75973	,000925
	95% Confidence Interval for Mean	Lower Bound	,75784	
		Upper Bound	,76162	
	5% Trimmed Mean		,76009	
	Median		,76100	
	Variance		,000	
	Std. Deviation		,005065	
	Minimum		,744	
	Maximum		,767	
	Range		,023	
	Interquartile Range		,007	
	Skewness		-1,162	,427
	Kurtosis		1,793	,833



Graphic-4. The Average Distribution Histogram of the Gunshot Residues of Supersonic and Subsonic Cartridges Test Fires in the 60 cm Range.

Evaluation: According to the results of the T-test, it was determined that there was a **significant difference** between the gunshot residue distribution area (mm^2) created on the target by the supersonic and subsonic cartridges of 9×19mm diameter and type produced by the same company (Turaç) when fired from a distance of 60cm with the TP9 Elite Combat model Canik semi-automatic pistol (Table 12).

Table-12. T-test Results of the Gunshot Residues of Supersonic and Subsonic Cartridges Test Fires in 60 cm Range.

T-Test

Group Statistics

	Silencer	N	Mean	Std. Deviation	Std. Error Mean
GSR	SPS_WoS-60cm	30	,64977	,005367	,000980
	SBS_WoS-60cm	30	,75973	,005065	,000925

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
GSR	Equal variances assumed	,121	,730	-81,620	58	,000	-,109967	,001347	-,112664	-,107270
	Equal variances not assumed			-81,620	57,806	,000	-,109967	,001347	-,112664	-,107270

5. 100 cm DISTANCE TEST FIRES

Thirty shots were fired with both supersonic (Figure 10) and subsonic (Figure 11) cartridges at a dye-free cotton fabric target at a distance of 100cm. Sodium rhodizonate solution was applied to the area of the bullet entry hole. The bright pink-colour formation was observed due to a reaction with lead, lead styphnate, or lead azide around the bullet entry hole.

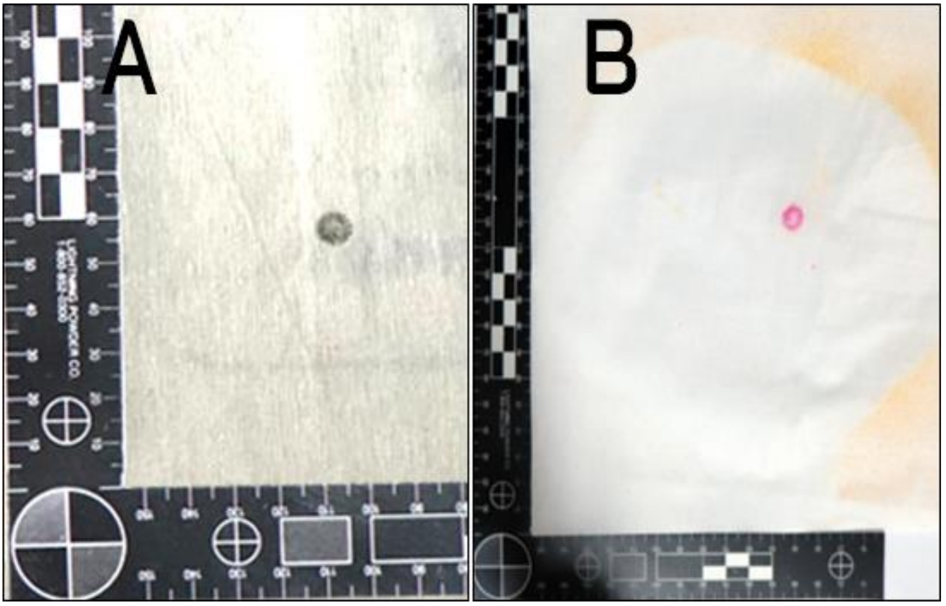


Figure-10. The Gunshot Residue Distribution Around the Bullet Entry hole of 9×19mm Supersonic Cartridges **A.** Original Bullet Entry Hole View **B.** The Gunshot Residue Distribution View After Sodium Rhodizonate Solution Application.

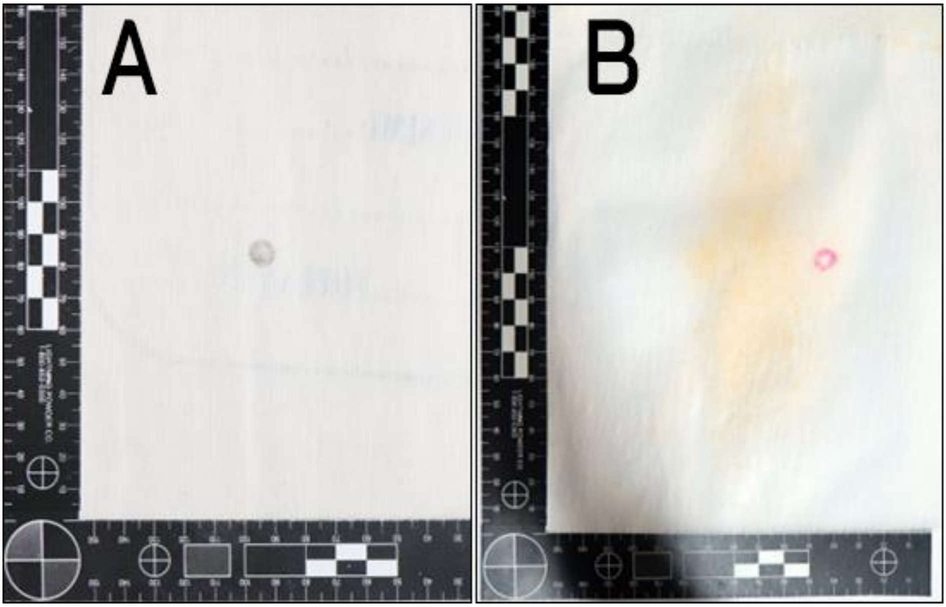


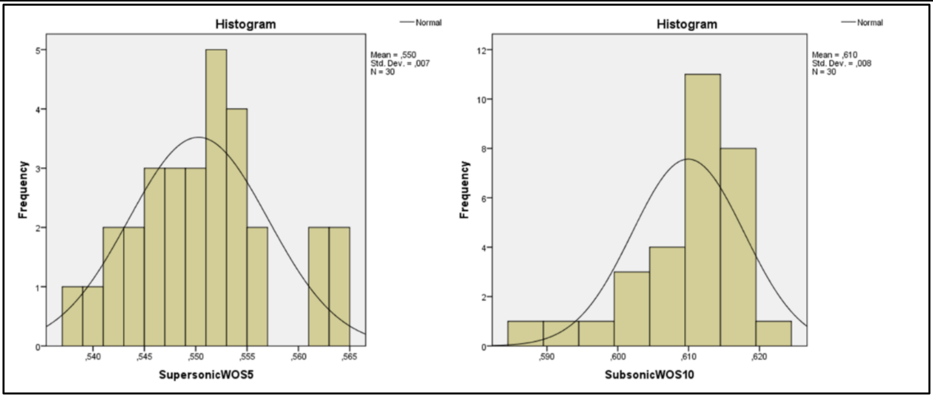
Figure-11. The Gunshot Residue Distribution Around the Bullet Entry Hole of 9×19mm Subsonic Cartridges **A.** Original Bullet Entry Hole View **B.** The Gunshot Residue Distribution View After the Sodium Rhodizonate Solution Application.

The pink-coloured gunshot residue distribution area (mm^2) on the target due to the shooting of supersonic and subsonic cartridges was measured using ImageJ® software. The values of the measured shot residue area on the target of thirty shots fired with each type of cartridge were analysed with SPSS® software, and it was determined that they showed a normal distribution (Table 13) (Graphic 5).

Table-13. Descriptive Analysis of the Supersonic and Subsonic Cartridges Test Fires in the 100 cm Range.

Descriptives

			Statistic	Std. Error
SupersonicWOS5	Mean		,55027	,001241
	95% Confidence Interval for Mean	Lower Bound	,54773	
		Upper Bound	,55280	
	5% Trimmed Mean		,55022	
	Median		,55050	
	Variance		,000	
	Std. Deviation		,006797	
	Minimum		,538	
	Maximum		,563	
	Range		,025	
	Interquartile Range		,008	
	Skewness		,239	,427
	Kurtosis		-,343	,833
SubsonicWOS10	Mean		,60993	,001444
	95% Confidence Interval for Mean	Lower Bound	,60698	
		Upper Bound	,61289	
	5% Trimmed Mean		,61054	
	Median		,61200	
	Variance		,000	
	Std. Deviation		,007909	
	Minimum		,587	
	Maximum		,621	
	Range		,034	
	Interquartile Range		,010	
	Skewness		-1,322	,427
	Kurtosis		1,690	,833



Graphic-5. The Average Distribution Histogram of the Gunshot Residues of Supersonic and Subsonic Cartridges Test Fires in the 100 cm Range.

Evaluation: According to the results of the T-test, it was determined that there was a **significant difference** between the gunshot residue distribution area (soot wiped area) (mm^2) created on the target by the supersonic and subsonic cartridges of 9×19mm diameter and type produced by the same company (Turaç) when fired from a distance of 100cm with the TP9 Elite Combat model Canik semi-automatic pistol (Table 14).

Table-14. T-test Results of the Gunshot Residues of Supersonic and Subsonic Cartridges Test Fires in 100 cm Range.

T-Test

Group Statistics

	Silencer	N	Mean	Std. Deviation	Std. Error Mean
GSR	SPS_WoS-100cm	30	,55027	,006797	,001241
	SBS_WoS-100cm	30	,60993	,007909	,001444

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
GSR	Equal variances assumed	,272	,604	-31,339	58	,000	-,059667	,001904	-,063478	-,055856
	Equal variances not assumed			-31,339	56,719	,000	-,059667	,001904	-,063480	-,055854

DISCUSSION

Subsonic ammunition is purposefully engineered to possess a velocity lower than the speed of sound. This is particularly crucial for persons who use suppressors on their rifles and want to mitigate the auditory impact generated by firing the handgun. Suppressors, sometimes known as silencers in common parlance, are supplementary devices affixed to the muzzle of a weapon to reduce the acoustic signature produced by the discharge of the firearm. A weapon's primary source of sound is mainly attributed to the expeditious discharge of heated gas through the muzzle. In order to mitigate this, suppressors are engineered with internal baffles that disrupt and dissipate the gasses as they are expelled from the barrel, thus facilitating their cooling (Monturo, 2019).

The most common colour test used in gunshot residue analysis to determine firing distance is the Sodium Rhodizonate Test, which detects trace amounts of lead in the form of vapour, particles, or capsule residue if a cartridge containing lead styphnate or lead azide is used in its capsule or if the bullet core is made of lead (Schwoeble & Exline, 2000; Wallace, 2018).

It is a successful test that allows the detection of the element lead. However, many states now prohibit using lead in the composition of cartridge capsules and the fabrication of bullet cores to safeguard human health and the environment (Von Rentzell, 2018). This circumstance precludes the use of the Sodium Rhodizonate test alone for the detection of gunshot residue and necessitates the use of different methods. For example, Harrison and Gilroy's Test can be used, which shows the presence of lead (Pb) as well as antimony (Sb) and barium (Ba), which are important indicators of the presence of gunshot residue in the cartridge capsule and are found in trace amounts in nature (Shrivastava et al., 2021).

Scanning electron microscopy (SEM) is a critical option at this stage. It is more favourable than other tests since it enables morphological and elemental evaluation of gunshot residues (Savage et al., 2006). However, the most significant drawbacks of shot residue analysis using SEM are the expensive cost and extended analysis time (Elkins, 2019).

Because the existence of lead components in the cartridge capsule and bullet core utilised in the study was known, the sodium rhodizonate colour test was preferred as it can detect even trace levels of lead (Feigl ve Suter, 1942; Shrivastava et al., 2021).

The gunshot residue analysis findings of tests done utilising supersonic cartridges, where the sodium rhodizonate test is used, are consistent with the results obtained within the scope of the research (Dillon, Jr., 1990). However, no research has been identified that compares the gunshot residue created on the target after shooting subsonic cartridges to the findings of supersonic cartridges.

It is considered that there are three main reasons for the difference between the gunshot residue density and patterns on the target of both cartridge types. The first is the slow-burning rate of the gunpowder in the cartridge; second, the amount of gunpowder in subsonic cartridges is less compared to supersonic cartridges; and finally, due to the low pressure of gunpowder gas after firing, gunshot residue spreads to the target in small amounts and at low density.

CONCLUSION

As a result of test firing with 9x19mm diameter Starling brand Supersonic and Subsonic cartridges and TP9 Elite Combat model Canik brand semi-automatic pistol from 0cm (contact), 15cm, 30cm, 60cm and 100cm distances, it is observed that there was a significant difference between the powder residue patterns and densities in the target depending on whether the cartridges were supersonic or subsonic. It has been determined that subsonic cartridges leave less and lower density shot residue on the target at all test distances than supersonic cartridges.

In this context, the distribution and pattern of gunshot residue on the target in a shooting incident with a subsonic cartridge from a distance of 30cm can easily be confused with a shot fired with a supersonic cartridge from a distance of 100cm. For this reason, if an indication that subsonic cartridges were used in the incident is detected as a result of the examination of the cartridge case or bullet core obtained from the crime scene, gunshot residue reference tests must be performed with subsonic cartridges. For this reason, confirmation tests employing single or multi-instrumental approaches (SEM-EDS, LIBS, FTIR, XPS, or Raman Spectroscopy) can be recommended to improve the objectivity of the results.

GENİŞLETİLMİŞ ÖZET

Ateşli silahların kullanıldığı olaylarda, atış mesafesinin tespit edilmesi, "Adli Atış Analizi" (Shooting Reconstruction) çalışmaları olayın orijinin tespit edilmesine yönelik analizlerin temel adımlarından biridir. Atış artıkları kısmen yanmış ve yanmamış barut taneleri, barut gazı ile inorganik ve organik kalıntılardan oluşmaktadır. Kapsül eczası; (örneğin kurşun stifinat; C6HN3O8Pb), Oksitleyici [örneğin Baryum Nitrat, Ba(NO3)2] ve yakıt (örneğin, antimon sülfür; Sb2S3) olmak üzere üç ana bileşenden oluşmaktadır. Ateşleme sonrasında barutun yanmasıyla organik ve inorganik atış artıkları ile yanmamış barut taneleri namlu ağzından dışarıya doğru barut gazı basıncıyla buhar bulutu formunda fırlar ve yakın atış mesafesi içerisinde hedef üzerinde atış artığı dağılım kalıpları oluşturur. Hedef üzerinde atış artıklarının ve yanmamış barut tanelerinin varlığı ve yoğunluğunun tespit edilmesi neticesinde atışın hangi mesafeden yapıldığı tespit edilebilmektedir.

Ateşleme iğnesinin kapsül kabına darbe yaptıktan sonra örs ile kapsül kabı arasında sıkışan kapsül eczası, alev alarak kapsül eczasının ana patlayıcısı olarak kabul edilen kurşun stifnatı ateşler. Baryum nitrat daha sonra kimyasal reaksiyonun sıcaklığını arttırmak için oksijenini çabukça bırakmaya başlar. Yüksek bir sıcaklığa ulaşıldığında antimon sülfür tutuşur. Bu reaksiyon, fişek içerisindeki barutu tutuşturur ve yanan barutun oluşturduğu barut gazı basıncı mermi çekirdeğini namlu boyunca iterek hedefe sevk eder.

Ateşleme sonrasında oluşan atış artıklarında kurşun, baryum ve antimon yaygın olarak bulunmaktadır ve günümüzde uygulanan birçok atış artığı tespit testi de bu elementlerin tespiti üzerine inşa edilmiştir. Bu temel elementlere ek olarak eser miktarda kalsiyum, silikon, kükürt, bakır ve çinko da atış artıkları içerisinde bulunmaktadır.

Günümüzde kullanılan dumansız barut; nitroselüloz (NC), nitrogliserin (NG) ve nitroguanidin (NGu), difenilamin ile etil santralit metil santralit gibi stabilizatörler ile nitrotoluenler ve dinitrotoluenler gibi duyarlılaştırıcı maddeler içermektedir.

Tamamıyla yanmış organik atış artıkları hedef üzerinde is lekesi şeklinde görülür. Ancak hafif ateşli silah fişekleri içerisinde bulunan barutun %20 – %25 oranında yanmadan namluyu terk etmesi beklenen bir durumdur. Bu çerçevede yanmamış ya da kısmen yanmış organik atış artığı parçacıkları hedef üzerinde gözle görülebilen "Barut Dövmesi" olarak isimlendirilen olguları oluşturur.

Hedef üzerinde oluşan atış artığı kalıplarında kimyasal renk testleri uygulanarak hedef üzerindeki nitritlerin varlığı araştırılır. Nitritlerin tespiti için Modifiye Griess Renk Testi (MGT) ve kurşun varlığında mavi-menekşe rengine dönüşen Sodyum Rhodizonat Testi (SRT) renk testleri uygulanmaktadır.

Sodyum Rhodizonat Testi (SRT) ise kapsül kalıntıları (kurşun stifnat veya kurşun azit) ile mermi çekirdeği veya saçma tanesinin imalatında kullanılan malzemelerden kaynaklı kurşun elementiyle reaksiyona giren bir renk testidir.

Atış mesafesinin tayininde adli bilim laboratuvarları, mermi çekirdeği giriş deliği etrafından veya olay yerindeki diğer eşyalar üzerinden elde edilen atış artığı kalıpları ile test atışları sonrasında laboratuvarda hedef yüzey üzerinden elde edilen hedef atış artıklarının karakteristik özelliklerini karşılaştırarak atış mesafesini tespit eder. Renk testleri, uzun süredir atış artıklarının tespit edilmesinde ve uygulama sonrasında geliştirdikleri yöntemle de mesafe analizinde kullanılan temel yöntemlerdir.

Yukarıda da ifade edildiği gibi hedef yüzey üzerinde biriken organik ve inorganik atış artıkları ile yanmamış barut tanelerinin yoğunluk ve dağılımları analizleri, adli atış analizi çalışmalarında atış mesafesinin ve olayın orijinin tespit edilmesi için en önemli araçtır. Ancak kolaylıkla kontamine olabilen atış artıklarının olay yerinden toplanması ve laboratuvar ortamında analiz ile test atışlarının yapılması sırasında yapılacak hatalar, atış artığı analizlerinin en zayıf noktasını oluşturmaktadır.

Atış artığı analizlerinde, olay yerinden elde edilen hedef üzerindeki atış artığı yoğunluğunun karşılaştırılması için referans atış artığı yoğunluğu tablolarına ihtiyaç duyulmaktadır. Bu noktada atış artığı analizlerinin sonucu etkileyen en önemli değişken ise testlerde silah ve mühimmattır. Hem silahın hem de mühimmatın olayda kullanılanlar ile aynı veya aynı özellikte olması gerekmektedir. Bu değişkenlerden birinin olayda kullanılan değişkenden farklı olması, atış artığı analizinin doğruluğunu olumsuz yönde etkileyecektir.

Bu çalışmada, Turaç firması üretimi olan Sterling® marka 9×19mm çap ve tipinde Süpersonik ve Subsonik fişeklerin standart namluya sahip TP9 Elite Combat model Canik marka yarı otomatik tabanca ile 0 cm, 15 cm, 30 cm, 60 cm ve 100 cm mesafelerden yapılan atışlarda hedef üzerinde oluşan atış artığı yoğunluğu arasında anlamlı fark olup olmadığının tespiti için Bağımsız T-testi uygulanmıştır.

Sonuç olarak 0 cm, 15 cm, 30 cm, 60 cm ve 100 cm mesafelerden yapılan atışlar neticesinde hedef üzerindeki atış artığı yoğunluğu Süpersonik ve Subsonik fişeklerin imalat amaçlarına uygun olarak farklılık göstermiştir. Süpersonik fişeklerde, mermi çekirdeğini süpersonik hızlarda yüksek kinetik enerjiyle uzak mesafedeki hedefe sevk etmek için daha fazla barut yakılmakta ve daha hedef üzerinde de daha fazla atış artığı yoğunluğu oluşmaktadır. Subsonik fişeklerin kullanımında amaç, bastırıcıyla birlikte yakın mesafelerde gerçekleşecek atışlarda düşük "atış sesi" oluşturmaktır. Bu amaçla subsonik fişeklerde daha az hız ve enerji açığa çıkartacak barut miktarı ve cinsi kullanılarak mermi çekirdeğinin ses altı hızda namluyu terk etmesi sağlanır.

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