Material Culture and Military History: Test-Firing Early Modern Small Arms

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Résumé

Cet article est divisé en deux parties. Dans la première, Krenn et Kalaus résument les résultats d'une série de tirs d'essai d'armes légères authentiques des débuts de l'ère moderne, effectués en 1988-1989 par le personnel du Landeszeughaus *(manège militaire provincial) de Graz, en Autriche, une division de l'Administration du musée provincial. Les résultats obtenus constituent les meilleures données quantitatives jamais recueillies au sujet des caractéristiques balistiques (vitesse initiale, justesse du tir, pouvoir de pénétration des balles) des armes légères utilisées à l'époque à des fins militaires. Dans la deuxième partie, Hall interprète les résultats de ces essais. Les armes légères des débuts de l'ère moderne étaient, même dans les meilleures circonstances, extrêmement imprécises. Les balles perdaient la majeure partie de leur énergie cinétique dans les 30 à 50 premiers mètres de vol. Les pistolets, cependant, ont donné lors des essais de meilleurs résultats que prévu. Ces résultats confirment les vues de certains historiens, qui estiment que le pistolet a joué un rôle important dans la disparition de l'armement lourd du chevalier. Cet article vise à démontrer la pertinence de l'information tirée de l'histoire matérielle pour illustrer les thèses historiques générales.*

Abstract

This article is in two parts. Part 1 summarizes the results of a series of test-firings of genuine early modern small arms carried out in 1988–89 by staff of the Landeszeughaus *(Provincial Armoury) in Graz, Austria — a division of the Provincial Museum Administration. The results constitute the best quantitative data ever obtained about the ballistic characteristics (muzzle velocity, accuracy on target, penetrating power of bullets) of early modern military small arms. Part 2 interprets the significance if the test findings. Early modern small arms under the best of circumstances were extremely inaccurate. Bullets lost most of their kinetic energy within 30–50 metres of flight. Pistols, however, tested better than might have been expected. The results confirm the views of some historians giving more weight to the role of the pistol in challenging the supremacy of the heavily armoured knight. This article demonstrates how information from material history is relevant to sweeping historical theses.*

From the mid-16th to the mid-19th century, the "musket" was the most widespread weapon in almost all armies (Fig. 1). Knowing this, military historians tend to credit firearms with the creation of a new epoch in military affairs. But hard evidence about how well early small arms performed has been unavailable until recently. ("Small arms" here is used as a catch-all category that includes any arm that could be carried and used by a single soldier, including muskets, pistols and arquebuses.) For the most part, rigorous, empirical, ballistic tests depend on instruments that were not invented until after the mid-19th century. By then, however, firearms themselves were in the midst of profound changes. Naturally, the weapons 19th-century researchers tested were the newer and more promising arms. The older guns were never scrutinized very thoroughly.

In late 1988 a series of tests began on early weapons selected from the extensive collection held by the *Steiermärkisches Landeszeughaus* (Styrian Provincial Armoury) at Graz, Austria. The Provincial Armoury is a division of the Styrian Provincial Museum administration, and it houses an immense collection of early modern armour and weapons including more than 7 800 muskets and pistols. The data from these tests form the best information ever assembled on the performance of early small arms, and the manner in which the tests were conducted eliminates the "human factor" in judging performance (Fig. 2). The Graz data provide information about the intrinsic properties of these guns, including bullet speed, trajectories, energy levels and penetrating power.

The Graz tests represent material culture research that challenges comfortable historical assumptions. The data reveal that early guns were highly inaccurate and subject to very high drag on the bullets. As well, that the penetrating power of the bullets dropped off dramatically within a relatively short range. This article is divided into two parts. First is a presentation of the major firing tests and their results under the names of the principal investigators, Dr. Peter Krenn and Col. Dipl. Ing. Paul Kalaus.[1] Second is a discussion of the implications of the Graz findings for military history by Prof. Bert Hall, of the University of Toronto. Prof. Hall edited and translated the material in Part One and is solely responsible for the judgments expressed in Part Two.

Part 1: Tests and Results

Testing Procedures

Sixteen specimens were selected under the supervision of the Armoury's director, Prof. Dr. Peter Krenn. The weapons selected date from 1571 to post-1750, with roughly equal numbers of specimens from the 16th, 17th, and 18th centuries. They were meant to represent a cross-section of firearm types (rifles, smoothbore muskets and pistols) but they were mostly "mass produced" or "munitions grade" specimens. This meant no weapon would be unique in the Armoury's collection (in case it were damaged during testing), but also that the guns tested would be more nearly typical of "standard issue" weapons than a gunsmith's highly crafted premium firearm might be. Three of the historic weapons tested were rifles, while the remainder were smoothbore guns. Two specimens were rejected after preliminary inspection revealed potentially dangerous weaknesses in their metal. The remaining 14 were test fired a total of 325 times under controlled conditions in the testing range operated by the Austrian Army in Felixdorf under the supervision of Col. Dipl. Ing. Peter Kalaus.

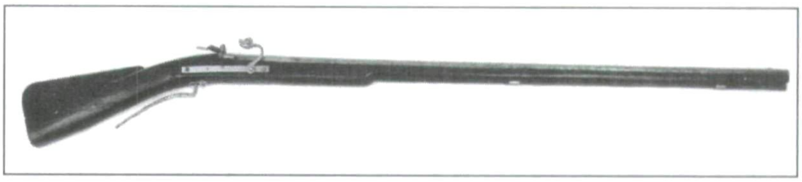

Fig. 1
Matchlock musket, French, ca 1660–1670. (Courtesy Parks Canada)

All shots were fired with weighed charges of standardized modern gunpowder. The powder used was hunter's black powder "Köln-Rottweil Nr. 0" grain 0.3–0.6 mm.[2] The guns were mounted on modern fixed frames (to absorb recoil), sighted on target, ignited electrically (bypassing their original firing mechanisms), and their bullets were tracked and measured electronically. For comparative purposes, some 60 shots were fired and tracked in the same manner from a series of four production-model Austrian military assault rifles and pistols. In all cases, electronic measurements of the bullets were taken at 7.5 or 8.5 metres and at 24 metres from the muzzle, and muzzle velocities were calculated from these data. The exact weight of powder charge for the historical weapons was determined to be approximately one-third of ball weight, but this varied from piece to piece; in each case the optimal charge was determined experimentally and results are reported with that charge. (Obviously, comparison firings of the modern weapons were conducted with standard modern ammunition.)

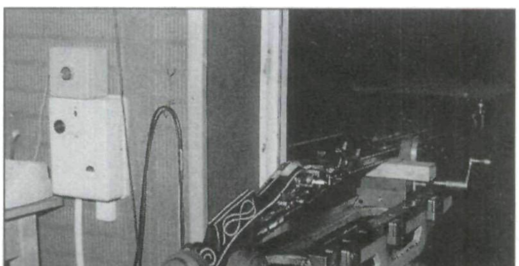

Fig. 2
Frame used to immobilize and sight the weapons as they were fired on the Austrian Army indoor testing range. (Courtesy Steiermärkisches Landesmuseum Joanneum, Abteilung Landeszeughaus, Graz, Austria)

Results

In both tables 1 and 2, the weapons are briefly labelled and their Armoury inventory numbers given. The following is a more detailed description of the weapons in the order of their appearance in the tables.

"Doppelhaken" G 284
: Heavy or "Spanish" musket, wheellock, rifled, Styria, 1571.

"Doppelhaken" G 358
: Heavy or "Spanish" musket, wheellock and matchlock, Styria, 1580s.

Matchlock LG 1514
: Musket, Styrian, first quarter of 17th century.

Wheellock RG 33
: Musket, Augsburg, ca 1595.

Wheellock RG 117
: Musket, Suhl, 1593.

Wheellock RG 272
: Musket, rifled, south German, first half of 17th century.

Wheellock pistol RP 2895
: Nuremberg, ca 1620.

Flintlock STG 1287
: Musket, converted from matchlock ca 1700, no indication of original maker or date.

Flintlock STG 1288
: Musket, rifled, Austrian, second half of 18th century.

Flintlock STG 1316
: Musket, converted from matchlock ca 1700, probably Styrian.

Flintlock STG 1317
: Musket, converted from matchlock, ca 1700, probably Styrian.

Flintlock STG 1318
: Musket, combined with matchlock, Suhl, 1686.

Flintlock pistol, STP 1128
: Ferlach, ca 1700.

Barrel, Dep. E 28
: Flintlock, first quarter of 18th century (outfitted as pressure tester).

Comparison weapon — Assault Rifle 58
: Austrian Army issue (after NATO-type Belgian FAL), model 1958.

Comparison weapon — Assault Rifle 77
: Steyr, Austrian Army Issue, model 1977.

Comparison weapon — Glock 80 Pistol
: Semi-automatic, Austrian Army issue, model 1980.

Table 1 gives the basic physical dimensions of the weapon and the speed of the bullet as measured along its trajectory.

Table 2 gives the results of further tests, beginning with the kinetic energy of the bullet at the muzzle. Penetration data against both spruce and mild steel targets are given for ranges of 30 metres or 100 metres, respectively (although some weapons were test-fired at both ranges). Then the maximum possible range is expressed.

In addition, the weapons were tested on the firing range for accuracy by measuring the scatter pattern of bullet holes made in paper targets at 100 metres (30 metres for pistols). A rectangular target measuring 167 cm × 30 cm (5 010 cm^2) was used to simulate the frontal area of a standing enemy soldier. The number of shots actually fired varied from weapon to weapon, but usually numbered about 18. Table 2 incorporates two results concerning accuracy. On the far right is the probability that the target was hit at all. The other numbers represent the dimensions of the smallest rectangle that could be drawn on a larger secondary paper target that would enclose all the bullet holes. Height and width of this figure are given, then the surface area.

Further Results: Impact and Wounds

Additional tests involved shooting bullets into special targets, blocks of soap or gelatine, modern steel plate, and 16th-century armour plate. Soap- and glycerine-block targets are one modern method of evaluating small arms. The Austrian tests indicated that, as one might expect, the relatively large spherical bullets of early modern weapons left large-volume wound cavities — but only at short ranges. At nine metres, for example, a Flintlock musket (STG 1318) firing a 31-gm bullet left a cavity of 530 cm^3, and a similar weapon (STG 1288) firing a 27-gm bullet left a cavity of 369 cm^3. Modern rifle bullets, tapered in shape and spinning as they reach the target, generally do less damage; at the same nine metre range, a 5.65-mm assault rifle left a cavity of only 101 cm^3.

On the other hand, the wound cavity made by spherical bullets diminishes sharply as range increases. The same musket that created a 369-cm^3 cavity at nine metres made only a 155-cm^3 hole at a range of 100 metres. By comparison, the cavity caused by a modern assault rifle at 100 metres is 70 cm^3, down only about 31 per cent from the cavity at nine metres. The comparable drop for spherical bullets is about 58 per cent. The typical wound cavities made by early modern bullets were usually trumpet-shaped, widest at the point of entry and tapering steadily downwards in diameter as the bullet lost energy. Modern bullets often leave cavities of a much different shape, sometimes wider after several centimetres of penetration, owing to the effects of tumbling.

Table 1: Ballistic Performance Data

Firearm	Physical Dimensions						Speed			
	Length[1]	Weight[2]	Calibre[3]	Diameter of Bullet[4]	Weight of Bullet[5]	Charge[6]	Muzzle Velocity[7]	Velocity at 7.5/8.5 m[8]	Velocity at 30 m[9]	Velocity at 100 m[10]
"Doppelhaken" G 284	1 100 mm	13.40 kg	19.8 mm	19.0 mm	38.26 g	14.00 g	482 m/s	461 m/s	418 m/s	305 m/s
"Doppelhaken" G 358	1 655 mm	18.00 kg	20.6 mm	20.2 mm	49.14 g	20.00 g	533 m/s	514 m/s	470 m/s	349 m/s
Matchlock LG 1514	760 mm	2.50 kg	15.1 mm	14.3 mm	17.38 g	6.00 g	449 m/s	428 m/s	378 m/s	264 m/s
Wheellock RG 33	1 000 mm	5.48 kg	17.8 mm	17.2 mm	30.06 g	11.00 g	456 m/s	435 m/s	394 m/s	287 m/s
Wheellock RG 117	645 mm	2.90 kg	13.2 mm	12.3 mm	10.84 g	5.00 g	427 m/s	406 m/s	349 m/s	238 m/s
Wheellock RG 272	675 mm	3.69 kg	18.1 mm	17.5 mm	32.06 g	10.00 g	392 m/s	371 m/s	342 m/s	260 m/s
Wheellock pistol RP 2895	480 mm	1.59 kg	12.3 mm	11.8 mm	9.56 g	6.00 g	438 m/s	416 m/s	355 m/s	—
Flintlock STG 1287	910 mm	4.39 kg	17.4 mm	16.8 mm	27.54 g	9.33 g	474 m/s	453 m/s	406 m/s	291 m/s
Flintlock STG 1288	680 mm	3.88 kg	16.4 mm	16.6 mm	26.73 g	8.50 g	455 m/s	434 m/s	390 m/s	281 m/s
Flintlock STG 1316	952 mm	4.74 kg	18.3 mm	17.6 mm	32.16 g	10.70 g	451 m/s	430 m/s	391 m/s	287 m/s
Flintlock STG 1317	955 mm	4.82 kg	18.4 mm	17.8 mm	34.25 g	11.56 g	467 m/s	446 m/s	406 m/s	300 m/s
Flintlock STG 1318	1 050 mm	4.20 kg	17.8 mm	17.5 mm	30.93 g	10.70 g	494 m/s	473 m/s	426 m/s	305 m/s
Flintlock pistol STP 1128	332 mm	1.16 kg	13.7 mm	13.5 mm	14.45 g	5.00 g	385 m/s	362 m/s	323 m/s	—
Barrel, Dep. E 28	1 106 mm	—	17.8 mm	17.2 mm	29.89 g	15.00 g	543 m/s	522 m/s	—	—
Comparison weapon: Assault rifle 58	535 mm	4.55 kg	7.62 mm	7.85 mm	9.45 g	2.90 g	835 m/s	—	815 m/s	770 m/s
Comparison weapon: Assault rifle 77	508 mm	3.60 kg	5.56 mm	5.70 mm	3.60 g	1.70 g	990 m/s	—	955 m/s	874 m/s
Comparison weapon: Glock 80 pistol	114 mm	0.66 kg	8.82 mm	9.3 mm	8.00 g	0.40 g	360 m/s	—	342 m/s	—

[1] Effective length of the barrel, in millimetres (mm).
[2] Weight of the gun, in kilograms (kg).
[3] Nominal caliber, in millimetres (mm).
[4] Average diameter of bullet, in millimetres (mm). Note: Calibre – DiamBull = windage. For rifles, the diameter of the bullet may be slightly larger than the nominal calibre of the barrel.
[5] Average weight of bullet, in grams (g).
[6] Average weight of gunpowder charge, in grams (g).
[7] Muzzle velocity, in metres/second (m/s).
[8] Velocity at 7.5 or 8.5 metres, in metres/second (m/s).
[9] Velocity at 30 metres, in metres/second (m/s).
[10] Velocity at 100 metres, in metres/second (m/s).

Table 2: Penetration, Range, Scatter and Probability

Firearm	Energy at Muzzle[1]	Penetration				Maximum Range[6]	Scatter			
		PS30[2]	PW30[3]	PS100[4]	PW100[5]		Height[7]	Width[8]	Area[9]	Per cent of Hits[10]
"Doppelhaken G 284	4 444 J	—	—	2 mm	153 mm	1 141 m	87.0 cm	65.5 cm	5 699 cm^2	52.5
"Doppelhaken G 358	6 980 J	—	—	4 mm	189 mm	1 279 m	53.5 cm	58.5 cm	3 130 cm^2	51.5
Matchlock LG 1514	1 752 J	2 mm	146 mm	1 mm	93 mm	957 m	78.5 cm	59.5 cm	4 671 cm^2	60.9
Wheellock RG 33	3 125 J	3 mm	190 mm	2 mm	80 mm	1 095 m	46.0 cm	50.5 cm	2 323 cm^2	54.5
Wheellock RG 117	988 J	2 mm	132 mm	1 mm	84 mm	834 m	29.0 cm	50.5 cm	1 465 cm^2	54.5
Wheellock RG 272	2 463 J	2 mm	168 mm	—	103 mm	1 085 m	Test cancelled: excessive scatter			
Wheellock pistol RP 2895	917 J	2 mm	121 mm	—	—	812 m	26.0 cm	33.5 cm	871 cm^2	85.0
Flintlock STG 1287	3 094 J	4 mm	115 mm	2 mm	83 mm	1 071 m	118.0 cm	108.0 cm	12 744 cm^2	32.7
Flintlock STG 1288	2 767 J	3 mm	—	2 mm	80 mm	1 058 m	31.0 cm	39.5 cm	1 225 cm^2	83.0
Flintlock STG 1316	3 271 J	3 mm	195 mm	2 mm	147 mm	1 110 m	95.0 cm	63.0 cm	5 985 cm^2	48.6
Flintlock STG 1317	3 735 J	—	—	—	—	1 151 m	77.0 cm	68.0 cm	5 236 cm^2	54.0
Flintlock STG 1318	3 774 J	4 mm	183 mm	2 mm	114 mm	1 107 m	82.0 cm	53.5 cm	4 387 cm^2	50.2
Flintlock pistol STP 1128	1 071 J	2 mm	114 mm	—	—	883 m	23.5 cm	18.0 cm	423 cm^2	99.0
Barrel, Dep. E 28	No applicable data									
Comparison weapon: Assault rifle 58	3 294 J	—	—	12 mm	483 mm	3 980 m	10.2 cm	7.5 cm	77 cm^2	100.0
Comparison weapon: Assault rifle 77	1 764 J	—	—	9 mm	287 mm	2 734 m	5.1 cm	5.9 cm	30 cm^2	100.0
Comparison weapon: Glock 80 pistol	518 J	2 mm	126 mm	—	—	1 650 m	13.5 cm	15.2 cm	205 cm^2	99.5

[1]Energy of bullet at muzzle, in Joules (J).
[2]Penetration, steel target at 30 m, in millimetres (mm).
[3]Penetration, spruce target at 100 m, in millimetres (mm).
[4]Penetration, steel target at 30 m, in millimetres (mm).
[5]Penetration, spruce target at 100 m, in millimetres (mm).
[6]Theoretical maximum range, 60° elevation, in metres (m).
[7]Height of the enclosing rectangle in centimetres.
[8]Width of the enclosing rectangle in centimetres.
[9]Area of the enclosing rectangle in square centimetres.
[10]Percentage of bullets that struck a 167 cm × 30 cm primary target.

The final set of tests undertaken focussed on the protection offered by body armour. Modern steel plate 3-mm thick (of the same standard as employed in the indenting test tabulated above), was lined with two layers of linen and placed before a soap block; the entire target was mounted nine metres from the muzzle. Flintlock musket STG 1288 (responsible for a 369-cm^3 cavity in an unprotected target at nine metres) was fired again. The bullet penetrated the metal and the linen and entered the soap target. It penetrated only a short distance, however, and left a small-diameter cavity of only 25 cm^3. There was splintering of the shot and the armour plate, leaving splinters some 80-mm deep in the cavity. A comparative test involved an unprotected soap target shot over a nine-metre range with one of the early modern pistols (STP 1128). In this test the unprotected target sustained a wound cavity of only 23 cm^3. This is virtually identical to the cavity in the protected target shot with a musket.[3]

The most dramatic of the Austrian tests involved a pistol shot fired at a 16th-century breastplate from a distance of 8.5 metres. The breastplate was a fragment of a piece meant to protect horses; it was manufactured in Augsburg between 1570 and 1580, and made of 2.8–3.0-mm thick cold-worked mild steel (hardness 290 HB).[4] It was mounted on a sandbag covered with two layers of linen (meant to simulate a normally clothed wearer). The pistol was RP 2895, with a shot weighing 9.54 gm and a calculated energy/surface ratio of 838 J/cm^2 at the muzzle, and 550 J/cm^2 at 30 metres. (This figure expresses the energy in the shot in a manner independent of the ball's size.) At the instant of impact, the ball was travelling at a calculated speed of 436 m/s and with a kinetic energy of 907 Joules.[5] The breastplate was completely penetrated by the bullet, but the shot lost all its kinetic energy in piercing the armour. The ball was highly deformed, lost 24 per cent of its initial mass, and was found lodged in the linen. It had not penetrated the sandbag. There were no secondary splinters from the armour plate to cause damage either. The experimenters judged that a human being struck in the same manner would have survived with only bruises to his chest. The fact that modern mild steel failed to absorb all the bullet's kinetic energy, while the 16th-century breastplate did, can probably be attributed to the early armourer's skill at cold-working the breastplate and hardening its surface.

Part 2: Implications

Accuracy and Anecdotes

There are many anecdotes about early small arms, most of them contradictory. For every tale of astounding marksmanship, there are other stories of infantry companies blazing away without causing serious damage to the enemy. In the 18th century, trials were conducted to determine how accurate the fire from infantry battalions was. Moritz Thierbach, writing in 1866, summarized several Prussian, Bavarian and French tests as if they had been one standardized effort involving 60 shots at target approximately 100 feet (30 m) long by seven feet (2.13 m) high.[6] Thierbach calculated that from a distance of 75 metres, only 36 shots (60 per cent) penetrated the target; from 150 metres, 24 shots (40 per cent); from 225 metres, 15 shots (25 per cent); and from 300 metres, only 12 bullets (20 per cent) found their mark. The Graz tests suggest Thierbach may have been optimistic in his estimates.

The Graz accuracy data reveal quite unequivocally how poor the early modern weapons were. Only one musket (STG 1288) had a significantly better than chance probability of hitting the target. (Not surprisingly, it was rifled; but see the poor scores of the other two rifled muskets, G 284 and RG 272.) The scatter area (enclosing rectangle) for four of the 13 guns tested was larger than the target area, and for two others it was nearly as large as the target. If we eliminate from comparison the one cancelled test and the two pistols, then six out of ten long-barrelled weapons scattered their bullets so badly that they effectively hit the intended target solely by random variation. Keep in mind that the guns were sighted on the target from their firing blocks; none of this variation can be attributed to human error in aiming.

The ultimate reason for the inaccuracy of smoothbore firearms lies in the uncontrollable spin that any sphere *must* assume when it passes down the barrel. The so-called "Magnus Effect" creates an aerodynamic lift on the spinning sphere that pulls the bullet off its intended course. The effect is familiar to any golfer or tennis player who has ever sliced or hooked a shot and watched the spinning ball veer off the course or court; baseball pitchers use the effect to throw curve balls.[7] Within the technical regime of smoothbore guns, nothing can be done to eliminate the Magnus Effect. Other features of the gun can exacerbate the inaccuracy of the gun if it is poorly made, but even the best-made smoothbore weapon can never overcome this fundamental problem.

Under the some circumstances, of course, the inaccuracy of smoothbore firearms could be made into an advantage. In July 1609, Samuel de Champlain set out with a mixed war party of Indians to challenge the military supremacy of the Iroquois in the St. Lawrence. On 29 July, his party encountered a war band of Mohawks on the shores of what is now Lake Champlain. The parties agreed to battle at sunrise. To impress his wavering allies, Champlain promised to kill the Mohawk war chiefs single-handedly, even though there were three in the band. At dawn Champlain, armed with a single arquebus, advanced by himself to within 30 yards (27.3 metres) of the Mohawks. As they began to draw their bows, he levelled his firearm and took aim at one of the three chiefs. With one shot he killed two of them and wounded another. As he slyly explained, "I put four bullets in my arquebus."[8]

New Evidence for Old

The Graz tests confirm in a more rigorous manner some things about early weapons that we already knew, and they extend our insights into the performance of smoothbore small arms. The muzzle velocities of all the Graz firearms were surprisingly high, averaging 454 m/s. There is also a surprisingly narrow range within which all muzzle velocities fall; ten of the 13 were between 400 and 500 m/s.[9] The early modern weapons even compare favourably to the modern arms tested in respect to muzzle velocity. All the bullets in the Graz tests were moving at supersonic speeds when they left the barrel. (Sound travels at approximately 330 m/s at 20°C at sea level.)

These figures are all somewhat higher than those commonly cited in the literature,[10] but they are roughly consistent with the finding of pioneers students of ballistics. In 1742, Benjamin Robins reported ballistic pendulum test results showing an average calculated velocity of 509 m/s at 25 feet (7.62 metres) from the muzzle for muskets.[11] Charles Hutton's late 18th-century experiments, extending Robin's work to artillery, provided similar data; muzzle velocities ranged from 406 m/s to 504 m/s depending on shot weight and charge.[12] J. G. Benton's 1862 textbook of ordnance rates several military and civilian small arms, as well as artillery pieces. Benton's muzzle velocities range from 232 m/s for a Colt's pistol to 579 m/s for James' Sporting Rifle,[13] and from 438 m/s to 570 m/s depending on shot weight and charge for artillery pieces.[14]

Drag and Impact

This high initial muzzle velocity is quickly overcome, however, by the effects of aerodynamic drag. Spheres are among the very worst objects for aerodynamic drag, largely because they create wakes disproportionate to their cross-sectional area, generally about nine times more drag than a streamlined airfoil of equal thickness.[15] The Graz tests indicated that the spherical bullets in their tests were decelerated at a rate of approximately 2.5 m/s for every metre of distance traveled during the first 24 metres of trajectory. This compares with similarly measured values of 0.6 –1.0 m/s speed lost per metre of trajectory for modern bullets.[16] In other words, spherical shot loses speed, on average, three times faster than modern bullets do. These velocity losses mean lower energy on impact, despite the greater mass of early modern bullets, and this loss accounts for the results of the impact and wound tests.

The artificial wound data and the evidence concerning the protective value of armour are also very valuable results of the Graz tests. They show that, while firearms were capable of inflicting horrible wounds, this ability was restricted to very close-range fire. The ability to cause lethal wounds declines sharply as distance increases. (Admittedly, infection would make even superficial wounds more lethal than now, but it should also be noted that gunshot wound infections are not inherently more prone to infection than many other sorts of battlefield lesions, although 15th-century medical practice thought that they were.[17] Good-quality body armour would offer significant protection to anyone who could afford it, a fact that is also witnessed by the number of surviving specimens of body armour that have been subject to proof by gunshot.[18] The twin characteristics of musket fire — inaccuracy and lack of penetrating power — helps explain why the European battlefield saw a shift in the balance of power between traditional heavy cavalry (*gens d'armes*, "knights in armour") and infantry only late in the 16th century, long after the introduction of muskets. Early guns simply were very ineffective weapons against properly armoured knights.

Pistols

Pistols, on the other hand, fared much better than we might have expected (Fig. 3). At the shorter ranges appropriate to such weapons, pistols scored hits 85 per cent and 99 per cent of the time, while their scatter areas (871 and 423 cm^2 respectively), were only 10 to 15 per cent as large as the average for long-barreled weapons. To be sure, the pistols did not possess the muzzle velocity of the longer guns, and thus their total energy was less, but they could still damage any target they hit at close range, even if their wounds were sub-lethal. This helps explain why the rise of pistoleers on horseback, the German *Reiter*, was such an important phenomenon in 16th-century warfare. Unlike the slow moving formations of arquebusiers or even heavier musketeers, the *Reiter* could close the gap between themselves and the *gens d'armes* firing only when the target was within range. La Noue, who had seen them in action, praises the *Reiter* at length in his *Discourses*, claiming that a squadron of *Reiter* could beat a comparable squadron of traditional cavalry.[19] This is compatible with more recent analyses of military change in the 1500s, which also highlight the importance of the pistoleers. As Claude Gaier summed it up, "*Ce n'est pas l'infanterie mais les pistoliers à cheval qui mirent fin au long règne du cavalier lourd armé de la lance.*"[20] Such judgments have influenced only some of the standard interpretations of renaissance military change,[21] while others remain focussed on artillery and fortifications,[22] but the Graz data constitute powerful evidence in support of the pistol's importance.

Conclusion: Rewriting Military History

The Graz tests represent one way in which material culture studies can challenge and supplement conventional historiography based on textual sources. By examining in detail the performance characteristics of early modern small arms, the experimenters have created a body of data that clarifies the ways in which early firearms were used, and the influence they had on the conduct of military operations. The technical efficacy of early small arms could never have been the primary reason they were adopted into widespread use. Anecdotal evidence suggested long ago that the historian's focus on the capabilities of guns was a misplaced faith, as did pioneering empirical studies carried out as early as the 18th century. Historical interpretation, vaguely informed by this, has already largely given up any notion that early guns could, in the optimistic phrase of a gun advocate, "kill, and kill selectively, from afar."[23]

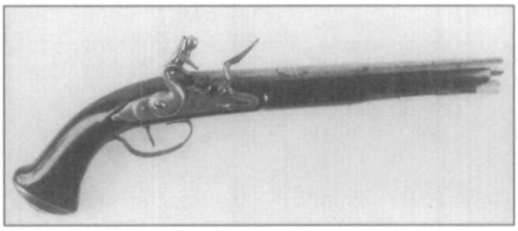

Fig. 3
French pistol, ca 1660 (Courtesy Parks Canada)

Yet the problem of integrating small arms into a coherent picture of early modern military changes remains an acute issue, and the temptation persists to emphasize the gun's progressive improvement. Geoffrey Parker is only the latest historian to claim that "the effectiveness and reliability of firearms improved" throughout the 16th and 17th centuries, leading to the predominance of shot over pike by the 1650s.[24] Yet the Graz investigators expressly noted that there is no ballistically significant improvement in the firearms they tested, despite the fact that these guns ranged from the 16th to the 18th centuries. Technical improvements concerned ignition mechanisms and methods of manufacturing barrels and stocks, but these changes did not affect the primary ballistic characteristics of these guns.[25] Deprived of the argument from technological progress, historians face a real challenge in explaining the spread and influence of small arms. Their low cost (less than half that of a crossbow), and the relatively small amount of training required to use them certainly ought to be considered.

Above all, however, it is clear that the shift to small arms in the 16th century demanded different psychological characteristics of the soldier than had once been the norm among warriors. Champlain's feat in tricking his Mohawk adversaries reveals in a crude but striking manner how Europeans had grown accustomed to the random quality of death on the gunpowder battlefield. Fatalistic, or merely possessing *sang froid*, the European soldier of Champlain's day held his place in geometric ranks, accepting that chance, not valour, ruled the field of combat. Dying and killing had both ceased to be under the control of individuals and had instead become a function of unpredictable and invisible forces. Perhaps the Graz data really suggest what made this fundamental transformation possible in the first place: the ballistic limitations of early modern small arms. Most men go to war believing that, however dangerous their weapons may be to the enemy, the odds still favour their own survival as individuals. Early modern soldiers learned to face bullets with surprising poise, even though we know that firearms were potentially much more lethal than the weapons they supplanted. The inaccuracy and lack of penetrating power in such firearms must have encouraged soldiers in this primordeal — but utterly necessary — act of self-deception.

NOTES

1. Peter Krenn (ed.), *Von alten Handfeuerwaffen: Entwicklung, Technik, Leistung: Katalog zur Sonderausstellung im Landeszaughaus*, "Veröffentlichungen de Landeszeughauses Graz, Nr. 12 (Graz: Landesmuseum Johanneum, 1989), containing Paul Kalaus, "Schießversuche mit historischen Feuerwaffen des Landeszeughauses Graz and der Prüf- und Versuchsstelle für Waffen und Munitionen des Amtes für Wehrtechnik," pp. 41–113. Peter Krenn, "Was leisteten die alten Handfeuerwaffen: Ergebnisse einer Ausstellung des Landeszeughauses in Graz." *Zeitschrift für historische Waffen- und Kostümkunde* 32 (1990): 35–52. An earlier English version of the test data was consulted in preparing this summary: Peter Krenn, (trans. Erwin Schmidl), "Test-Firing Selected 16th–18th Century Weapons, *Military Illustrated Past and Present* 33 (February 1991): 34–38.
2. Kalaus, in Krenn, *Alten Handfeuerwaffen*, 45.
3. Ibid., 73–78.
4. This is roughly consistent with the dimensions reported by Peter N. Jones, "The Metallography and Relative Effectiveness of Arrowheads and Armor during the Middle Ages," *Materials Characterization*, 29 (1992): 111–117; see p. 115 for selected 15th- and 16th-century body armor specimens. See Jones, Table 2.
5. Kalaus, in Krenn, *Alten Handfeuerwaffen*, 73. The shot was measured at 5.2 metres from the muzzle; impact occurred at 8.5 metres.
6. Moritz Thierbach, *Die Geschichtliche Entwicklung der Handfeuerwaffen* (2 vols. Dresden: 1886; reprt. Graz: Akademische Druck- u. Verlagsanstalt, 1965), vol. 1, p. 115. Cf. Kalaus, p. 67. See also David G. Chandler, *The Campaigns of Napoleon* (New York: Macmillan, 1966), 342. The target was meant to approximate the frontal area of a hostile battalion.
7. See H. M. Barkla and L. J. Auchterlonie, "The Magnus or Robins Effect on Rotating Spheres," *Journal of Fluid Mechanics* 47 (1971): 437–447; especially figures 1 and 2, pp. 438–439. For background, see Robert W. Fox and Alan T. McDonald, *Introduction to Fluid Mechanics*, 3rd ed. (New York: Wiley, 1985), 481–482.
8. H. P. Biggar, et al (eds.) *The Works of Samuel de Champlain*, Vol. 4: *1608–1620* (Toronto: The Champlain Society, 1932), 94–99. See Samuel Eliot Morison, *Samuel de Champlain: Father of New France* (Toronto: Little, Brown, 1972), 109–110.
9. Kalaus, in Krenn, *Alten Handfeuerwaffen*, 66.
10. Basil Perronet Hughes, *Firepower: Weapons Effectiveness on the Battlefield 1630–1850* (London: Armour and Armaments Press, 1974; New York: Scribner's, 1974), 26; claims a French fusil of the 18th century had a muzzle velocity of only 320 m/s. He does not cite the source for this figure.
11. Benjamin Robins, *New Principles of Gunnery: Containing the Determination of the Force of Gun-Powder, and an Investigation of the Difference in the Resisting Power of the Air to Swift and Slow Motions* (London: Nourse, 1742). Later reprinted in the first posthumous edition of Robin's papers, *Mathematical Tracts of the Late Benjamin Robins, Esq.: Fellow of the Royal Society and Engineer General to the Honourable East India Company*, 2 vols. (Ed. James Wilson, M.D.; London: printed for J. Nourse..., 1761.), which is the edition I have consulted. See p. 133. Robins charged his test musket with "about half" the ball's weight in powder.
12. H. A. Baker, "Hutton's Experiments at Wollwich: 1783–1791," *Journal of the Arms and Armour Society* 11 (1985): 257–298; see pp. 267 and 294.
13. J. G. Benton, *Course of Instruction in Ordnance and Gunnery: Compiled for Use of the Cadets of the United States Military Academy*, 2nd. ed., rev. (New York: Van Nostrand, 1862), 316–318.
14. Benton, *Ordnance and Gunnery*, 387.
15. Ascher H. Shapiro, *Shape and Flow: The Fluid Dynamics of Drag* (Garden City, NY: Doubleday, 1961), 148.
16. Both figures from Kalaus, in Krenn, *Alten Handfeuerwaffen*, 46.
17. Kelly DeVries, "Military Surgical Practice and the Advent of Gunpowder Weaponry," *Canadian Bulletin of Medical History* 7 (1990): 131–146.
18. A. R. Williams, "The Knight and the Blast Furnace," *Metals and Materials* 2 (1986): 485–489; Harold A. Dillon, "A Letter of Sir Henry Lee, 1590, on the Trial of Iron for Armour," *Archaeologia* (2nd ser. 1) 51 (1888): 167–172.
19. François de la Noue, "Discours politiques et militaires," in F. E. Sutcliffe , ed. (Geneva: Droz, 1967): 355–362 and 367.
20. Claude Gaier, "L'opinion des chefs de guerre français du XVI^e siècle sur les progrès de l'art militaire," *Revue Internationale d'Histoire Militaire* 29 (1970): 723–746; quote from p. 743. See also Frederick J. Baumgartner, "The Final Demise of the Medieval Knight in France," in Jerome Friedman, ed., Regnum, *Religio et Ratio: Essays Presented to Robert M. Kingdon*, Sixteenth Century Essays and Studies, Vol. VIII (Kirksville, MO: Sixteenth Century Journal Publishing, Inc., 1987), 9–17 for a similar judgment.
21. Archer Jones, *The Art of War in the Western World* (Oxford: Oxford University Press, 1987), 195–198, for example.
22. For example, Geoffrey Parker, *The Military Revolution: Military Innovation and the Rise of the West, 1500–1800* (Cambridge: Cambridge University Press, 1987).
23. M. G. A. Vale, "New Techniques and Old Ideals: The Impact of Artillery on War and Chivalry at the End of the Hundred Years War," in C. T. Allmand, ed., *War, Literature, and Politics in the Late Middle Ages* (Liverpool: Liverpool University Press, 1976) 57–72; quote from p. 64.
24. Parker, *Military Revolution*, 18.
25. Kalaus, in Krenn, *Alten Handfeuerwaffen*, 79. Note that Schmidl, "Test-Firing," p. 38 misrepresents the original investigator's position on this matter.