BIOLOGICAL LIMITS TO POLICE COMBAT HANDGUN SHOOTING ACCURACY

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History suggests that police shoot with far less accuracy than many citizens, public officials, and policymakers believe. For example, Justice John Paul Stevens interrupted the oral arguments in Tennessee v. Garner to ask why the officer involved could not have aimed at a leg or arm or otherwise "shot to wound" the fleeing Garner (471 U.S. 1). As many researchers have noted, however, police officers seldom shoot accurately in combat situations (Geller & Scott 1992; Binder & Fridell 1984; Scharf & Binder 1983; Geller & Karales 1981:90; Fyfe 1978). And the ability of police to hit opponents in gunfights appears to have improved little over the past 100 years despite improvements in weapons and substantial increases in firearms training. This highlights the lack of handgun training validation and raises the possibility that the limits to how accurately police can shoot under combat situations may have been reached.

Although variables such as cognition and perception also are important, the body's nervous and mechanical systems place finite limits on combat handgun shooting accuracy. Research in neurophysiology and biomechanics (e.g., Calvin 1983; Leavitt, Martenik & Carnahan 1987; Poppel 1988) indicates that these limits may be unexpectedly low—especially when officers suddenly confront armed opponents at close quarters. Accurate handgun shooting places substantial demands on human nervous, muscular, and skeletal systems because it requires so much steadiness and hand-eye coordination. These demands dramatically increase in complex, rapidly changing combat situations. We use contemporary and historical data on police combat handgun shooting accuracy and a simple mathematical model to test the hypothesis that the biophysical limits of combat handgun shooting
performance may have been reached. Our results support the hypothesis and indicate that physical limits to police combat handgun shooting accuracy must be better understood before valid training can be developed.

**Are There Biologically Based Limits to Combat Handgun Accuracy?**

The ability of police to accurately shoot in complex, fast-moving combat situations obviously is vital for their survival and for the safety of bystanders. It also is important because each additional increment of accuracy and confidence possessed by officers can increase the time available to them in violent confrontations. Additional time can improve decision making and provide opportunities for officers to use persuasion or less than lethal tactics to control opponents (Scharf & Binder, 1983). For example, when an officer first confronts an armed suspect whose weapon is pointed away from the officer, he or she has a finite amount of time to make a "shoot/don’t shoot" decision. The officer can divide this time between activities such as taking cover, convincing the suspect to drop the weapon, assessing the location of—and risks to—bystanders, and preparing to shoot. More proficient shooters may require less time to prepare and thus may have more time for other activities. And more confident shooters may be more inclined to spend time on nonlethal activities because their assessment of risks are relatively lower.

Since the mid-1920s, United States law enforcement agencies increasingly have attempted to improve combat handgun shooting performance by providing training throughout an officer’s career. A basic assumption underlying these attempts is that more/better handgun training can improve police combat shooting performance. During the past 100 years, the amount of handgun training received by police officers has increased dramatically, as has the quality of the weapons they carry. However, on average, there appears to have been very limited improvement in the ability of officers to hit their targets during combat situations. Police entrance requirements and training criteria in areas such as physical fitness and academic subjects often have been validated to ensure that they properly reflect actual job requirements. However, there do not appear to have been any systematic attempts to validate police handgun training—i.e., to scientifically assure that what is taught on the range actually improves performance in combat shooting situations. As the attention of researchers and policymakers properly begins to focus on this issue, it is important not to overlook a seemingly counterintuitive possibility—that the lack of substantial improvement in combat shooting performance may not be due to inadequate training.

Research in neurophysiology and biomechanics indicates that biology may set unexpectedly low practical limits on handgun shooting accuracy in certain situations. This article discusses the ways in which neurophysiological and biomechanical systems limit performance in combat shooting situations of the type often encountered by police officers. We argue that the physical limits to police combat handgun use must be understood before valid criteria for handgun training can be developed.

**Background and Definition of Terms**

Most police shooting incidents involve an officer’s use of a handgun, a compact weapon principally designed for defensive purposes. Although it has limited accuracy and power, portability makes the handgun a standard law enforcement tool in most of the world. Shoulder-fired weapons (e.g., rifles and shotguns) are easier to fire accurately and provide more stopping power, but they generally are too cumbersome for officers to routinely carry on their person (Cooper, 1975:24).

The discussion that follows focuses on a particular type of police combat handgun shooting—gunfights in which officers unexpectedly confront at close quarters armed opponents who present an immediate deadly threat (as defined in *Tennessee v. Garner* 471 U.S. 1). We do not define as combat shootings incidents in which officers are forewarned and take time to prepare, such as those more often handled by special weapons and tactics teams. They are fundamentally different and beyond the scope of this research. We define these as “tactical” situations. For example, when a police sniper in a well-concealed and highly stable position shoots a stationary barricaded suspect 50 meters away it is a tactical shooting.

Although police are aware of the potential for deadly confrontation at any time, most shooting incidents are unpredictable because they arise from routine police activities that seldom become deadly (Flanagan & Maguire 1992: Table 3.161). In other words, while police frequently handle disturbance calls and make traffic stops
and arrests—and seldom encounter violence while doing so—they know that most of the officers killed each year die while performing these duties. In addition to the problem of unpredictability, officers tend to become complacent because they are regularly exposed to potentially deadly situations (see Breznitz, 1967:176-178). Even though officers who respond to potentially extra hazardous calls such as crimes in progress or disturbances are forewarned, they often are surprised because the great majority of such calls turn out to be false alarms or are otherwise peacefully resolved without regard to how well or cautiously they behave.

There has been little research on police combat shooting accuracy. Most information on this topic comes from research on police use of deadly force that typically focused on descriptions of violent police-citizen confrontations, the need to modify departmental policies to reflect a greater reverence for human life, and strategies to reduce the frequency of police shootings (see, e.g., Fyfe, 1979; Geller & Karales, 1981; Scharf & Binder, 1983). These studies helped curtail "elective shootings" such as those involving non-dangerous fleeing felons, warning shots, shots to summon assistance, and shots at or from moving vehicles (Fyfe, 1979). Thus, in contrast with previous decades, contemporary police shootings are more likely to reflect the combat conditions on which we focus—gunfights in which officers unexpectedly confront armed opponents who present an immediate deadly threat at close quarters.

**INDICATORS OF POLICE COMBAT SHOOTING ACCURACY**

Accuracy measures from the police use of deadly force literature generally fall into four different categories: incident hit rates, person hit rates, fatality rates, and bullet hit rates. Another shooting variable, shots fired per incident, also is important because of the way it influences accuracy measures.

**Incident Hit Rate**

Incident hit rate—the percentage of police shootings in which at least one police bullet hit at least one opponent—is the broadest and most commonly reported measure of field shooting accuracy. The national average during the 1970s was about 50 percent (See Geller & Karales, 1981; Blumberg, 1982; Binder & Fridell, 1988). During the past twenty years Dallas, Los Angeles, and Portland,\(^1\) reported the highest incident hit rates—between 60 and 65 percent (Kindrick, cited in Geller & Scott, 1992:105; Geller & Karales 1981:162; Geller & Scott, 1992:106). Chicago officers had the lowest at 27 percent (Geller & Karales 1981:162).

**Person Hit Rates**

Person hit rates measure the percentage of police opponents who are hit by at least one police bullet during a shooting. Geller and Scott (1992:97-99) report that the percentage of civilians hit by police bullets ranged from 22 to 42 percent during the 1970s and 1980s. During 1986, person hit rates for the six largest police departments varied considerably but still were consistent with the range reported by Geller and Scott: Houston (42.7%), Los Angeles (41.7%), Philadelphia (32.8%), Chicago (25.5%), Detroit (24.6%), and New York (23.8%) (Police Foundation, 1987:139).

**Fatality Rates**

Fatality rates appear in one of two ways, either as the percentage of all opponents fired upon by the police who were killed (discharge-based), or as the percentage of opponents struck by police bullets who died (hit-based). Discharge-based fatality rates use all opponents who were fired at by police as the denominator. For example, during the 1970s, New York City police officers killed about eight percent of those at whom they shot, Chicago police officers killed about six percent (Geller & Karales 1982: 90-91; Fyfe, 1978:464-465). The second, more commonly used hit-based category only includes in the denominator opponents that were hit. Fatality rates provide somewhat more information about combat shooting accuracy than person or incident hit rates. Because officers are taught to shoot at vital areas, higher fatality rates could indicate a greater percentage of very accurate shots. Alternatively, they could result from the cumulative effect of multiple hits to less vital areas—quantity versus quality. Figure 1 illustrates the generally linear positive relationship between number of bullet wounds and probability of death.
Figure 1. The proportion of opponents of Chicago Police who died as a result of their wounds increased with the number of wounds sustained (Geller and Karales 1981:217).

Fatality rates may be biased by factors that vary between communities, such as type of shooting, terminal ballistics associated with different ammunition, and the timeliness and quality of medical care. During the 1970s, Chicago's hit-based rate was roughly 33 percent (Geller & Karales 1982: 91) and New York City's 30 percent (Fyfe, 1978:464)—the same as the aggregate rate calculated by Binder and Fridell (1984:254) for Atlanta, Birmingham, Newark, and Oakland. Horvath (1987:226-238) found an aggregate hit-based fatality rate of 35 percent for 155 Michigan cities surveyed from 1976 to 1981. In 1986, hit-based fatality rates among the six largest police departments (Chicago, Detroit, Houston, Los Angeles, New York, and Philadelphia) ranged from roughly 20 percent in Detroit to 40 percent in New York City (Police Foundation 1987:140).

Bullet Hit Rate

Bullet hit rate measures the proportion of all police shots that strike opponents. Though less commonly used, bullet hit rates provide more information about combat accuracy than other measures. Unlike incident or person hit rates and fatality rates, bullet hit rates do not conceal the number of shots fired by police. This is important because many shots fired with low accuracy can result in a hit from chance alone. For example, an incident hit rate of 50 percent could result either from 50 percent accuracy and one shot fired per incident or 10 percent accuracy and five shots fired per incident. Bullet hit rates also are unbiased by the kinds factors that can confound fatality rates. Still, bullet hit rates provide a rather crude estimate of accuracy because they show only that an opponent was hit—not where the bullet struck. They do not differentiate hitting opponents' toes from hitting their hearts. A hit is a hit.

In spite of its limitations, bullet hit rate provides the best available measure of combat handgun shooting accuracy. Figure 2 compares bullet hit rates for city police departments for which data were available for at least three consecutive years. Contemporary rates range from 15 to 30 percent. Bullet hit rates calculated from aggregate data for 155 Michigan cities surveyed from 1976 to 1981 averaged 32 percent (Horvath 1987:226-238). Historical data, as will be discussed later, are surprisingly similar. More recent data generally also are consistent with this range. The 1990 New York Police Department rate was 19 percent (Cerar, cited in Geller & Scott, 1992:105) and Los Angeles Police Department reported a 39 percent hit rate for 1988 (Salseda, 1992).

Shots Fired Per Incident

The number of shots fired obviously is important from a public safety standpoint: Police bullets that miss opponents can strike bystanders (see Geller & Karales 1981:111-112). Though the number of shots fired by police during each incident is not an accuracy measure per se, it influences the probability that officers will wound their opponents. Even when the probability that any single bullet will hit an opponent is very low, each additional shot multiplies that probability. Data from the field support this idea: In both Atlanta and Kansas City during the 1970s, an average of 2.2 shots were fired in incidents in
which there were no hits; in incidents in which opponents were hit at least once, an average of 4.1 shots were fired (Blumberg 1983:177-178). During the 1970s, average shots fired per incident ranged from 3.0 in Chicago (Geller & Karales 1981:162-163) to 4.4 in the City of Los Angeles (Geller & Scott 1992:106; Meyer 1980:33-34). During the 1970s, average shots fired per incident ranged from 3.0 in Chicago (Geller & Karales 1982:163) to 4.4 in the City of Los Angeles (Geller & Scott 1992:106; Meyer 1980:33-34).


POLICE GUNFIGHTING

Information regarding police gunfighting performance from historical and contemporary sources—as well as anecdotal information comparing police and opponent performance—is consistent with the hypothesis that biology may limit combat handgun shooting accuracy. Over time, there appears to have been relatively little improvement in accuracy, and the generally superior amount of firearms training received by police compared to opponents may not necessarily translate into superior performance.

Historical Comparison

Over the past 100 years there have been substantial improvements in the handguns carried by police and the firearms training they receive. However, as Figure 2 shows, the ability of police officers to hit their targets when involved in gunfights may have improved only marginally during that time—if at all. Consider the following comments regarding the New Orleans police department during the late 1800s:

... only 42 percent of the policemen who fired their guns struck their antagonists. No more than 22 percent of the shots fired found their intended targets [bullet hit rate], and the figure was probably closer to 15 percent or even less. The result was that of the people fired upon by these officers, a maximum of only one-third were wounded or killed [person hit rate], and fatalities amounted to just 14 percent of the civilians involved (Rousey 1984:57).

Nearly a century later, Fyfe reported that approximately 45 percent of the New York City officers who fired at opponents hit an opponent with at least one bullet (1978:655). As Table 1 shows, person hit rates, fatality rates, and bullet hit rates from nineteenth-century New Orleans are indistinguishable from contemporary rates. This close parity is especially surprising because New Orleans officers of that period received little or no handgun training while, on average, officers in the contemporary departments with whom they are compared received 50 hours of recruit firearms training (mostly with handguns), participated in five hours per year of in-service firearms training, and fired a qualification course three times per year (Matulia 1982:Table K17). Moreover, the 1800s officers also had technologically inferior handguns—15 percent of which were "mechanically useless" (Rousey, 1984:58).
<table>
<thead>
<tr>
<th>Measure</th>
<th>New Orleans 1863-89a</th>
<th>Range for Contemporary Police Departments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Person Hit Rate</td>
<td>33%</td>
<td>22 - 42%b</td>
</tr>
<tr>
<td>Fatality Ratesc</td>
<td>14%</td>
<td>9 - 13%d</td>
</tr>
<tr>
<td>Bullet Hit Rates</td>
<td>15 - 22%</td>
<td>15 - 30%e</td>
</tr>
</tbody>
</table>

a New Orleans (Rousey, 1984:57).
c discharge-based.
d Chicago and New York City only (Fyfe, 1978; Geller and Karales, 1982).

**Police vs. Assailant Shooting Accuracy**

Although data comparing police hit rates with those of their assailants is scarce, the New York Police Department reports that assailants' bullet hit rates during the mid-1980s were roughly eight percent. In 1990, this rate was six percent (Cerar, in Geller & Scott 1990:105). This is surprisingly close to police rates, given the differences between police and their assailants. For example, although the police have greater restrictions on when and in what manner they can fire, they usually also have had a great deal more firearms training than their opponents. Moreover, in addition to being generally untrained in handgun use, a large body of evidence supports the assumption that many—perhaps a majority—of officers' assailants are under the influence of alcohol or other drugs at the time of the confrontation (USDOJ 1988:51). If the reputed close parity between the combat handgun performance of police and their assailants exists in fact, it is consistent with the possibility that basic physical capabilities may limit combat handgun performance. Otherwise we might expect differences in training and pharmacological impairment to result in larger performance differences.

It obviously also may be the case that the apparent parity of police combat handgun performance over time compared to their opponents results from failure to employ valid firearms training programs. This is an important research question currently being examined in-depth by one of us (Morrison).

**BALLISTIC MOTIONS, COMBAT HANDGUN SHOOTING, AND THE NERVOUS SYSTEM**

**Biology Limits What Is Possible**

Combat shooting involves many different movements. For example, one must draw the gun, disengage safeties, face the target, assume a firing stance, aim, and press the trigger. As will be discussed later, making these movements more quickly tends to degrade accuracy. Even under ideal conditions, there is a finite limit to how quickly and accurately these actions can be performed because perception, cognition, nerve impulse travel, muscle response, and skeletal movement all take time. Although speed and accuracy vary between individuals and from time to time for any individual, the body's nervous and mechanical systems place finite limits on combat shooting performance.

Although our focus is on biological factors, a brief description of other factors associated with variation in speed and accuracy helps provide a more complete view of the complexities associated with combat shooting performance. Environmental variables, as well as cognitive and perceptual factors (e.g., those associated with detecting a problem and deciding what to do about it) obviously have major effects on combat handgun performance. Some environmental variables (e.g., lighting, terrain, weather, and crowding) can interfere physically with accurate shooting. They also can affect cognition and perception by increasing the number, type, and magnitude of stimuli being processed (see Rose & Christina 1990; Poppel 1988). Other factors that interfere with cognition and perception as well as psychomotor performance include such things as fatigue, affective state (e.g., mood, alertness, arousal level), physical fitness, and training (e.g., Etou et al. 1989; Leavitt, Marteniuk & Carnahan, 1987). Some of these factors change more or less uncontrollably with the infinite variety of police work. Others may be controlled to some extent by officers or the organizations for which they work. Potentially controllable factors that may
Joints can move is limited (Cordo, 1987). Although this speed varies directly in front of them from a distance of seven meters in about range conditions, excellent shooters accurately can shoot chest-high gun is holstered, maximum expert speed slows to about one second. Have important effects on combat handgun performance, they are beyond the scope of this article.

Nerve impulse and muscle response times have absolute limits associated with the biological and electrochemical processes they entail. The speed with which a nerve impulse can travel from, say, the eye to the brain and then to a group of muscles is finite. Similarly, the speed with which even optimally trained muscles can respond and joints can move is limited (Cordo, 1987). Although this speed varies from individual to individual as with any other biological trait, it has a fixed range in humans. In other words, although many of the factors associated with combat handgun shooting are mutable, biology sets the absolute limit for performance (see Calvin, 1983).

These biological limits define what is possible in combat handgun shooting. Practical experience indicates that, under shooting range conditions, excellent shooters accurately can shoot chest-high targets the size of a person's vital zone (roughly 25mm or 10 inches) directly in front of them from a distance of seven meters in about one-half second. This speed is achievable from a ready pistol position where the shooter has the gun in hand and the muzzle is depressed 45° from line of sight (e.g., Morrison 1991:75-76). If the shooter's handgun is holstered, maximum expert speed slows to about one second.

The Not-So-Simple Act of Shooting

Two kinds of biologically based factors may be expected to have important effects on combat handgun performance: biomechanical factors associated with the muscles and bones of the skeletal system, and neurophysiological factors associated with the system of nerves that transmits and processes information in the body. The biomechanics of combat shooting easily can involve the following acts in rapid succession: swiveling the head; raising, lowering, and placing one foot while pivoting on the other in order to turn toward an opponent; flexing the fingers and hand to grasp the handgun; lifting the gun by flexing at the shoulder and elbow; and raising the forearm and straightening the elbow and wrist in the opponent's direction while simultaneously bringing up the other hand to steady the gun hand. These gross movements then are followed by progressively finer adjustments in alignment of the bore with the target until the trigger is pressed.7

Even apparently simple acts like raising the hand to point—or shoot—at an object actually are incredibly complex processes that require coordination of nervous, muscle, and skeletal systems. The nervous system receives and processes information, then directs some groups of muscles to contract (and others not to contract) in a particular sequence. Movement occurs when elements of the skeletal system are manipulated by contracting skeletal muscles. The following brief overview discusses some of the basic biomechanical and neurological systems associated with movement. Campbell (1987: 984-991) and Starr and Taggart (1981: 374-83) provide more detailed general discussions of vertebrate motor system functioning that are very accessible.)

Biomechanical Factors

The shape, size, and connections between the bones of the human skeletal system allow us to perform complex movements such as walking, running, pointing, grasping, and turning. From a stationary position, the directions of movement available to us are quite limited. However, by combining a sequence of movements in a dynamic fashion, the range of possibilities increases dramatically. If we picture the average person standing still inside a sphere two meters in diameter, it is plain that any single motion only will allow her to reach limited areas of the sphere. However, by combining several movements, she can reach any part of the volume of the sphere quite easily. These motions involve movement of skeletal bones at the joints by muscles.

Joints occur at points where two or more bones meet. Many of the shooting postures people are taught attempt to improve accuracy by limiting the number of degrees of freedom in the skeletal system—often by eliminating flex or rotation at several joints. Different types of joints allow different degrees of movement. Freely moveable (synovial) joints such as those between the limb bones allow considerable movement. Hinge joints such as those in the middle of the fingers allow movement in one direction. Ball-and-socket joints such as those at the shoulders and hips allow movement in all directions. Pivot joints allow one bone to rotate against another in a single plane and glide joints allow one bone to slide over another. Some joints such as the elbows allow more complex movements by combining hinge and pivot
simple movements

Shooting requires...
failed to see. Relatively slow dynamic motions like this can be performed very accurately by using feedback. But this control system is too slow for some types of motions.

**Predictable and Unpredictable Ballistic Motions**

Ballistic motions, like accurately throwing a ball long distances—or quickly drawing a handgun and bringing it to bear on a target during a combat situation—are particularly difficult because they involve very rapid, complex, and dynamic motion, while permitting only small margins of error. These motions require a complex sequential interplay between perception, cognition, and muscular-skeletal movement. However, they happen so quickly that adequate feedback for fine tuning is precluded. That is, the time required for nerve impulses to travel in the loop from sensor to spine to brain to neurotransmitter to muscle is greater than the window of opportunity for the action.

We can learn to accomplish predictable ballistic motions like basketball free throws or shooting at targets on 'combat' ranges by training ourselves to forgo the feedback process. Essentially what happens is that we store whole series of instructions in neural buffers—much as notes might be programmed into a player piano or telephone numbers into the speed dial functions of a telephone. When the decision is made to initiate the predictable dynamic motion, instructions are given sequentially. So long as one "stays in the groove" and does not let other stimuli interfere with the instructional sequence, the motion is performed smoothly. Accuracy and speed can be enhanced by repetition, but the limits of both ultimately are set by neurophysiological and biomechanical factors.

Speed and accuracy are competing qualities in ballistic motions, in part because increased speed multiplies torsional forces in the (mechanical) skeletal system, increasing the need for counterforces to dampen or restrain movement. For example, as the speed with which you bring a handgun to the shooting position increases, so does its tendency to keep moving beyond correct alignment with the target. Counter-pressure by opposing muscle groups is required to prevent this. Accuracy also is degraded by speed in ballistic movements that require precise timing of release in the arc of throw (e.g., such as pitching a strike or throwing a dart). Here, increased speed of motion decreases the window of opportunity for accurate release (see Leavitt, Marteniuk, & Carnahan 1987).

Less predictable ballistic motions such as accurately shooting a handgun in combat situations in which body position and grip are often suboptimal, physical and emotional stress degrade steadiness, and fear argues for a quick shot are much more problematic than predictable ballistic motions. The unpredictability of these situations means that it is not possible to obtain accuracy by initiating a long series of instructions stored in a neural buffer—the strategy applied for predictable ballistic motions. Combat handgun shooting often demands rapid complex biomechanical movement as an officer turns to face a potential target—frequently while moving to minimize the target he or she presents. It also requires precise timing of trigger press during the brief moment that the handgun is properly aligned and the potential bullet impact area is free of bystanders. Even if the handgun momentarily appears to be properly aligned, gun barrel movement can cause accuracy to rapidly diminish. Steadiness therefore is likely to be the aspect of combat handgunning most vulnerable to biological limitation—and perhaps least amenable to improvement via training.

**MODELING THE STEADINESS REQUIRED FOR ACCURATE COMBAT HANDGUN SHOOTING**

The rapid movement often associated with combat handgun shooting degrades the stability required for accurate handgun shooting. We developed a simple mathematical model to obtain a general idea of how much steadiness is required for accurate combat handgun shooting and then compared its results with available data on actual police shootings. Stadiness is calculated in terms of wobble—deviation of the muzzle from a line extending from the rear of the bore (henceforth the breech) to the target.

Accurate handgun shooting requires accurate alignment of both endpoints of the bore with the target. In other words, the breech, muzzle, and target must be in line. The model applies equally to sighted and unsighted shooting techniques because it is insensitive to alignment method. It only is concerned with deviation from accurate alignment.
Figure 3. Diagram of factors associated with handgun shooting accuracy. In the example shown, a 12mm (-1.12 inch) of muzzle wobble at 7.0m from the target leads to roughly 6.25 percent accuracy.

\[
\theta = \frac{\theta}{\tan \frac{x}{\theta}} = \theta
\]

The distance from breach to target (x) is:

\[ p - D = x \]

As Figure 3 illustrates, the model calculates accuracy as a function of muzzle-induced wobble at the tip of the barrel. The model does not overestimate initial wobble.

**Assumptions**

In order to assure that the model does not overestimate initial wobble.

**Model Description**

On the test range, the model uses the following equation:

\[
\frac{\varepsilon(L)}{\varepsilon(M)} = \frac{\varepsilon(L)}{\varepsilon(M)} = \alpha
\]

Accuracy is defined as the proportionate relationship:

\[ x \times \theta \tan \frac{x}{\theta} = \frac{x}{\theta} = \theta \]

where x is the range between the barrel length (x) and distance from the breach to breech (y), and distance from the breech to target (z).

\[ p - D = x \]
which may be calculated given the relationships in equations (1) and (2) as:

\[ \alpha = \frac{t^2}{(y')^2} = \frac{t^2}{(\tan \theta \times x')^2} \]  

(4)

Estimated Steadiness Required

Figures 4 and 5 were generated by the model using Mathematica™ software on a NeXT™ workstation with a standard precision setting of 16 decimal places. As Figure 4 shows, the demand for stability rapidly increases with distance. Beyond seven meters, 100 percent accuracy requires that wobble be restricted to less than 3mm (=1/8 inch).

The slope function of accuracy is so steep relative to distance and wobble that, as Figure 5 shows, even 50 percent accuracy demands restriction of wobble to less than 4.3mm (=1/16 inch) beyond seven meters shooting distance. According to our mathematical model, even modest combat handgun shooting accuracy requires a substantial amount of control over barrel movement. This is consistent with our hypothesis that the physical limits to police combat handgun shooting accuracy may have been reached. But how well does the model capture reality?

Figure 5. Even 50% accuracy is difficult to achieve at common combat handgun shooting distances. (Target radius = 127mm, distance from rear to front sight = 152 mm, and distance from shooter's chest to rear sight = 762 mm.)

Testing the Model

We tested the reasonableness of the model by comparing its predictions with estimates of the amount of wobble common in real-life shooting situations. We derived our estimates from data about police
shootings. Although complete data to match all of the model’s parameters were not available, we developed a very conservative rough estimate based on police bullet hit rates and the frequency with which those shot by the police die (fatality rates). The data used did not include distance. Nor did they discriminate between handgun and long-gun use or what we define as “tactical” versus “combat” shootings. This means that the test would tend to overestimate accuracy. In other words, we expect that our findings substantially underestimate wobble because accuracy tends to be better with long-guns and in tactical situations than it is in combat handgun shootings. It is important to remember that these estimates are intended merely to test the reasonableness of our model—the model would be falsified if it turned out that actual police performance was superior to what we predict is possible.

We estimated observed accuracy ($a'$) using data about police bullet hit rates ($bhr$) and hit-based fatality rates ($fr$), then calculated estimated wobble ($ey$) for a range of distances. Our assumptions included numbers 1-4 above as well as: (5) Bullets that strike an opponent in a 25mm diameter circular target zone centered on the chest and extending downward from the top of the sternum will be fatal; (6) fatalities do not result from bullet hits outside this zone; (7) each fatality results only from a single bullet hit within this zone (i.e., there are not multiple accurate hits in a single shooting; and (8) all fatalities are the result of combat handgun shooting as defined in this paper. (As was noted previously, this is a conservative assumption.)

Given assumptions 5-8, the product of average bullet hit and fatality rate provides a rough approximation of the proportion of all bullets fired by the police that actually hit the lethal dinner-plate sized lethal zone at which police are taught to aim in most combat situations. Thus

$$\alpha' = bhr \times fr$$

(5)

Using the constants, and given the assumptions and definitions of variables, it is possible to calculate estimated wobble ($ey$) as follows: Given equation 1,

$$ey = x \times \tan \theta$$

and

$$\tan \theta = \frac{\sqrt{\frac{l^2}{\alpha'}}}{x'}$$

Thus,

$$ey = x \left( \frac{\sqrt{\frac{l^2}{\alpha'}}}{x'} \right)$$

(8)

As was noted earlier, the highest reported single-year bullet hit rate ($bhr$) among larger U.S. departments was Los Angeles Police Department's 39 percent. As Figure 2 showed, rates of 15 to 30 percent are much more common. Contemporary hit-based fatality rates generally are in the 20-39 percent range. Table 2 shows "observed accuracy" estimates for high, average, and low values of these parameters calculated using equation (5).

<table>
<thead>
<tr>
<th>High Value</th>
<th>Average Value</th>
<th>Low Value</th>
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<tbody>
<tr>
<td>Bullet Hit Rate ($bhr$)</td>
<td>39%</td>
<td>27%</td>
</tr>
<tr>
<td>Fatality Rate ($fr$)</td>
<td>39%</td>
<td>30%</td>
</tr>
<tr>
<td>Observed Accuracy ($\alpha'$)</td>
<td>15%</td>
<td>8%</td>
</tr>
</tbody>
</table>

### Analysis of Test Results

Using the observed accuracy estimates, we applied equation (8) to estimate the amount of wobble ($y'$) common in real-life combat
shooting situations using high, average, and low observed accuracy (α'). Because distance data were not available, Figure 6 presents the results of these calculations continuously from two to 15 meters—the range of distances within which most police gunfights occur (Fyfe, 1978). As this figure shows, it would appear that police often may shoot when their muzzles are misaligned by from 4 to 90mm (0.15 to 3.54 inches). These results are consistent with the model.

![Figure 6. Amount of variation from perfect sight alignment that occurs in actual police combat shootings as estimated from bullet hit rates and fatality rates.](image)

In spite of the conservativeness of our assumptions, it still is conceivable that these figures might underestimate police accuracy because fatalities were caused by more than one hit. We could not obtain enough information to estimate how often this might be the case. However, even if each fatality resulted from three bullet hits in the lethal zone (i.e., if 3 x Bullet Hit Rate x Fatality Rate = Observed Accuracy) there still would be substantial muzzle wobble. For example, using the average parameter values for bhr, fr, and α, it still would appear that muzzles were misaligned by from 3 to 32mm. These results also are well within the bounds predicted by our model.

**RECOMMENDATIONS FOR FUTURE RESEARCH**

**Data Collection**

Although the work reported here is far from conclusive, it strongly suggests the need for several kinds of additional research. More accurate and representative data regarding police shootings need to be gathered from law enforcement agencies. At a minimum, these data should include the type of shooting, distance, weapon used, amount of movement by officer and opponent, ambient lighting, topography, bullet placement, and bullet track. Much of this could be gleaned from official records.

The relationship between bullet hit rates and shots fired per incident also needs attention. Blumberg's (1983) research suggests that the two are positively correlated. From a policy standpoint, it is important to determine more clearly the direction and strength of this relationship as well as the relationship between shots fired per incident and the frequency with which bystanders are hit by police bullets.

**Limits of Accuracy**

Based on generally-accepted knowledge about how humans function, our results indicate that biological limits to combat shooting accuracy may be important. However, there still is a need to identify much more precisely what those limits are because they place a ceiling on performance. The effects of cognitive, perceptual, and environmental factors also are important and their relationship to combat shooting should be studied directly. Laboratory work by specialists in fields such as neurophysiology, biomechanics, robotics, industrial psychology, and sports medicine could identify the practical limits of combat shooting accuracy much more clearly.

**Training Validation**

There also is a pressing need to determine the validity of contemporary firearms training regimes, of which there are many different types. Although no department has what we would consider high levels of combat accuracy, there is a great deal of variation. We need to
determine the sources of this variation. Moreover, some types of training actually may degrade combat performance by teaching an inappropriate set of skills. For example, there is a great deal of debate within police training circles regarding sighted vs. unsighted shooting (i.e., whether or not shooters should use sights or "point shoot" in combat situations). There also are those who assert that either technique can be effective, depending upon circumstance. Debates such as these should be resolved by scientific inquiry.

The research described above would make it possible to empirically determine what kinds of shooting situations are most common, what skills those situations demand, and the reasonableness of those demands on human performance. Training then could be based on accurate information rather than supposition, tradition, and personal preference as now is generally the case. Identifying the limits of human performance associated with combat police shooting could help us avoid teaching unproductive—perhaps counterproductive—shooting techniques and increase returns on scarce training resources. This kind of knowledge also might help identify situations that officers should attempt to avoid and suggest novel tactics to improve the odds when they cannot.

Equipment Engineering

As long-time pistol shooters and former police officers, we both are personally fond of the handgun. Nonetheless, it may be time to examine anew its appropriateness as a police sidearm. The basic designs of Samuel Colt and John Browning for pistols date from 1836 and 1897 respectively (Johnson & Haven 1945:74-75 and 228-234), and these basic designs have been part of the institution of police work in the United States for over a century. Given the astounding changes in both police work and technology, however, it may be fruitful to critically reexamine this tool (see Peak, 1990). Is it possible to develop a weapon with superior stopping power, accuracy, and versatility? A weapon that is more difficult for assailants to take away from officers? A weapon that provides more options than 'talk' or 'shoot'?
REFERENCES


