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Shooting Dynamics: Elements of Time & Movement in Shooting Incidents

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Abstract

In the analysis and reconstruction of shooting incidents, a key element is often the timing involved in shooting, reacting, and moving. These data can be significant because they may be helpful in defining significant elements. These elements can include: how much movement or distance a person could have achieved before or during the shot sequence. Other determinations can relate to perception, reaction, and response before and during the shooting. This paper examines elements involved in shooting incidents including the performance of both shooter and target person.

Key Words: Forensic Science; Crime Scene Reconstruction

Introduction

In the analysis and reconstruction of shooting incidents, a key element is often the timing involved in shooting, reacting, and moving. These data can be significant because they may be helpful in defining significant elements within the incident. These elements can include how much movement or distance a person could have achieved before or during the shot sequence. Other determinations can relate to important psychophysiological factors including perception, reaction, and response before and during the shooting.

Within the literature, there is very little data on the ranges of typical, average, or expected rate of firing. Although there is much available data on the mechanical firing rates of automatic weapons, there is very little data on basic questions as "How fast could someone have shot," "How fast could the officer draw and fire?" "How could the person have been shot in the back?" or certainly, "Why were so many shots fired?" This paper addresses these questions.

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Primary Issues Examined:

1. Shooting performance baselines.
2. Time to draw a pistol from a holster and fire the first shot.
3. Time intervals between shots.
4. Time required to stop shooting.
5. Time required to move from standing erect to a prone/supine position.

Shooting Speed

This project measured and analyzed the performance of individuals with highly diverse levels of experience with firearms: (1) Professional shooting competitors, (2) a 26 year old woman who had never shot a gun, (3) highly experienced shooters, and (4) a group of "street" police officers of different ages and experience levels with an age distribution very close to what would be found in a group of U.S. law enforcement officers directly exposed to violent situations.[1] All were used to provide useable data on the time to draw from a holster and fire, the range of minimum (fastest) shooting intervals, "typical" or average rates of fire and on the time required to stop shooting.

The speed at which someone shoots a gun is, of course, highly variable and directly related to many factors. First, the basic factors are: An individual's motivation, skill, and very significantly, the size of the target – which is a function of the distance from the shooter to the target. At a fixed distance, a small target (such as a person's head) would require more aiming time than a large object (such as a truck). When the distance from shooter to target is increased, the required aiming time would also be increased. The amount of aiming time required varies greatly: What a highly skilled shooter can do in a fraction of second may require several seconds by a less skilled person.

Additional factors affecting performance include environmental elements such as lighting and weather conditions and the internal elements such as the level of stress along with mental state factors (surprise, confusion, fear, etc.). Since these factors cannot be accurately replicated for subsequent measurement of a shooter's performance, it is not possible to determine the actual shooting performance of any person during a particular incident. It is, however, possible to use available data to establish baselines upon which reasonable estimates can be made.

Real, life-threatening situations in which a police officer is motivated to fire multiple rapid shots will add an additional element: Mental and/or physical stress increases the rate and strength of heartbeat and can affect an individual's performance and perception. In this experiment, it was not possible to induce a comparable level of stress. This experimental limitation should be taken into consideration when applying the results of this project with real-life shooting incidents.

One known effect of low to moderate physiological arousal is an increase in performance.[2] This fact -- along with the author's (and other's[3]) many years of studying shooting dynamics – indicates that real-life shooting incidents will usually result in faster shooting times and rates of fire than seen in the experiments presented here. This means the lowest shooting rates of fire shown here can be regarded as conservative values when compared with real-life incidents.

Fastest Shooting: Competitive Shooters

The empirical data shown in this section represents the performance of some of the world's most skilled and experienced champion shooters. It provides a baseline to show what is human and mechanically possible.

A. Multiple Small Targets – Five Shots

Figure 1 - Speed Shooting Championship Event "Five To Go"

An example of how fast and accurately a highly skilled shooter can shoot a handgun is clearly demonstrated in a selected shooting event: the "Five To Go" which is part of a major competitive shooting match in southern California, USA: "The Steel Challenge." This particular event requires a shooter to draw from a holster and to shoot five steel targets. The shooter starts with a holstered handgun and his/her hands raised shoulder high. At the signal, the shooter draws and fires at all five targets. The last target struck stops the electronic timer. It is important to note that four of the targets are 10" (25.4cm) diameter round steel plates at 30 (9.1m) to 54 (16.5m) feet distance. The stop plate is 12" (30cm) diameter at 21 feet (6.4m).

The total time represents complex events: Perceiving and reacting to a signal, drawing a handgun from a holster; aligning the sights on the target; squeezing the trigger, and moving the point of aim to the next target and repeating the sequence for the next three targets. From a videotape of the 1990 event, the author utilized an acoustical timer to analyze the shooting intervals of some competitors. An analysis of the fastest shooter's (Rob Leatham) performance showed:

Total time = 2.55 seconds (for five well-aimed shots striking each target.)
Average interval between shots = 0.40 seconds
(including the first shot which required a draw from holster.)

Time from 1st to 5th shot (after the draw) = 1.6 seconds
Average interval (between shots) = 0.32 sec
Rate of Fire: 3.1 RPS (rounds per second)

A review of the most recent event (2008) demonstrated even faster times: Five shots on target in 2.38 seconds.

B. Single Large Target – Five Shots

Professional shooter Jerry Miculek set a world fast shooting record by firing 5 double-action shots from a .38 cal, Smith &Wesson Model 66 revolver (3" barrel) at a single 23" x 35" target at 5 yards distance. Miculek's time – starting at the first shot – was 0.57 seconds. All shots struck the target within an 8" diameter.

Total Time (1st to 5th Shot):	0.57 seconds
Average Interval:	0.11 seconds
Rate of Fire:	9.09 rounds per second (RPS)
Rounds Per Minute:	545 RPM

Miculek also set another world speed shooting record by firing 8 double-action shots from a Smith & Wesson Model 627, 38 cal revolver:

Total Time (1st to 8th Shot):	1.00 seconds
Average Interval:	0.125 seconds
Rate of Fire:	8.00 RPS (rounds per second)
Rounds Per Minute:	480 RPM

Experiment 1: Experienced & In-Experienced Shooters

The shooting speeds of different types of shooters were tested:

A. Inexperienced Shooter: A 26 year old woman who had never fired a firearm of any type was tested. Basic safety instructions were given along with minimal instruction regarding how to hold the firearm and how to operate the trigger. There was no shooting practice.

B. Experienced Shooter #1: 46 year old male with more than 20 years of military, law enforcement, and competitive shooting experience and training.

C. Experienced Shooter #2: 44 year old male with more than 20 years of law enforcement and competitive shooting experience.

Methodology

Procedure
Starting position was pistol raised and gripped with two hands. Shooter was told to start firing upon command and to continue to fire until empty (7 shots).

Setup
No target was utilized. Timing recorded by a PACT Mark II digital timer. Visual recording by SVHS camcorder.

Data Analysis
Shot intervals were recorded by electronic acoustic timer.

Results

Table 1. New Shooter: Never Shot Before								
C. C.								
Firearm: Glock 19								
Caliber: 9mm								
No. of Shots	7		7		7		7	
1	0.00		0.00		0.00		0.00	
2	0.38	0.38	0.34	0.34	0.34	0.34	0.32	0.32
3	0.77	0.39	0.66	0.32	0.66	0.32	0.62	0.30
4	1.15	0.38	0.97	0.31	0.99	0.33	0.91	0.29
5	1.57	0.42	1.28	0.31	1.34	0.35	1.21	0.30
6	2.01	0.44	1.59	0.31	1.67	0.33	1.50	0.29
7	2.47	0.46	1.91	0.32	2.00	0.33	1.81	0.31
Total Time First to Last Shot		2.47		1.91		2.00		1.81
Average Interval		0.41		0.32		0.33		0.30
Rounds Per Second (RPS)		**2.43**		**3.14**		**3.00**		**3.31**

Table 2. Experienced Shooter #1								
A.J.								
Firearm: Glock 19								
Caliber: 9mm								
No. of Shots	7		7		7		5	
1	0.00		0.00		0.00		0.00	
2	0.24	0.24	0.21	0.21	0.22	0.22	0.21	0.21
3	0.40	0.16	0.49	0.28	0.38	0.16	0.35	0.14
4	0.71	0.31	0.64	0.15	0.55	0.17	0.52	0.17
5	1.00	0.29	0.80	0.16	0.78	0.23	0.66	0.14
6	1.17	0.17	0.95	0.15	0.93	0.15		
7	1.33	0.16	1.11	0.16	1.08	0.15		
Total Time First to Last Shot		1.33		1.11		1.08		1.33
Average Interval		0.22		0.19		0.18		0.17
Rounds Per Second (RPS)		**4.51**		**5.41**		**5.56**		**6.06**

Table 3. Experienced Shooter #2

M. S.
Firearm: Ruger P89
Caliber: 9mm

No. of Shots	10		16	
1	0.00		0.00	
2	0.20	0.20	0.13	0.13
3	0.33	0.13	0.47	0.34
4	0.55	0.22	0.60	0.13
5	0.68	0.13	0.88	0.28
6	0.81	0.13	1.01	0.13
7	0.94	0.13	1.14	0.13
8	1.07	0.13	1.27	0.13
9	1.30	0.23	1.40	0.13
10	1.44	0.14	1.53	0.13
11			1.66	0.13
12			1.81	0.15
13			1.95	0.14
14			2.08	0.13
15			2.22	0.14
16			2.35	0.13
17			2.49	0.14
Total time: First to Last Shot		1.44		2.35
Average Interval		0.16		0.16
Rounds Per Second (RPS)		**6.25**		**6.43**

Note the six consecutive shots (marked in gray above). These are fired at 7.69 rounds per second (RPS).

Shooting Rate Summary Findings

- There is great variation in the shooting rate of different individuals. The fastest known shooting rates (usually by professional shooters) can be regarded as benchmark rates of fire (minimums) unlikely to be exceeded even by law enforcement and other experienced shooters.
- The average rate of fire for the tested police officers was 4.26 rounds per second.
- The range of shooting speed was from 2.43 rounds per second for a new shooter firing a pistol for the first time to an experienced shooter's very high rate of 7.76 rounds per second.

- A person with little or no training can fire a pistol at rate of more than two to three rounds per second.
- Trained shooters such as police officers can fire from 2 to 5 shots per second.
- Highly experienced shooters can fire 16 rounds in approximately two seconds: 8 rounds per second or 480 rounds per minute (RPM.) This rate of fire is equal or close to the cyclic rate of some fully automatic weapons (M3 Submachine gun fires at 450 RPM; The AK47 Assault Rifle at 600 RPM).

Experiment 2: Police Officers: Time to Draw & Fire, Shooting Speed

The goal of this experiment was to determine the minimum, maximum, and average time required for a group of police officers to draw their handgun from a holster and fire one shot.

Figure 2 - Police Officer Fires During Time Tests

Methodology

Equipment

Officers used their duty weapons and a variety of leather gear (belt & holster) models. All firearms were semi-automatic pistols: Sig Sauer P226 & P220, Glock Models 17, 19, 22, 23, Colt 1911, Springfield XD40. The ammunition was factory produced, department issued in 9mm, .40 S&W, .45 ACP calibers.

Setup

Full size “Hostile Man” target was used. Distance from shooter’s foot location to target was 5 feet (1.5m). Start signal and shooting time was generated and recorded by a Competitive Edge Dynamics Model CED6800 acoustic shooting timer. Target stand had two 100 watt spotlights pointing at the shooter.

Each participant was also videotaped using a digital camcorder.

Procedure

Participants started with their hands at their sides. They drew their weapon from their holsters. The only instruction given was to “*Start shooting at the buzzer. Shoot as fast as you can. Stop shooting when the lights come on*.” The electronic shooting timer provided a random interval start signal.

Data Analysis

The timing of the shots was detected and displayed by the electronic timer and recorded for each shooter. The videotape of each shooter was digitized into a computer and analyzed frame by frame to determine the number of “excess shots”: the shots fired after the stop lights were activated.

Results

Table 4. POLICE OFFICERS			
Data Set		**Age**	
Number of Tests	36	Youngest	23
Number of Police Officers	32	Oldest	56
Total Shots Fired	296	Average Age	37
		Median Age	33
Experience		**Gender**	
Average Years Exp	10.9	Male	30
Median Exp	10.0	Female	2
Lowest Years Exp	<1		
Highest Years Exp	25		
Rate of Fire			
The firing rate is shown in Rounds Per Second (RPS). These values represent a total of the entire shooting sequence. The number of shots fired varied from 4 to 13. Note that there were two and three round shot sequences with higher rates of fire: One 3 shot sequence = 6.25 RPS; One 2 shot sequence = 6.67 RPS			
Highest RPS	5.68		
Lowest RPS	3.04		
Avg RPS	4.44	Standard Deviation	1.54
Shot Interval			
This is the time between shots, the time required to release and press the trigger. This data set does not include the first shot (from holster).			
Shortest	0.11		
Longest	0.51		
Avg Interval	0.23	Standard Deviation	0.04
First Shot			
The first shot time represents drawing the pistol from the holster and firing. A holster can make a significant difference in the time required for a first shot: snaps and straps add time and manual operation to the task.			
Fastest 1st Shot	0.88		
Slowest 1st Shot	2.93		
Average 1st Shot	1.52	Standard Deviation	0.45

Summary Findings

Draw From Holster

- The average time required for police officers to draw from a holster and fire one round was 1.5 seconds. (Most holsters had snaps or straps which were engaged.)
- The average shooting rate was 4.44 rounds per second

Experiment 3: Police Officers: Time Required to Stop Shooting

Most people have experienced instances in which they decided to inhibit or stop an action but were unable to do so. Clicking a computer mouse just after you noted that the dialog window closed or tossing an object (like a pen or candy bar) at someone just after you noted that their head turned away and would not see it coming. You know you shouldn't do it, but you can't stop your action.

There are psychophysiological mechanisms which limit the time in which a human action (motor program), once begun, can be stopped. This experiment was designed to test both the perception and the stop reaction time of a group of police officers.

Methodology
(Same personnel & equipment as in Experiment 2)

Equipment

Officers used their duty weapons and leather gear (belt & holster). All firearms were semi-automatic pistols: Sig Sauer P226 & P220, Glock Models 17, 19, 22, 23, Colt 1911, Springfield XD40. The ammunition was factory produced, department issued in 9mm, .40 S&W, .45 ACP calibers.

Setup

Full size "Hostile Man" target was used. Distance from shooter to target was 5 feet (1.5m). Start signal and shooting time was generated and recorded by a Competitive Edge Dynamics Model CED6800 acoustic shooting timer. Target stand had two 100 watt spotlights pointing at the shooter.

Each participant was also videotaped using a digital camcorder.

Procedure

Participants started with their hands at their sides. They drew their weapon from their holsters. The only instruction given was to "*Start shooting at the buzzer*. *Shoot as fast as you can. Stop shooting when the lights come on*." The electronic shooting timer provided a random interval start signal. The stop lights also activated on a random interval – after a minimum of four shots.

Data Analysis

The video footage was digitized and analyzed on a computer. Total shots were noted. Shots fired after stop lights were activated were noted as "extra shots."

Results

Table 5. POLICE OFFICERS

Data Set		**Age**	
Number of Tests	36	Youngest	23
Number of Police Officers	32	Oldest	56
Total Shots Fired	296	Average Age	37
		Median Age	33
Experience		**Gender**	
Average Years Exp	10.9	Male	30
Median Exp	10.0	Female	2
Lowest Years Exp	<1		
Highest Years Exp	25		

Number of Shooters Firing Extra Shots	25
Percentage of Shooters Firing 0 Extra Shots	31%
Percentage of Shooters Firing 1 Extra Shots	44%
Percentage of Shooters Firing 2 Extra Shots	17%
Percentage of Shooters Firing 3 Extra Shots	8%
Maximum Extra Shots Fired	3
Average Extra Shots Fired	1.1
Percentage of Shooters Firing Extra Shots	**69%**

Summary Findings

- Most police officers were unable to immediately stop shooting at the stop signal: 69% of officers fired at least one "extra" shot. The stress involved in a real shooting situation would likely increase the number of "extra" shots.

Discussion

At a random interval after the shooter has started, the lights came on as a visual signal to stop firing. Most shooters reacted as quickly as they could but still fired one more shot because the brain-to-trigger finger impulse was "in motion". This is known as the stop signal reaction time (SSRT) which reflects the time required to internally suppress an ongoing response. Other factors known to affect shooting performance are:

- Perceptual narrowing ("tunnel vision"): by intensely focusing upon their sights and/or target, the stop lights were not within their area of visual attention.

- P300 Latency: Psychophysiology research establishes that the brain requires approximately three tenths (0.3) of a second for stimulus evaluation (recognition of the stop signal).[4]

- The "Slater-Hammel" experiment which established that the minimum time required to inhibit (cancel) an anticipated action (like firing the next shot) was approximately 0.16 seconds.[5]

All of the above factors can contribute to a shooters inability to stop shooting immediately.

It is important to compare and note the different effects on performance between the conditions facing a shooter in this safe and relatively stress-free situation with an urgent, life-threatening, and highly stress inducing situation as would be found in a real-life shooting incident. The shooters in the test only had one, clearly defined stimulus to stop firing: the light signals. Once they perceived that the lights were on, their choice was simple: To continue shooting or to stop shooting.

A shooter in a genuine shooting incident will include both a higher level of physiological arousal (stress) and additional choices (Should I take cover? Is the target person no longer a threat? Should I look around for other threats? Are there others who may be exposed to my gunfire?, etc) Human performance research has determined[6] that as the number of choice alternatives increases, reaction time (including perception, decision, and action) will increase. The elevated arousal and multiple alternatives effect will likely cause the shooter to fire additional "extra" shots – more than was measured in this test study. An earlier experiment by Lewinski and

Hudson[7] produced similar results and found that the less "motivated" a shooter was to shoot, the quicker he was able to stop shooting.

Experiment 4: Time to Fall

The goal of this experiment was to measure the amount of time required for a person to fall to the ground from a standing position.

Most law enforcement shooting doctrines governing the use of deadly force utilize the concept of continuing to shoot until the threat has ceased. During a shooting incident involving a standing, armed person, the most commonly understood and accepted indication that the person is no longer a threat is when that person either releases the gun from his hand(s) and/or drops to the ground.

There have been cases known to this author in which questions were raised regarding the necessity for the number of shots fired at an armed person. In several incidents, the person being shot did fall to the ground from a standing position and received multiple shots. The movement from standing to prone/supine could be done either because of physiological incapacitation or simply as a defensive reaction or a tactical maneuver (to reduce one's target size.)

Going to Ground Movements:

There are two basic methods of falling to the ground:

1. The Rapid Collapse: An immediate drop/fall (sometimes referred to as "dropping like a sack of potatoes") preceded by the loss of skeletal muscle control. The rapid collapse is usually associated with a significant disruption of the central nervous system or sudden loss of consciousness (also known as: fainting, "blacking out," or syncope.)[8]

2. The "Crumple" – A relatively slow change of posture often characterized by a flexing of the knee joints (also known as "buckling at the knees") until the knees make contact with the ground with the torso subsequently falling forward or down until the body is essentially flat on the ground. The crumple can be the result of either a slow loss of consciousness and/or skeletal muscle control or a conscious decision to go to ground.

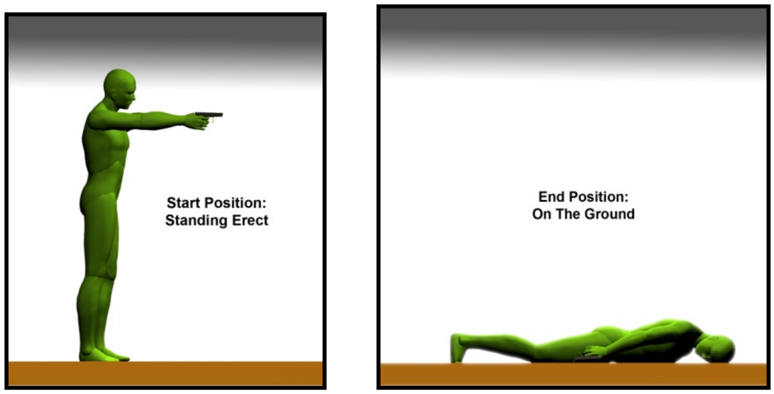

Figure 3 - Start position was standing while pointing;
End position was either face down or face up
(Graphic by author)

Methodology

Rapid Collapse:

Since it is not possible to induce sudden loss of consciousness in human test subjects, 6 test volunteers performed a series of "falls/drops" based upon the instruction to "get on the ground as quickly as possible." The subject started from an erect position.

Crumple:

Test of human subjects while crumpling to the ground revealed an inherent problem: An almost infinite variability in the time to complete the movement. There is no upper time limit for a crumple: The movement can be accomplished in a slightly longer time than a rapid collapse but a person could also conceivably crumple for 30 seconds, 1 minute, 5 minutes, etc. For this reason, the crumple movement was not used in this study.

Procedure

Five test subjects (4 men, 1 woman) stood erect with hands out in front (as if holding a gun). Upon a verbal command, the subject would be free to drop to a padded mat as quickly as possible. A digital video camera was used to record the movements.

Data Analysis

The video footage was digitized and analyzed on a computer. Visual analysis of video footage of the rapid collapse test began timing at the first detectable motion initiating the movement of the body to the ground. Timing ended when the upper torso was horizontal to the ground and in contact with the mat.

Results

Number of Tests: 35
Average time for a fall to the ground from an erect position: 1.1 seconds
Standard Deviation: 0.03

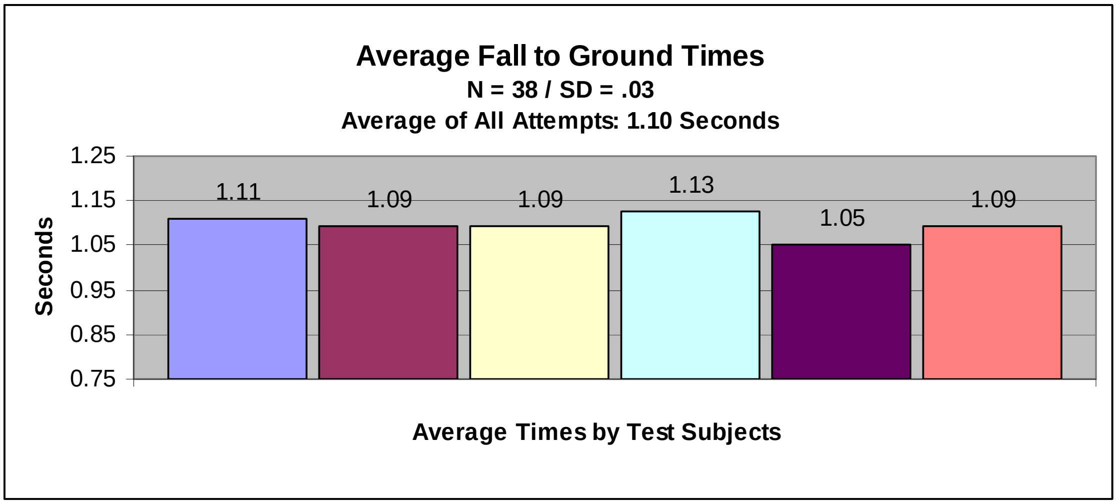

Table 6.

Discussion

The 1.1 seconds noted in this study was for persons falling directly to the ground. A crumpling fall will take longer time. The author did note that with tests where the person fell first to the knees before going directly to the ground (not included in the above data results), the time from erect to horizontal was longer: approximately 0.3 seconds additional.

The difference in time between the test falls to the ground conducted in this study and a genuine rapid collapse is not known. However, when the data in this study is considered with the fact that 0.61 seconds is the minimum time (based on the gravity acceleration rate) that an object will contact the ground when released from a height of six feet (1.83m), it appears reasonable to conclude that a human body – with the joint linkages and resistance will fall at a slower rate than a free falling object.

A crumple – as discussed above – is so inherently variable that no time quantification can be made. It will, however, certainly take longer than a rapid collapse or simulated fall.

Shots Fired at a Falling Person

The falling movement -- whether a rapid collapse or a crumple resulting from incapacitating wounds -- cannot be distinguished from a deliberate tactical maneuver of someone who has decided to go to ground to avoid being shot or to assume a less exposed position while returning or preparing to return gunfire. Falling to the ground itself cannot be a reliable indicator that a threat is no longer active. Even a mortally wounded person can fall to the ground and fire one or more shots before becoming incapacitated and/or unconscious.

The tests showed an average time of 1.1 seconds to fall to ground. During this time, 4 shots could be fired by an "average" police officer. A crumple fall will take more time and could result in several more shots fired during the movement. Additional shots could also be fired until the shooter perceives that the person is no longer a threat and is able to interrupt his shooting sequence.

While a person is considered a threat, the total number of shots fired at a person standing then going to the ground could reasonably be a minimum of 6 shots: 1 or more before the standing person begins to fall; 4 shots during the fall; 1 or more as the body contacts the floor during the P300 latency period: The time required for the brain to recognize and process the new visual information (that the threat has ceased). For these reasons and the physiological factors described in the discussion section of Experiment 3, it is likely that in a shooting incident additional shots may be fired at a falling person.

In situations with more than one shooter firing, the total number of reasonable shots could be 6 x Number of Shooters; i.e., if three officers were firing simultaneously, then 18 shots (6 x 3) would be expected. Four officers firing: 24 (6 x 4). Five officers firing: 30 (6 x 5), etc.

Additional Points

- There is no significant momentum or "push" from a bullet strike. The total amount of "knockdown power" of a bullet is always slightly less than the recoil of the gun firing the bullet. If a bullet had the force required to knock a person down, it would also knock down the shooter. This means that there would be no significant visual or motion effect of a bullet striking a standing or falling person. It may not be possible for the shooter to know if his shots have actually struck the target person.

- It is also important to note that unlike the shootings seen in dramatic films and TV shows, it is most often not possible to visually determine if a shot has actually struck a target person. Bullet entry holes do not project large amounts of blood and the defect in the skin -- always smaller than the bullet diameter – may not be visible at all if the shot was fired through clothing, particularly loose or layered clothing.

- Shots fired from a position in front of the target person during a fall to ground may expose posterior areas of the person's body to bullet strikes. These gunshot wounds will be described in an autopsy report as "back to front" or "entry in posterior" – and may be described by others as "shots in the back."

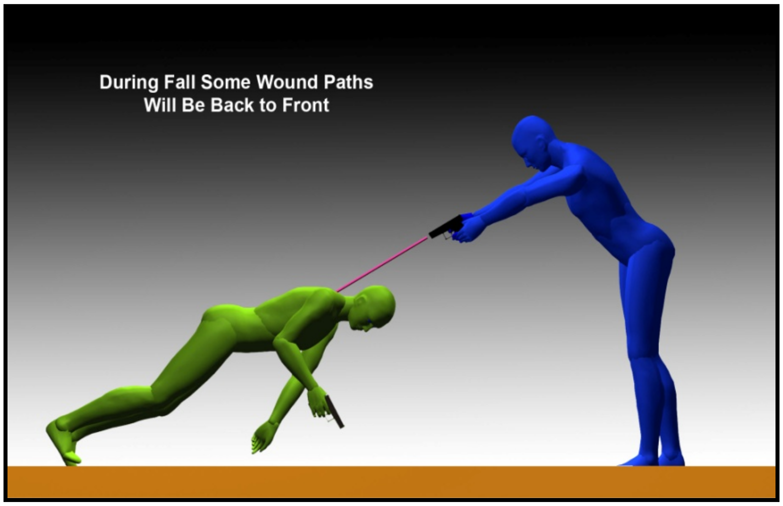

Figure 4 - Wound Paths While Falling Forward May Strike Back (Graphic by author)

Summary Discussion

A central element in any analysis of a shooting incident is the realization that all shootings involve time and motion: From visual perceptions, decision process, neural transmission, to muscle movement during the "squeeze" of the trigger, bullet travel, and gross movements of shooter and victim. Along with this understanding, the analysis and reconstruction of shooting incidents often requires an understanding of several forensic and human performance components including wound ballistics, psychoneurological factors, bullet flight dynamics, gunshot residue characteristics, firearms operation and other associated areas of knowledge such as bloodspatter interpretation. The integration of the data from these areas can be extremely useful in any forensic examination of a shooting incident – particularly when multiple shots are involved.

The research discussed in this paper is results from the author's forensic analyses and reconstruction of shooting incidents performed for criminal and civil litigation. Many of the findings presented here have been used during court testimony and found to be relevant to the understanding of significant issues relating to the position, orientation, and location of persons involved in shooting incidents

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