Performance Evaluation of Chemical Agent Delivery Systems

Charlie Mesloh, PhD, Associate Professor, Weapons and Equipment Research Institute
Komaal Collie, MS, Project Manager, Weapons and Equipment Research Institute
Laura Gibson, MS, Graduate Researcher, Weapons and Equipment Research Institute
Joann Werbalis, BS, Research Assistant, Weapons and Equipment Research Institute
Jacob Grimes, BS, Research Assistant, Weapons and Equipment Research Institute

Introduction

In a recent civil court case, a law enforcement agency was criticized for not deploying pepper spray against an armed offender prior to using deadly force. The suspect, armed with a hammer, pursued the officer through a residential neighborhood. The officer drew his weapon and attempted to disengage by returning to the patrol vehicle. After a pursuit that lasted over one and a half minutes, the suspect managed to block the officer's path to the vehicle and closed to a distance of six feet. With the hammer raised, the suspect lunged forward and the officer fired a single round. Although striking the suspect in the chest, the suspect survived to file a civil suit based partially on the fact that the officer was equipped with pepper spray and failed to deploy it prior to the use of deadly force. The issue of reactionary (nondominant) hand use of pepper spray was critical to this suit as the officer's dominant hand contained a firearm. This concept had not been explored as pepper spray training does not include reactionary hand use of the products. As with most product-based training, agencies tend to mandate that their personnel utilize their tools in accordance with the approved techniques taught in training. The end result was that officers did not train with nor deploy chemical agents with the reactionary hand. Consequently, there were no case studies or data to disprove that an officer shouldn't be able to hold a suspect at gun point and accurately deploy a chemical agent with the reactionary hand. This disturbing trend suggests that unrealistic expectations continue to be attached to even the most basic of law enforcement technology. Furthermore, officers may be placing themselves at risk due to the dearth of research regarding the performance of pepper spray. This study examines the physical properties of nine pepper sprays, quantifies the operational limits, and determines the feasibility of reactionary hand use.

Literature Review

Historical

The use of chemical agents can be found throughout history. In 178 AD, a peasant revolt in China was quelled through the use of lime dust, a severe irritant, which was used to create an early form of tear gas (Mayor, 2003). Quicklime projectiles

were used to create clouds that both suffocated and blinded enemies throughout the Byzantine war in 941 AD (Partington, 1999).

Noxious smoke from poisonous plants was also propelled from a smoke device to repel attempts of the Roman invaders to tunnel under the city of Ambracia's walls (Mayor, 2003). Leonardo Da Vinci later created a similar poison smoke machine in the late 1400s (Partington, 1999). Ancient Chinese writings contain literally hundreds of recipes for creating chemical agents that were able to disable or even kill enemy troops (Mayor, 2003). The earliest form of pepper spray appeared in the 16th and 17th centuries by means of the Caribbean and Brazilian Indians who burned hot pepper seeds to create an irritant cloud against Spanish conquistadors (Mayor, 2003).

CN (Chloroacetophenone) is a lacrimal gas that causes profuse, uncontrollable tearing; shallow labored breathing; tightness of the chest; and severe skin irritation (Edwards, Granfield, & Onnen, 1997). A CN agent is commercially known as Mace, one of the first American companies to market CN in its aerosol form (Dobrowolski & Moore, 2005).

CS (Chlorobenzylidene malononitrile) was named after Corson and Stoughton who first synthesized the compound in 1928 (Tyler & King, 2000). The lower toxicity along with its fast-acting results helped CS's acceptance in many agencies. In fact, the U.S National Guard transitioned from CN to CS for riot control as early as 1960, with many law enforcement agencies following suit shortly thereafter (Edwards et al., 1997).

OC Spray

In the law enforcement community, CN and CS were eventually replaced by oleoresin capsicum or OC. Commonly known as pepper spray, OC is a naturally occurring inflammatory agent derived from cayenne peppers (Lumb & Friday, 1997). Contact with the OC in pepper spray causes blephrospasm (involuntary tight closure of the eyelids) attributed to the dilating of capillaries, copious amounts of nasal/sinus drainage, gagging, coughing, and shortness of breathe (Das, Chohan, Snibson, & Taylor, 2007; Lumb, 1997; Zollman, Brag, & Harrison, 2000). These reactions allow OC to be effective even when dealing with the mentally ill, highly intoxicated, and very agitated suspects, unlike its predecessors.

Delivery Systems

Commercially available chemical agents utilize various types of carriers in order to deliver the payload a greater distance. Carriers used to deliver the OC can come in stream, fog, foam, and gel form. Each type has a specific issue that it attempts to address (i.e., single target, large groups, or greater accuracy and distance). The facial area is the primary target for all of these delivery systems.

The stream delivery system is a concentrated method which allows for a solid stream of spray to be administered to the target. The foam delivery system uses a sticky foam solution with consistency similar to shaving cream. Once deployed, the foam will stick to the subject causing the solution to be immediately absorbed. Foam has minimum blowback risk and breaks down within minutes, resulting in

a nonstaining residue that is easy to clean up and is nonvaporizing. Gel pepper spray sticks to the subject and penetrates their pores. Blowback is minimal to nonexistent.

Effectiveness

Under ideal conditions, the hope for OC spray is to cause a reduction in aggressive behavior and officer/suspect injuries by incapacitating the suspect (Morabito & Doerner, 1997). When OC spray first hit the market, there was much enthusiasm, which was eventually linked to exaggerated claims about its effectiveness (Morabito & Doerner, 1997).

When compared with impact weapons, as a less-lethal force alternative, OC spray was found to be as effective in stopping subject resistance, with the added benefit that the majority of suspects sprayed did not require medical treatment (Rogers & Johnson, 2000). OC was one of the cutting-edge less-than-lethal weapons of its time as it incapacitated suspects by "causing the eyes to tear and swell shut, mucus to drain profusely from the nasal passages, bronchial passages to constrict, and breathing [to] become more labored" (Morabito & Doerner, 1997, p. 681). Prior literature suggests that many law enforcement agencies believe pepper spray to be the "magic bullet" to reduce officer and suspect injury as well as citizen complaints (Kaminski, Edwards, & Johnson, 1998; Rogers & Johnson, 2000).

A study conducted in Baltimore for the National Institute of Justice found that out of 194 incidents involving pepper spray, 90% of the suspects were incapacitated enough to be arrested effectively (Greinsky, Martin, & Holland, 2000). This study was evaluated through a dichotomous variable of effective or noneffective (Kaminski et al., 1999). While reviewing the Baltimore Police report on pepper spray, it was noted that there were significant variations in human responses that could not fully be explained by just using a dichotomous variable (Kaminski et al., 1999). When New York City conducted their own survey of officers, it was found that officers rated the pepper spray at 85% effective (Greinsky et al., 2000). More recent studies indicated that effectiveness was between 68 and 72% (Mesloh, Henych, & Wolf, 2008).

Differences in effectiveness are likely the result of the difficulty quantifying a "successful" deployment as pepper spray formulations differ greatly. Initially, the strength of the spray was believed to be related to the heat rating, the quality of the source peppers, and the percentage of OC in the formulation. The Scoville Heat Rating, created in 1912, assigns a value to each pepper. Pure capsaicin has a rating of 15 million, while pepper spray has an average rating of 5.3 million. Most OC sprays identify their specific heat rating for consumer comparison. Recovery time after exposure is believed to be based on the percentage of capsicum in the formulation. A 15% solution may require one and a half to two hours to recover, while 2% may require only 15 to 30 minutes. Thus, suspects are forced to endure burning pain for a shorter period of time. An added benefit of lower solutions comes in the fact that the solution can penetrate mucus membranes and the skin's pores much easier, which leads to faster more immediate results. More recently, emphasis has been placed on the percentage of capsaicinoids as they are considered the active ingredient.

Methodology

A series of research trials were conducted to evaluate the physical performance of nine OC products currently used by law enforcement. The goal was to define operational limits and quantify performance factors previously untouched in the extant literature. These factors fell into two primary groups: (1) product and (2) human. Product-related factors include maximum range, number of uses per canister, and the cost of deployment. Human-related factors focus upon the ability for test subjects to accurately strike a target with an inert stream of chemical agent.

Nine chemical agents were tested under controlled conditions utilizing a standardized protocol. All of the chemical agents were law enforcement products and designed to be carried on an officer's duty belt. Each product was test fired from a fixed position at predetermined distances beginning at six feet and extending outward to 21 feet in three-foot increments. One-half second deployments were utilized to prevent inadvertent aim correction. Photographs and measurements were taken after each shot.

Twenty-one volunteer test subjects agreed to participate in the human factors study. Each participant fired an inert liquid (non-irritant) from a standard chemical agent dispenser. The inert liquid was fired at a standardized target from a distance of eight feet (see Figure 1). Accuracy was measured as hit/miss and difference from central point of aim to point of impact of the spray. The primary goal was to examine the differences in accuracy between the dominant and nondominant firing hands. Hand dominance is an important variable when applied to accuracy with weapons. Dominant hand activities were shown to be less laborious on the cerebellum, which may be important when an officer is forced to make a split second decision (Jancke, Specht, Mirzazade, & Peters, 1999). There is also a crucial union between the visual system and nervous system that controls goal-directed movement (Horstmann & Hoffman, 2005). Each volunteer fired a total of ten shots (five with each hand), while research assistants collected measurement, photo, and video data.

Findings

Each brand's statistics (e.g., size, type, and cost) was combined with the physical performance data of the nine pepper sprays (see Table 1).The sample of pepper sprays included seven streams, one foam, and one gel.

Sizes varied and included five MK-3s, three MK-4s, and one MK-5. Each canister was fired in one-half second bursts until its reservoir was empty. Not surprisingly, there were substantial differences between products as performance ranged from 12 to 61 shots (M = 28.6; SD = 15.2). Utilizing this data and the cost for each product, it was then possible to formulate a cost per shot (CPS) value for each brand. The number of uses per canister depends upon the duration of each spray. Firing at a suspect at greater distances consumes a greater portion of the canister.

Table 1. Description and Performance of Pepper Sprays

Brand	Size	Type	Liquid (oz)	Cost[1]	Shots	CPS[2]	15′ Drop	18′ Drop	21′ Drop	Max. Range
1	MK-4	Stream	3.0	19.99	33	0.61	0.0	17.0	nd	16′ 2″
2	MK-3	Stream	1.5	15.99	12	1.33	0.0	18.0	nd	15′ 2″
3	MK-4	Stream	3.1	12.99	61	0.22	0.0	17.0	nd	13′ 8″
4	MK 3	Stream	1.5	11.99	28	0.43	0.0	34.0	nd	13′ 8″
5	MK-3	Foam	2.4	19.99	33	0.61	25.5	nd	nd	9′ 2″
6	MK-3	Stream	1.8	14.99	13	1.15	0.0	22.0	43.0	15′ 2″
7	MK-4	Stream	3.3	16.99	24	0.71	0.0	13.0	51.0	17′ 2″
8	MK-5	Stream	4.0	20.99	37	0.57	0.0	14.0	43.0	13′ 8″
9	MK-3	Gel	1.6	16.99	16	1.06	0.0	12.5	27.5	16′ 8″

[1] Cost in dollars

[2] Cost per shot in dollars

nd = no data

Secondary testing of the pepper spray examined the linear drop of each brand as the distance between the target and canister increased. Of the nine products tested, only the foam-based product produced a substantial deviation in trajectory at 15 feet (25.5″ drop). However, this changed dramatically at 18 feet where the linear drop ranged from 12.5 to 34.0 inches (M = 18.4; SD = 7.0). At 18 feet, the foam-based product was unable to reach even the bottom of the target. This trend continues at 21 feet where five of the nine brands were unable to reach the target. The remaining four products' drop was substantial (27.5 to 51.0″) and would be unlikely to deliver a sufficient amount of chemical agent to the suspect to induce incapacitation.

As a result of these findings, the maximum effective range was identified for each product. These ranges varied considerably (M = 14.6; SD = 2.5) and appear to be uncorrelated to canister size. Foam was identified as having the least reach (9′2″) while gel was able to score near the top of the maximum range scale (16′8″). The highest maximum range score was obtained from a MK-4 stream (17′2″).

The human subjects test group was made up of 13 men and eight women. Seventeen reported being right handed, while only four were left handed. The median age was 22 years (M = 23.8; SD = 5.4). A *t*-test indicated that no statistically significant differences existed between the genders which allowed the groups to be aggregated. The distribution of scores varied greatly between the dominant (M = 4.57; SD = 0.51) and nondominant hands (M = 3.52; SD = 1.03), although both groups were negatively skewed. The dominant hand scores were limited to the upper end of the scale, while the nondominant hand scores were in a somewhat normal distribution across the entire scale. Interestingly, perfect scores occurred 57% of the time for dominant hands and only 19% of the time for nondominant hands (see Table 2). It was also noted that the most common type of miss with the nondominant hand was high. In fact, more than 50% of the misses that occurred with the nondominant hand were above the target. This trend is illustrated below in Figure 2.

Table 2. Comparison of Hand Score Accuracy

	Dominant		Nondominant	
Score	Frequency	Percent	Frequency	Percent
1	0	0.0	1	4.8
2	0	0.0	1	4.8
3	0	0.0	9	42.9
4	9	42.9	6	28.6
5	12	57.1	4	19.0

Figure 1. Dominant Hand Firing

Figure 2. Nondominant Hand Firing

Conclusions

This type of testing was not without difficulty. Contamination of the test area by the chemical agents necessitated the use of respirators and protective garments. These precautions only reduced the level of exposure to research personnel as a fine mist was frequently created by the pepper spray as the stream separated into smaller and smaller droplets. This drop and spray effect has been noted in prior scientific literature (Lin & Rietz, 1998) and most recently applied to the liquid dynamics of pepper spray (see Fatah, Presser, & White, 2007). This pepper spray mist is the most common cause of cross-contamination of law enforcement officers and provides significant challenges in deployment. Photographic records of testing indicated that as the stream of pepper spray left the nozzle, it began to break up into large uniform drops consistent with the Rayleigh type breakup (a core theory of jet dynamics). As these droplets travel further and further from the source, they continue to break apart and eventually atomize into a mist. As a result, missing the target is not without consequence. After passing the target, the stream will

continue on and break into an unpredictable mist that may not be easily visible to the eye (see Figure 3). Law enforcement officers may unintentionally stray into this cloud and become incapacitated.

Figure 3. Mist Created from Pepper Spray

Testing the physical parameters of the different pepper sprays suggests that there are substantial differences between similar products. These differences are quantifiable in the maximum range, number of shots, and cost. Maximum range, utilized as a dependent variable in this analysis, provided the greatest linear distance that each product could be deployed. However, it was always possible to extend this range by elevating the canister nozzle. This was eliminated from testing as it was found that blowback risk increased dramatically and appeared to hasten the development of a pepper spray mist.

Initially, it was hoped that a cost/benefit ratio could be produced that could aid in the procurement of chemical agents. While it is possible to some degree to create this model, the number of unquantifiable factors (such as effectiveness and delay of onset for each product) significantly degrades its utility. Additionally, there are some factors such as the reduction of blowback risk that completely elude quantification. Pepper foam substantially reduces the risk of blowback but has a corresponding reduction in maximum range and requires the user to be much closer to a combative suspect. Pepper gel appears to reduce blowback while maintaining a high maximum range, but to date, no known studies have been conducted on its effectiveness. As a result, many of these test results produced more questions than answers.

It was assumed that a product that contained sufficient propellant for a larger number of shots would also lead to larger maximum ranges. However, there was no correlation between the number of possible shots and the range of the chemical agent. MK-3 canisters, representing the smallest duty belt carried pepper sprays, contained a smaller amount of liquid, which frequently translated into a smaller number of shots and, thus, a higher cost per use. Canisters, despite their size markings (e.g., MK-3, MK-4, MK-5), did not conform to a uniform amount of

liquid content. Additionally, the size of canisters and amount of liquid contents were not a consistent indicator of performance. Three different size canisters had identical maximum ranges, with some MK-3s outperforming MK-4s and some MK-4s outperforming the MK-5.

The human subjects testing provided considerably more insight. Dominant hand performance was clearly more accurate than nondominant hand. However, the distribution of scores is even more meaningful. With the dominant hand, none of the test subjects scored below 80%. Conversely, over half of the nondominant hand scores fell below the eighty percentile. This dichotomy in performance suggests that nondominant hand use of pepper spray is not appropriate in even low-level confrontations due to the substantial risk of blowback contamination. This risk in a deadly force confrontation is completely unacceptable given that the margin for error is so small.

The vast majority of research focuses upon the officer-suspect factors in the analysis of use of force encounters. However, the officer-product factors may be able to explain significantly more of the variance in the successful deployment of law enforcement technology. Each law enforcement tool has distinct strengths, weaknesses, and operational limits. This was especially true with the products examined in this study. Some products were able to reach considerable distances but created substantial contamination issues as their streams began atomizing within feet of the user. Other products were able to combat this problem but at the cost of reduced range. Unfortunately, there is no regulating agency for the vast majority of law enforcement products, and agencies frequently rely on data provided by manufacturers that may be skewed to their benefit. Consequently, agency testing and evaluation prior to procurement becomes critical to the success of later field deployments.

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Charles Mesloh, PhD, is associate professor and director of the Weapons and Equipment Research Institute at Florida Gulf Coast University. He has over 12 years of experience as a law enforcement officer and holds instructor certifications in impact weapons, chemical agents, compressed air weapons, and police canines. His areas of research include law enforcement training, canine utilization, forfeiture, and use of force. He has numerous publications in areas ranging from police canines to use of force and issues in corrections.