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# Use of pepper spray in policing: retrospective study of situational characteristics and implications for violent situations

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## Abstract

Pepper spray (OC) is a policing tool aimed to prevent or stop aggressive behavior by quickly and temporarily incapacitate without injuring. To date, few studies have investigated OC's operational usefulness and limitations. OC reduced violent behavior in 93% of the 936 incidents investigated. However, the operative range was often <2 m and it took between 3 and 5 s of spraying before obtaining effect, partly owing to the difficulties of hitting a small, sometimes erratically moving target. Collateral hits were noted in 24% of the incidents, whereof 90% were other officers. Noteworthy, in 21% of incidents officers put themselves at large personal risk by using OC at close range against people armed with lethal weapons. Hence, OC emerges as a suitable tool for handling low threat situations but lacks key traits to ensure safe and efficient policing of high threat situations, e.g., handling armed assailants.

## Keywords

Oleoresin capsicum; pepper spray; policing; efficiency ratio; psychomotor effects

## Introduction

A major problem for most police forces across the world is the challenge to incapacitate violent assailants without causing unnecessary harm, while minimizing personal risk. One approach has been to develop less-lethal and non-lethal weapons, such as pepper spray, aimed at having a momentary physical incapacitating effect without causing long-term injuries. Pepper spray, also known as OC spray (from the effective agent 'Oleoresin Capsicum') is a lachrymatory agent that affects the eyes and causes tears, pain, and temporary blindness (Busker & van Helden, 1998). The major pathophysiology is neurogenic inflammation caused by capsaicinoid in the pepper spray and there is no antidote for oleoresin capsicum (Yeung & Tang, 2015). The spray causes an immediate closing of the eyes through activation of nociceptors and thermoceptors triggering pain and burning heat, and aggravates the airways causing difficulty breathing, a runny nose and coughing. The duration of these effects depends to some extent on the strength and concentration of the spray and the type of carrier as oil, foam and gel commonly prolong irritation. Other effective irritants used in other countries are Chloroacetophenone (CN), commonly known as Mace®, and tear gas (CS). CS is more effective and less toxic than CN (Warden, 2005), whereas OC causes a stronger initial effect but shorter lasting than CS (Karagama, Newton, & Newbegin, 2003). On average, the full effect of OC lasts about thirty to forty-five minutes, but the residual effects can last for hours (Busker & van Helden, 1998; Zollman, Bragg, & Harrison, 2000). Effects can be reduced by decontamination or supportive measures (Yeung & Tang, 2015).

Concerns have been raised that exposure to OC spray may be harmful and potentially lethal to the elderly or people with poor health (Steffee, Lantz, Flannagan, Thompson, & Jason, 1995), and fatalities have been reported in the United States in association with police

use of pepper spray. Forensic investigations have, however, concluded that in most cases other factors, such as drug use and health issues, were the likely causes of deaths. That said, reports suggest that subjects suffering from asthma may be particularly vulnerable to OC spray and that these factors in combination may cause death (Busker & van Helden, 1998). Hence, the risk of using OC has to be weighed against benefits (MacDonald, Kaminski, & Smith, 2009).

The design of the OC device can influence a number of the operative parameters, e.g., the maximum range, precision, sensitivity to wind and time to reach effect (Heal et al., 2010). For example, compared to stream and gel patterns the cone, fog and foam patterns have a shorter spray distance, have a larger spray area but the spray can drift in windy conditions. Cone and fog patterns are more easily inhaled producing a faster response compared to stream, foam and gel patterns. NATO have developed a method to assess the use and effectiveness of non-lethal weapons (Heal et al., 2010). However, a weakness of this material is that simulated scenarios in laboratory settings give limited information about how subjects in real life respond when being targeted to less-lethal weapons, and about when and how less-lethal weapons are used by the police in real life (Edwards, G, & Onnen, 1997; Kaminski, Edwards, & Johnson, 1999). The present study may here contribute with unique information addressing limitations in prior studies, and thus, contribute to a better operative analysis of one of the most commonly used less-lethal weapon.

When evaluating equipment developed to support performing police work, e.g., firearms and OC spray designs, it is essential to regard both the operative limitations and the tactical contexts in which the equipment is intended to be used (Bertilsson & Fredriksson, 2014; Heal et al., 2010). Real life data on the effective range, precision and effect latency may be different from the technical or simulated scenario retrieved data and pose marked tactical limitations. This since such factors might be noticed first when a device is set into use under more complex real life encounters. Moreover, most technical equipment requires some degree of perception, cognition and motor performance, all of which under real life missions can become affected by psychological stress (the stress response). Thus, devices that require fine dexterous motor skills to operate might effectively be impossible to use for persons exposed to high levels of stress or threat. The psychological sympathetic stress response is triggered before higher cognitive levels can inhibit the response (LeDoux, 2000). Specifically, it has been noted that if the triggering stimulus (threat) is sudden and unexpected, unfamiliar or catastrophic, the stress effects will affect perception, cognition and performance of even highly trained fine and complex motor programs (Atkins & Norris, 2004; Bertilsson & Fredriksson, 2014; Linsdell, 2012; Meyerhoff et al., 2004; Murray, 2004). Therefore, the selection of the equipment, methods of training and the chosen tactical techniques might be of significant importance for the level of operative policing performance (Bertilsson et al., 2013; Linsdell, 2012).

The aim was to investigate responses, situational characteristics and the effectiveness of OC to address violent behavior in Skåne County, Sweden from its first introduction in 2006 and over the following 7 years. Another aim was to evaluate human factors associated with operative and tactical limitations with OC spray during real policing situations.

### **Material and methods**

The situational conditions and effectiveness of using OC spray was monitored in one of Sweden's then twenty-one Police Departments, the Skåne (Scania) County Police Department, during a 7-year period from 2006 to 2012. Swedish regulations stipulate that OC spray may be used to reduce the risk of injuries to subjects and police officers alike. Valid situations for OC use is if a subject is non-cooperative, combative or perceived as aversive and problematically strong/skilled compared to the intervening police officers obligated to

enforce the policing task (RPSFS 2004:6; FAP 104-4). The aim in those cases is to use the OC spray from a distance before a physical confrontation occurs. To our knowledge, all OC interventions investigated in this study were acted out legally.

### ***Population, violent crime rates and police force within the investigated county***

The population in the investigated Skåne (Scania) County, Sweden, was by the end of 2012 about 1.3 million, distributed to one larger city (290,000 people); 5 medium-sized cities 30,000–100,000 people and to smaller communities. Violent crimes (including categories; murder, forcible rape, robbery and aggravated assaults) increased from 2006 to 2012 in Sweden and in the Skåne County by 9%, reaching 259 per 100,000 citizens in 2012, for details see Table 4. For comparison, the violent crime rate was 639 per 100,000 citizens in New York in 2012, USA. Violent crimes were 76% more common in the county's large city compared with the five medium-sized cities and 196% more common than in smaller communities in the county.

The Skåne County Police Department had on average about 1320 police officers employed performing active field duty service, detached to subunits including a SWAT team, patrol units, recon units, drug units and so forth, with somewhat different armament and training. The county police department were assigned an average of 230,000 policing tasks per year during this period.

### ***Police equipment and training***

Swedish police officers that are assigned to field duty work in pairs and are typically equipped with one canister of OC spray (Sabre® Security Equipment Corporation, MO, USA) with about 10 dosages, which is equivalent to 10 s of spraying. The spray selected uses water as OC carrier distributed in a coherent stream pattern, which extends the effective possible range to about 5 m. Continuing an earlier evaluation from 2002 to 2003, in 2006 the OC spray MK-3™ (Defense Technology, FL, USA) was also used within the county. However, in the 15 incidents MK-3™ was used, the conditions and effectiveness was largely the same as with Sabre®, thus, the data presented are from using the two different sprays pooled together. The police equipment also included a 9 mm caliber Sig Sauer® Classic Line pistol and a 21" or 26" expandable baton and a medium-weight ballistic protective vest.

When first equipped with OC, the police officer had to attend a one day course including both theoretical and practical parts. The theoretical part included education about legislation and regulations when OC can be used and about medical aspects. The practical part included familiarization exercises with the OC device and decontamination procedures. Only thumb release of the OC spray was trained. Additionally, between 2006 and 2008, the officers were irregularly offered training in various tactics and use-of-force/self-defense. From 2009 till 2012 training was provided twice a year in integrated tactics, firearms and use-of-force/self-defense training. The focus of the training given between 2009 till 2012 was on decision-making and problem solving in micro scenarios (role play) using baton, firearm Simmunition® and inert OC as possible choices. Role play is a preferred method when training fast decision-making and problem solving, including adaptation to changes by making weapon transitions, verbal commands or tactical dispositions (Adang, 2012).

### ***Collected OC incident information***

Information about the incidents and effectiveness of OC spray were collected from the standardized protocols for reporting OC incidents. The information collected are largely consistent with the data collected in the OC study performed by Kaminski et al. (1999). The police officers who had used OC during policing were required to fill in such protocols before

the end of the working shift. The OC incident information presented in Table 1 were collected and analyzed.

**Table 1.** OC Scenario information collected.

Information collected	
OC scenario information	Evaluation of Age, Gender, Suspected felony, Armament and Presumed drug abuse/mental illness of the subject addressed with OC; Frequency that individual police officers use OC.
Evaluation of factors influence on subject's response to OC spray, dosages used and distance	Evaluation of whether Gender, Species, Intoxication, Mental Illness, Armed assailant, Indoors/Outdoors location, Windy condition and Age had any significant effect on the response to OC, Reduction of violence, Dosages used and Distance at which OC was used.
Longitudinal changes of OC incident properties	Evaluation of longitudinal changes of Violent crime rates, Number of incidents, Population area differences; Frequency OC was used; Armed, Intoxicated and Mentally Ill; Variations in tactical application of OC in terms of Response achieved, Dosages used and Distance used.  OC incident frequency variations over the Years, Months, Day of the Months, Day of the Week and hour of the Day.

### ***Statistical analyses***

Tests of distribution revealed that some data sets did not have normal distribution so non-parametric statistics were used. The collected data was analyzed with Mann–Whitney between-groups test and Spearman correlation test when applicable as shown in the text. Additionally, the distribution profiles were analyzed with linear regression except in three stated cases where an exponential regression model better matched the profile. In the analysis,  $p$  values  $<.05$  were considered statistically significant. All statistical tests were performed using SPSS™ 22.0 software (SPSS Inc., Chicago, IL, USA).

### **Results**

During the 7 year investigational period, OC was used about 1400 times within the Skåne County. Detailed situational information was obtained from 936 of these incidents. In some of these cases complete information could not be obtained retrospectively, e.g., the individual effects when OC was used against crowds.

#### ***OC scenario information***

##### ***Subject addressed with OC spray***

The typical subject addressed with OC spray was a single middle-aged male aged 31 years (SD 12 years). Proportionally, 93.9% of the OC incidents involved a male; 4.1% a female and in 2.0% a canine. In 16.0% of the incidents, more than one subject was active or threatening when the OC spray was used. In 19.9% of the encounters, the subject addressed was presumed to be under the influence of drugs or alcohol and 5.3% of the cases presumed to be involved in illegal drug handling. In 10.0% of the cases, the subject was presumed to be mentally ill.

In most OC use scenarios (56.2%), the subject addressed was unarmed and the encounter involved a physical confrontation with police officers (e.g., resisted arrest and/or made physical attacks). In additionally 17.5% of the cases, the unarmed subject had a threatening behavior, suggesting an imminent escalation into violence. However, in a large proportion of the incidents (21.1%) the OC spray was used to address subjects armed with potentially lethal short range objects. In 10.7%, the subject was armed with a sharp object (e.g., knife, axe) and in 6.5% a blunt object (e.g., flask, pipe, stick). More rarely, the incidents involved controlling



canines (1.7%) and subjects armed with harmful substances (1.7%) such as syringes, spitting and flammable substances.

In 20.1% of the incidents, the police officer was physically attacked by an unarmed subject and in 6.4% of the incidents attacked by an armed subject. In 5.4% of the incidents, the police officer interrupted ongoing fights and attacks against other civilians. In addition, in 11.3% of the incidents the police officer acted under threat of an immediate attack whereas in .6% of the incidents the police acted to prevent a threat being implemented on a civilian. In summary, 43.9% of the OC incidents included defense of oneself or others.

*Case example:* Assault on wife. Suspect is described as about 190 cm tall and weighing about 130 kg. On arrival the suspect threatens to kill the police officers. OC was used. Despite having OC in the eyes the suspect succeeded to get hold of a knife. A hand-to-hand fight started and one police officer managed to knock the knife out of the suspects hand with a baton. The perceived effect of the OC increased continuously. No decontamination was performed due to the continuous violence from the suspect all the way in to custody.

As illustrated above, an important limitation with OC use is that even when the OC affects the eyes of an assailant, it does not physically incapacitate the assailant.

#### *Frequency that individual police officers used OC*

More than 457 individual police officers used OC spray in the county during the 7-year period, whereof 80.2% were male and 19.8% were female police officers. The gender distribution corresponds well to the gender distribution within the police force in active field service in the county, see Figure 1(A). Among the police officers who had used OC spray, 57.3% had used it once and 22.8% twice during the period investigated, with the number of police officers using OC spray more times than this decreasing exponentially ( $p = .002$ ).

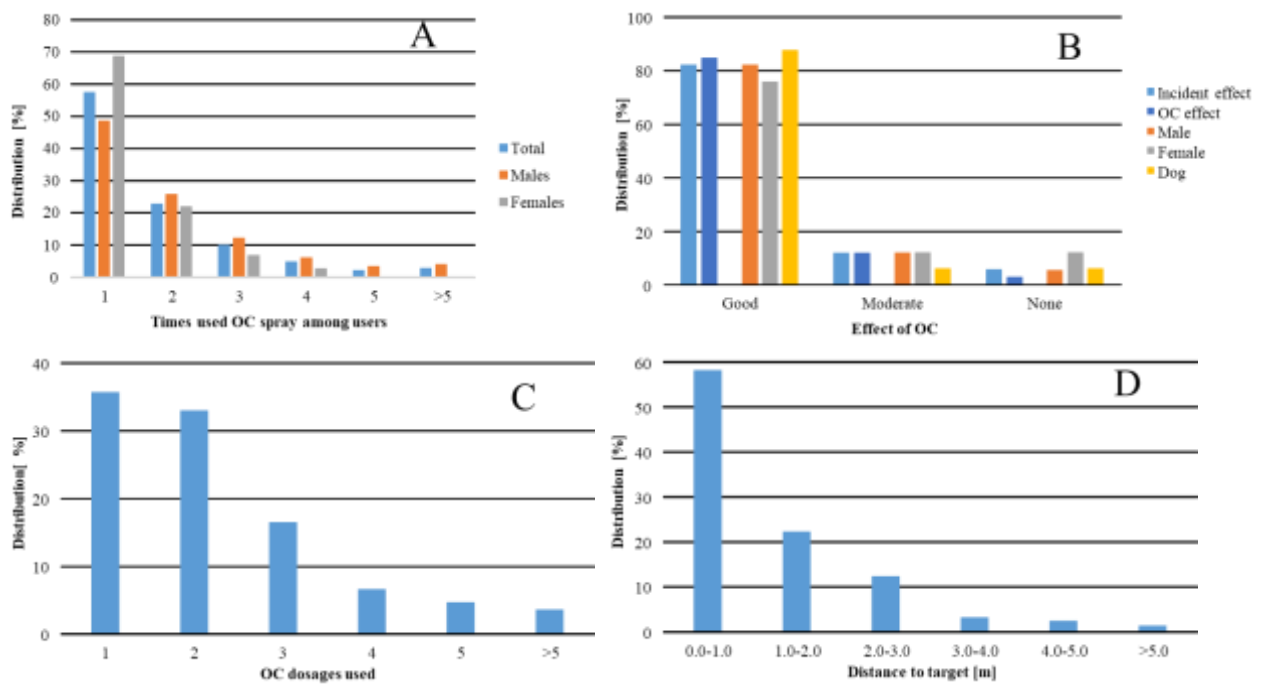
#### *Evaluation of factors influence on subject's response to OC spray*

##### *Subject's responses to OC spray and achieved reduction of violence*

The subjects responded strongly to OC spray in 82.1% of the incidents, while spraying caused a moderate response in 12.0% of the incidents and no noticeable response in 5.9% of the incidents, see Figure 1(B). However, in about 3.2% of the incidents the spray missed the eyes. When adjusting the findings for this, the effectiveness of OC spray when hitting the target was found to be 'Good' in 84.8% of the cases, 'Moderate' in 12.1% of the cases and 'None' in 3.1% of the cases. The OC spray had good effectiveness on males ( $n = 758$ ) (82.2%) and dogs ( $n = 16$ ) (87.5%) but was somewhat less effective on females ( $n = 33$ ) (75.8%), though these differences were not validated statistically, see also Table 2.

The ability for OC to reduce the violence corresponded with the effectiveness scores, with 93.1% of males responding with less violence whereas 87.5% of dogs and 90.6% of females responded with less violence.

Both the effectiveness of OC spray and its ability to decrease the violence decreased significantly with an increasing age of the subject addressed (Spearman's rank correlation:  $p = .002$ ,  $R = -.111$ ) respectively ( $p = .003$ ,  $R = -.114$ ).



**Figure 1.** (A) Number of times, among the users, an individual police officer had used OC spray. (B) Subject's response to OC spray. (C) Dosages applied till perceived effect. The dosages scale correspond to 1 dosage = 1 second of spraying. (D) Distance to target when spraying.

**Table 2.** Evaluation whether certain factors influence subject's response to OC spray and achieved reduction of violence.

Factors	Response to OC <sup>a</sup>		p-value <sup>b</sup>	Reduction of violence <sup>c</sup>		p-value <sup>b</sup>
	Male	Female		Male	Female	
Gender	2.8 (0.5)	2.6 (0.7)	0.272	1.9 (0.3)	1.9 (0.3)	0.719
Species	Humans	K9	0.724	1.9 (0.3)	1.9 (0.3)	0.620
Alcohol/Drug intoxication	Healthy	Intoxicated	0.054	1.9 (0.3)	1.9 (0.2)	0.410
Mental illness	Healthy	Mentally Ill	0.191	1.9 (0.3)	1.9 (0.3)	1.000
Armed assailant	Unarmed	Armed	0.470	1.9 (0.3)	1.9 (0.3)	0.518
Location	Indoors	Outdoors	0.361	1.9 (0.3)	1.9 (0.3)	1.000
Wind	Calm	Windy	0.218	1.9 (0.2)	1.9 (0.3)	0.315

Note: The values are presented as group mean (SD).

<sup>a</sup> The number convention used is defined as 1: None; 2: Moderate; 3: Good. Hence, increased number approaching 3 indicate better response on the subject addressed when using OC.;

<sup>b</sup> The statistical analyzes were performed with Mann-Whitney U (Exact two-tailed) between-groups test.;

<sup>c</sup> The number convention used is defined as 1: Unchanged; 2: Less violence.

### *Evaluation of factors possibly influencing subject's response to OC spray and achieved reduction of violence*

None of the factors: Gender, Species, Intoxication, Mental Illness, Armed assailant, Indoors/Outdoors location and Windy condition, had any significant effect on the response to OC spray or the reduction of violence achieved with OC, see Table 2. However, a clear trend

( $p = .054$ ) suggests that those under intoxication responded more strongly to OC spray (i.e., OC spray was more effective).

#### *Dosages applied till perceived effect and distance to target*

The OC spray had a perceived effect in 35.7% of the cases after 1 dose (corresponding to 1 s of spraying), which cumulatively increased following an exponential pattern to 68.7% after 2 dosages and to 85.1% after 3 dosages ( $p = .001$ ), see Figure 1(C). Of note, the dosages (or time) till reaching a perceived effect on the subject targeted include both dosages used till achieving a hit on the target and dosages used till the OC caused an effect. In 24.4% of the incidents the OC spray unintentionally contaminated bystanders through direct hits or secondary splatter. In 89.8% of these contaminations another police officer was hit by the OC spray.

In most encounters (58.2%) OC spray was used at distances shorter than 1 m, see Figure 1(D), and in additionally 22.3% at distances between 1 and 2 m. The distance distribution profile of OC spray matched an exponential pattern ( $p < .001$ ). The dosages used increased significantly with increasing distances to the target ( $p < .001$ ). The risk of missing the target also increased significantly with increasing distances to the target ( $p = .001$ ).

Both the dosages of OC spray used and the distance to the target subject increased significantly with an increasing age of the subject addressed (Spearman's rank correlation:  $p = .013$ ,  $R = .090$ ) respectively ( $p = .020$ ,  $R = .085$ ).

**Table 3.** Evaluation whether certain factors influence dosages used and distance at which OC was used.

Factors	Dosages <sup>a</sup>		p-value <sup>b</sup>	Distance [cm] <sup>c</sup>		p-value <sup>b</sup>
	Male	Female		Male	Female	
Gender	2.3 (1.4)	2.2 (1.7)	0.157	143 (141)	151 (115)	0.510
Species	Humans	K9	0.797	144 (140)	167 (110)	0.132
Alcohol/Drug intoxication	Healthy	Intoxicated	0.252	148 (130)	96 (84)	<0.001
Mental illness	Healthy	Mentally Ill	0.027	148 (130)	217 (234)	<0.001
Armed assailant	Unarmed	Armed	<0.001	116 (106)	233 (202)	<0.001
Location	Indoors	Outdoors	0.276	143 (124)	145 (148)	0.448
Wind	Calm	Windy	0.847	132 (116)	171 (153)	0.176

The values are presented as group mean (SD).

<sup>a</sup> Ranges from 1 to 10 where 1 correspond to 1 second of OC spraying. ;

<sup>b</sup> The statistical analyzes were performed with Mann-Whitney U (Exact two-tailed) between-groups test.;

<sup>c</sup> The maximum range of OC spray was about 5 meters.

#### *Evaluation of factors possibly influencing dosages used and distance at which OC was used*

The factor evaluation suggests that larger dosages were applied on mentally ill than on healthy subjects ( $p = .027$ ) to obtain effect, see Table 3. Furthermore, armed assailants were sprayed with significantly larger dosages of OC ( $p < .001$ ). Alcohol/Drug intoxicated subjects were sprayed at significantly shorter distances than healthy subjects ( $p < .001$ ) whereas mentally ill were sprayed at significantly longer distances than healthy subjects ( $p < .001$ ). Finally, armed assailants were sprayed at significantly longer distances than unarmed subjects ( $p < .001$ ).



### Effects of weather conditions

The majority of the encounters (69.1%) occurred outdoors. Of these incidents, none occurred during misty conditions whereas five incidents occurred during rainfall. However, the rain had no systematic effect on effectiveness and dosages used. That said, during 23.0% of the outdoor encounters it was windy and that significantly ( $p = .012$ ) increased the risk of collateral contamination from 20.3% during calm conditions to 35.6% during windy conditions.

Table 4. Longitudinal changes over the 7-year period investigated.

		Year							Statistics	
		2006	2007	2008	2009	2010	2011	2012	Coefficient <sup>a</sup>	p-value
Violent crimes <sup>b</sup>	Sweden	195	203	213	227	223	232	217	4.8 (1.7)	0.037
	Skåne County	236	225	242	267	272	289	259	8.1 (2.9)	0.039
	Large city	413	401	394	458	477	508	425	11.9 (7.0)	0.152
	Smaller cities	229	227	258	281	275	249	236	2.9 (4.3)	0.525
	Local communities	137	120	149	152	144	172	176	7.7 (2.1)	0.014
Population	County (. 1000)	1 184	1 199	1 215	1 231	1 243	1 253	1 263	13.3 (0.6)	<0.001
OC properties	Nr. Of incidents <sup>c</sup>	203	109	109	111	91	222	91	-4.6 (11.1)	0.699
	Location <sup>d</sup>	1.7	1.9	2.0	2.2	2.2	1.8	1.9	0.0 (0.0)	0.585
	OC vs. Armed [%]	17.7	16.5	22.9	25.2	19.8	20.3	27.5	1.2 (0.6)	0.114
	OC vs. Intoxicated [%]	28.1	24.8	15.6	18.9	19.8	14.0	16.5	-1.9 (0.7)	0.035
	OC vs. Mental Ill [%]	7.4	12.8	10.1	14.4	12.1	9.9	5.5	-0.3 (0.6)	0.610
	Response <sup>e</sup>	2.7	2.9	2.8	2.8	2.6	2.7	2.7	0.0 (0.0)	0.248
	Dosages <sup>f</sup>	2.2	2.3	2.6	2.9	2.3	2.3	1.2	-0.1 (0.1)	0.258
	Distance [cm] <sup>g</sup>	120	129	159	158	174	166	190	10.6 (1.7)	0.002

The number of reported violent crimes include categories; murder, forcible rape, robbery and aggravated assaults. The information was obtained from the Swedish General Criminal Register.

<sup>a</sup> The statistical regression coefficient values are presented as group mean (SD). ;

<sup>b</sup> Presented as rates per 100 000 citizens. ;

<sup>c</sup> OC reports received for each year. However, during periods the administrative routines handling OC reports were not defined, making local estimate of about 200 OC incidents per year in the county likely is more correct. ;

<sup>d</sup> The number convention used is defined as 1: Large city (23% of county population); 2: Smaller cities (22%); 3: Local communities (55%). Values approaching 1 indicate increased number of OC incidents in the large city. ;

<sup>e</sup> The number convention used is defined as 1: None; 2: Moderate; 3: Good. Hence, increased number approaching 3 indicate better response on the subject addressed when using OC. ;

<sup>f</sup> Ranges from 1 to 10 where 1 correspond to 1 second of OC spraying. ;

<sup>g</sup> The maximum range of OC spray was about 5 meters.

### Longitudinal changes over the period assessed

Analysis of longitudinal data showed three significant changes during the period investigated; a significantly increased violent crime rate in the Skåne county ( $p = .039$ ) and in Sweden ( $p = .037$ ). The violent crime rates increased the most in the local communities ( $p = .014$ ). The police officers decreasingly confronted intoxicated subjects with OC spray ( $p = .035$ ), and used OC spray at increasingly longer distances to the subject ( $p = .002$ ), see Table 4. Proportionally, the OC spray incidents occurred more frequently in the investigated county's large city than in the other county areas. Of the OC incidents, 42.2% occurred in the large city, which can be related to that 22.8% of the county population lived in this city. The crime rates were also disproportionately unfavorable for the main city with values 35.9% above average for the county.

### OC incident frequency variations over time

The frequency of OC incidents show a distinct pattern when investigating variations during the day, see Table 5. The number of incidents peaked between 00:00 and 04:00 am while

reaching a minima between 06:00 and 09:00 am ( $p < .001$ ), see Figure 2(A). Moreover, the OC spray incidents peaked during Saturdays and Sundays ( $p = .038$ ) across the week, see Figure 2(B). Similarly, the number of incidents peaked during the last days of the month and the first day of the month ( $p = .005$ ), see Figure 2(C). Finally, the OC spray incidents also peaked during the spring and summer period in Sweden between April and August ( $p = .044$ ), see Figure 2(D). However, the incidents recorded were fairly evenly distributed over the 7-year period, see Table 4, though the long-term trend is disrupted by higher incident rates during 2006, i.e., the year OC was introduced, and during 2011 when local areas suffered an unusually high violent crime rate.

Table 5. Incident frequency variations over time.

Incident frequency parameters	Statistics	
	Coefficient <sup>a</sup>	p-value
Hour of the day	2.6 (0.4)	<0.001
Day of the week	23.8 (8.5)	0.038
Day of the month	0.4 (0.1)	0.005
Month of the year	-1.8 (0.8)	0.044

<sup>a</sup> The statistical regression coefficient values are presented as group mean (SD).

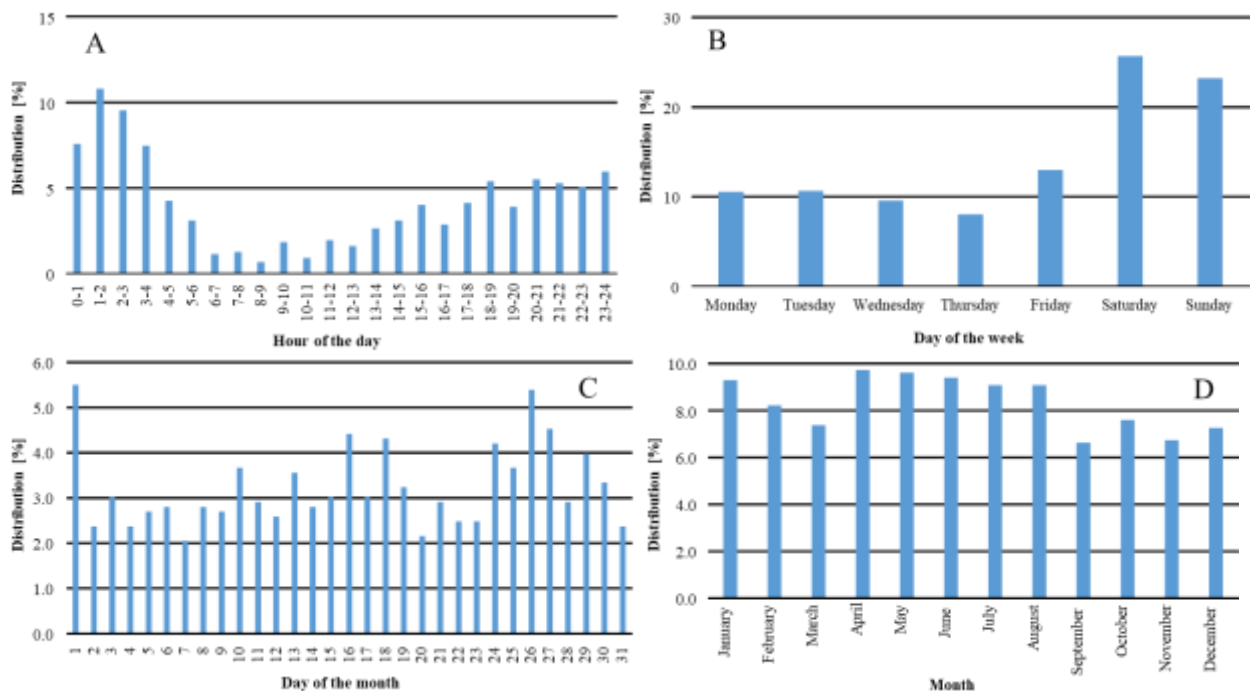


Figure 2. (A) Incident distribution hour of the day. (B) Distribution day of the week. (C) Distribution day of the month. (D) Distribution month of the year.

## Discussion

### *Effectiveness and limitations*

When studying the effectiveness and limitations of using OC spray in real life incidents, a complex picture emerges. The OC spray was beneficial in that in 82.1% of the cases it temporarily incapacitated a violent or threatening subject and substantially reduced a violent situation without causing any lasting injuries. That said, some serious limitations with OC spray also became apparent in this study. Although OC spray was mostly effective, it was not a fool proof method for incapacitation as shown by the 17.9% incidents where it proved less effective. Two factors seemed to markedly reduce the effectiveness of OC; the distance to the

target and increasing age of the subject addressed, the latter finding concurring well with the report by Kaminski et al. (Kaminski et al., 1999). In the first case, a likely contributing cause to the reduced effectiveness is that increased distance makes hitting the target more difficult and reduces the amount of OC spray reaching the target. In the second case, two reasons seem likely, either that older people are more resilient to OC spray or that police officers refrain from continued spraying so not to inflict unintentional harm to humans that appear frailer than a young person.

Intoxicated persons tended to respond more strongly to OC, in line with the observation by Kaminski and colleagues (Kaminski et al., 1999) but opposed by Edwards and colleagues (Edwards et al., 1997), which is possibly related to the significantly shorter spraying distances compared to non-intoxicated subjects. Moreover, mentally ill persons responded slower to OC, in line with the observation by (Edwards et al., 1997), which is possibly related to a higher state of resilience to OC or to the significantly longer spraying distances compared to healthy subjects. Hence, the perceived threat from a mentally ill person seemed commonly greater than that from a perceived healthy person, whereas an intoxicated person seemed to be perceived as less of a threat than a non-intoxicated person. Noteworthy, subjects perceived as mentally ill were addressed with largely the same approach as armed subjects, i.e., spraying from further distances and higher OC spray dosages, whereas perceived healthy, intoxicated and unarmed subjects were addressed at significantly shorter distances. Furthermore, perceived mentally ill subjects (10.0% of the assailant population) were disproportionately more common among the armed subject (27.7%).

A noteworthy limitation was that OC spray in 24.4% of the incidents caused collateral effects, affecting other police officers in 90% of the cases. Moreover, an underestimated problem was the time taken for OC spray to exert effects. This may be related to the difficulty hitting a small moving target with the spray. The liquid stream pattern produced by the device is thin and changes its trajectory with distance to the target. These and other findings make OC spray emerge as suitable for handling low threat situations only. From a police tactical point of view, OC spray cannot be recommended for acute high threat encounters. The average success rate of only 82.1%, the operative range of less than 2 m and likely delays of up to 3–5 s before obtaining effect means that an armed unscathed assailant has an opportunity to inflict serious or lethal harm on a police officer using OC spray. A normal subject can move 5 m from standstill (i.e., maximum range of the used OC) in about 1.2 s (Dysterheft, Lewinski, Seefeldt, & Pettitt, 2013).

### ***Motor control and psychological stress***

The difficulty to hit a quickly and/or erratically moving small target such as the eyes with a liquid stream should not be underestimated, even without considering the effects of psychological stress. The precision needed when tracking small moving objects demands a certain level of open fine motor skill control using visual cues for determining the targets position and predicting movements. The continuous stream of liquid used in OC spray increases the effective range and makes the timing somewhat less important, but at the same time makes the demands on spatial precision higher as opposed to spraying devices that produce a smaller droplet aerosol delivered in a cone or fog pattern (i.e., with a larger covering area). Thus, controlling a device with non-linear aiming properties with the objective to hit a small, fast and sometimes erratically moving target area demands an elaborate combination of strong/fast and fine motor skill control (Schmidt & Lee, 2011). Noteworthy, the fine motor skills are known to degrade already at relatively low psychological stress levels (Siddle, 1995; Villa & Morrison, 1994). This may partly explain why OC spray was used effectively mostly at very short distances.

Psychological stress is a natural human reflexive response evoked by perceiving a threat. The psychological stress response affects performance in the form of an inverted U curve, where one achieves optimal performance at a certain level of arousal (Yerkes & Dodson, 1908). More recent studies have added that performance under stress is influenced by factors such as previously developed stress inoculation due to experience; training; individual basic and adapted autonomous and endocrine homeostasis, and by prior experiences to the type of stimulus and to the environmental cues (Schmidt & Lee, 2011; Vonk, 2008).

### *Tactical application of OC spray*

When OC spray was introduced, the set aim was that the device tactically should serve a preventive role, by being applied early in an arresting situation or confrontation, and thus, mean that one would avoid or minimize the injuries, received and given, when use-of-force was determined necessary to arrest someone, stop ongoing violence or to prevent threatening situations to escalate into a physical confrontation (Kaminski et al., 1999). However, OC spray was rarely used in the early phases of the confrontations in the real life incidents. Instead, OC spray was predominantly used when the confrontation had already escalated into violence or was imminently threatening. Hence, the intended preventive tactical deployment of OC spray at longer distances before any physical contact could take place might have been misunderstood, misused, was not found practically effective or found impossible to implement due to the complex circumstances in real life events. Another reason could be implicit discrepancies between the official tactic and the implemented one, where OC has become regarded as an accepted tool but reserved for only the most violent encounters just below the level of where one might consider to use the firearm.

From tactical viewpoint, OC spray did not become a common tool to influence policing in the county during the 7-year period investigated. Less than half of the 1320 police officers in field service used OC during this time. Among those who did, 80.1% used it less than twice, though unaccounted for when it was sufficient to present the OC spray to bring the situation under control. Set into perspective, of all the about 230,000 policing tasks assigned to the police per year in Skåne County, about 200 encounters resulted in OC spray use, which corresponds to once per 1150 policing tasks.

A noteworthy finding was that the police officers frequently put themselves at high personal risk by using OC spray at close range and even against armed attackers. In 26.5% of the incidents the police officer was actively attacked physically by an assailant and in about 24.2% of these cases the assailant was armed. In 5.4% of the incidents the police officer interrupted ongoing fights and attacks against other civilians. The OC spray was most commonly (in 80.5% of all cases) used at ranges <2 m. This means that the officers rarely utilized the tactically safer possible ranges up to 5 m at best. That OC and other less-lethal weapons are unsuitable for use against assailants armed with firearms is generally accepted due to the apparent objective dangers with the small effective target area of OC, the close range needed, the often delayed or absent effect of OC, and that even an optimum blinding hit does not stop a person from using a firearm. However, the use of OC spray against assailants armed with sharp and blunt objects like knives, swords, axes, syringes, sticks, clubs and pipes seems much too common (21.1% of the cases) in the present material to be a result of rare unfortunate circumstances. Why is it then that OC spray is so frequently used against armed persons? Several explanations are possible.

- The inherent true risks of short distances and the lethal effects of different close-range weapons are not sufficiently known among police officers.
- Most humans are both subconsciously and consciously unwilling to use lethal force against other humans (Grossman, 1995; Swank & Marchand, 1946). In the absence of a better

tool to fill the gap between the short-range less-lethal OC spray and the sometimes lethal firearm, police officers resort to use OC spray in spite of the objective inability to avoid being reached with a knife within 1.2 s or less if a rush attack is made from 5 m distance (Dysterheft et al., 2013).

- The cues picked up from the armed subject give no indication that they present a threat to someone else, for example, it is a suicidal person equipped with a knife or a subject under strong influence of drugs or alcohol.
- The officer was already holding the OC canister before a weapon suddenly emerged. Using OC spray was therefore perceived to be the best tactical choice because that option offered the fastest response opportunity.

When studying the scenarios, these explanations emerge as some of the most common reasons for the seemingly awkward handling of armed subjects. Some problems can be addressed with better information whereas other issues are more problematic since they involve the design of tactical principals as well as the design of police equipment and training. One problem revealed when studying the OC scenarios is the lack of less-lethal weapon options that are fast and highly reliable at distances up to 10–15 m. A typical scenario that officers found difficult to address was handling subjects armed with sharp and blunt objects who had not started an assault yet but where the subject's future intentions were unclear. Such a subject might seem harmless for the moment but could perform a potentially deadly assault reaching the police officer in a few seconds from distances of 10–15 m. Another problem is that the presently available less-lethal weapons have a series of limitations that makes them unable to provide the same versatile and safe operative options as firearms do, e.g., distance and precision limitations, number of times it can be used, whether it can be reloaded fast etc. Hence, it is associated with severe risks when countering threats from firearms, closer proximity (<8 m) threats from blunt and sharp objects and ongoing assaults with firearms, knives and blunt objects, which all potentially can be used to inflict severe or lethal lesions within seconds.

A relevant point is society's negative perception of OC spray and how that might influence a police officer's actions. As shown in the current data, police officers tend not to use the spray regularly. A possibility is that police officers consciously tackle difficult assailants without OC spray given the potential for adverse reactions and public opinion. However, although the risks from adverse reactions is low, invariably police officers chose to use OC more frequently than other potentially lethal methods. In fact, police officers often disregard their own safety when using OC spray even when the use of lethal force would be legal and tactically sound (Castillo, Prabhakar, & Luu, 2012; MacDonald et al., 2009; Swank & Marchand, 1946). Our data therefore forms a strong argument in the case for improved OC spray training and greater public awareness of the risk police officers face when using less-lethal means.

#### ***Incident conditions and profiles of subjects addressed with OC***

The crime rate was markedly higher in the large city than in the medium sized cities and smaller communities, and disproportionally so, even if considering the larger population. One likely explanation is that the large city can produce gang culture and social pressures and has more social venues selling alcohol and other fairground facilities, which attract young and middle-aged people from the surrounding areas. Accordingly, the OC incidents peak during the early hours (00.00–03.00), during Saturdays and Sundays, at the last and first weekends of the month presumably corresponding to the monthly paycheck and in the summer time. Another indication that many incidents were associated with social gatherings is that many of the subjects involved in the incidents were perceived to be under the influence of drugs or



alcohol. Thus, OC spray incidents may not be restricted to addressing ‘violent criminals’ per se but may often include handling an average person who is heavily intoxicated. In line with this, the typical (93.9%) subject addressed with OC spray was a middle-aged male, which in 19.9% of the encounters was perceived to be under the influence of drugs or alcohol. However, this rate was probably underestimated due to limited opportunities to objectively evaluate this factor. Additionally, in 10.0% of the cases, the subject was presumed to be mentally ill. Erratic behavior in both intoxicated and mentally-ill patients makes it difficult to gauge the exact levels of threat, e.g., if the subject also is armed.

During the 7-year period monitored, the distance to target in OC spray use significantly increased and there was an indication that OC was used more commonly against armed assailants. Hence, the training received seemingly caused the officers to act earlier with OC spray though not to handle armed assailants more safely. A possible explanation could be the significant increase of violent crimes in the county, making the officers more commonly having to address armed assailants without alternative longer range less-lethal weapons, this combined with humans common unwillingness to use lethal force (Grossman, 1995; Swank & Marchand, 1946).

An unexpected finding was that proportionally so many incidents included attacks on police officers or civilians (31.9%) and that the subjects addressed were frequently armed with potentially lethal weapons (21.1%). Noteworthy, 43.9% of the OC spray incidents included defense of oneself or others (31.9% attacks and 11.9% direct threats). Hence, the situational contexts set a high demand on appropriate training and equipment but also highlight physical and psychological stress, even under what might be regarded as common police tasks (Castillo et al., 2012; MacDonald et al., 2009).

### *Study limitations*

One limitation of the study is that it has monitored the conditions in one country only, in the Scandinavian country Sweden with fairly low crime rates. Hence, it is possible that the legislation framework, profile of the local criminality and the trained police tactics vary in each individual country, and thus, that police officers in other countries may be more inclined to use a firearm or a baton, where a Swedish police officer instead selects OC spray. Another limitation is that the parameters analyzed from the events are based on subjective assessments made by the police officers involved, e.g., the OC dosages used and estimated distance to the target. On the other hand, the study is based on at least 457 individually different observers, meaning that the reported values are representative for what likely is perceived by the police officers themselves. Moreover, the standard protocols for reporting OC incidents are limited, and details are omitted e.g., about some scenario details, injuries and subject’s intoxication levels.

### *Design issues affecting OC operative use*

Several findings highlight the important role that the design of the OC spraying device may have on the OC’s tactical and operational usefulness. One challenge revealed was that mean frequency of OC spray use was less than twice by an officer during a 7-year period. This makes it essential that operating the device is simple and intuitive. Another challenge revealed was that the incidents commonly encompassed handling high levels of violence including addressing attacks from armed assailants. In such situations the police officer using the OC device will likely encounter high levels of psychological stress or threat, and thus, will be affected by stress-associated motor skill alterations. The psychological sympathetic stress responses are largely reflexive in nature, which can make them and subsequent effects such as motor skill alterations markedly difficult to modulate through training (Bertilsson et al., 2013; Falk & Bar-Eli, 1995; Linsdell, 2012). Hence, the choice of or design of operative techniques



(tactics, self-defense, first-aid, etc.), equipment (OC canister, handcuffs, weapons, radio-systems etc.) and training (use of equipment, weapon transition, open skills, etc.) should include an evaluation of robustness to psychomotor stress exposure as part of optimizing the operative performance and safety.

One equipment problem noted already during training was that the OC canister was difficult to detach from the holster. The canister was kept in place by a leather lid that needed to be pulled from a certain direction to make the canister detach from the holster. This holster design often required the officer to first visually or by tactile sensation determine how to release the canister from the holster and then again to visually determine and adjust the direction of the canister to a suitable direction for aiming and OC spray application.

The cylindrical shape of the canister emerged as a substantial drawback, since this surface provided no tactile information about the orientation of the canister, and thus, likely was a contributing factor to the high amount of collateral spraying reported. Grips and OC canisters shaped to make correct muzzle direction easier to perceive already exist (e.g., Sabre® red pepper spray SA15500 ORMD, Ruger® stealth pepper spray system), but were not used by the Swedish police during the period investigated.

Moreover, the design of the safety mechanism was also found problematic in that it required finer motor control, i.e., abilities that start to deteriorate already at low psychological stress levels. To activate the device required the user to apply fine motor control flexion and adduction in the proximal and distal phalanx in order to put the thumb under a protective lid to reach the activation button. Pressing the activation button could thereafter be performed using gross motor clenching of the whole hand. To ensure safety during close combat situations, the design of the OC canister may have to include a security mechanism making OC spray difficult to release if a perpetrator takes an officer's OC canister and try to use it (Heal et al., 2010). However, an alternative protective lid solution that ensures handling safety and functionality also under strong psychomotor stress might be a 'dead man's switch' design, where one only needs to clench the handle in a certain manner to deactivate the safety mechanism and enable pressing the spray activation button.

Observation (PJF): When training under the influence of the stress response, police officers tried to use the OC by pressing on the protective lid. Realizing their mistake they had problems voluntarily making their thumb retract and slide under the lid. Several shifted their attention (vision) to the canister and used two hands and two thumbs, before being able to put a thumb under the lid and start to spray OC.

Furthermore, it often takes time to achieve the desired effect with OC spray. A common reason for this was often the difficulty hitting a small moving target with a spraying device that produced a liquid stream with a trajectory that changed with the distance to the target. Moreover, most incidents occurred outdoors (69.1%) and wind significantly increased the risk for collateral incidents. Thus, one should consider adding a targeting mechanism with the objective to keep the stream more cohesive over longer distances or use gel as OC carrier. Cone or fog spray patterns are likely the best choices for crowd control or high stress self-defense situations (Heal et al., 2010). However, the high rates of collateral hits recorded in this study with a streaming spray pattern suggest that large area and short distance spray patterns would not be suitable for most real life encounters Swedish police presently address with OC.

## Conclusion

- Detailed scenario information was obtained from 936 OC incidents in a Swedish county. The parameters analyzed include three categories: OC scenario information; Evaluation of factors influence on subject's response to OC spray and Longitudinal changes of OC incident properties.
- OC spray was often found to be an effective means of preventing or stopping violence, and hence reduces the risk of injuries on all subjects involved in the incidents. OC spray therefore at least partly fulfills its functional tactical, legal, ethical and moral niche in the use-of-force continuum for an explicit category of incidents.
- Noteworthy, in 21% of incidents, police officers put themselves at high personal risk by using OC spray at close range against people armed with lethal weapons.
- Subjects perceived as mentally ill were addressed with largely the same approach as armed subjects, i.e., confronted from longer distances and with larger OC spray dosages, whereas perceived healthy, intoxicated and unarmed subjects were addressed at significantly shorter distances.
- Collateral hits/contaminations were noted in 24% of the incidents, whereof 90% were other police officers.
- From a tactical perspective, OC spray cannot be recommended for acute life threatening encounters. The average effectiveness of OC use of only 82%, the operative range of less than 2 m and likely delays of up to 3–5 s before obtaining effects, means that an armed unscathed assailant has opportunities to inflict serious or lethal harm on a police officer that uses OC spray.
- During the investigated period, Swedish police had a gap in the temporal and spatial use-of-force continuum in terms of lack of suitable less-lethal tools able to reliably produce a fast incapacitating effect within the operative ranges 2–15 m.
- The design of the OC canister could be enhanced by providing better aim and by being equipped with a safety release that is simple to use during severe physical or psychological stress.

Hence, research studies of this kind provides specific data on tactical effectiveness and use of specific equipment during actual settings e.g., effects of human physical limitations and of psychological stress in real life situations. Moreover, by establishing a scientific framework one would add the means to determine whether actions taken were safe, reasonable and well-balanced. Thus, criminal and other legal investigations and juridical decisions can be based on more precise parameters. The application of methods that objectively determine whether an action was effective or not based on sound scientific, empiric and clinical knowledge, would enable a higher trust in the professionalism and objectivity of the police and increase trust in the legal system as a whole.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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depending on the effects of internal and external pressure like pre-training, psychological and physical stress.

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