11-7-2020

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International Journal of Industrial Ergonomics 80 (2020) 103059

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: http://www.elsevier.com/locate/ergon

Civilian pepper spray for self defense: Understanding user perception and impact of design on user performance

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ARTICLE INFO

Keywords:
Pepper spray design
Pepper spray usage
Self-defense device
Usability
Perception

ABSTRACT

Pepper spray is widely used in the US, and is marketed as an effective self-defense device. While pepper spray can be useful in deterring an attacker, many pepper spray owners do not have any experience using it. There is a dearth of published studies that focus on civilian pepper-spray use, not to mention first time pepper-spray users. A study to analyze pepper-spray designs with first-time users, to see how the design, specifically the safety mechanism, affects response time and overall performance would be helpful. The study was conducted in 2 parts – a survey to understand user perception, and a lab experiment using a 2 × 2 randomized block design with two designs of pepper sprays (side-slide safety and flip-top safety) and the two starting locations for the pepper spray (purse or pocket) as the manipulated factors. Results revealed a significant difference in response times between the flip-top pepper-spray and the side-slide pepper-spray. There was also a significant difference in response times between using the index or thumb as the trigger finger but no significant difference in response times when the pepper-spray for location (purse or pocket). Overall, participants rated the side-slide device as the most effective self-defense device.

Relevance to industry: Because there is no other research in the area of first-time pepper-spray users, let alone civilian pepper-spray users, much can be learned about how well people use these devices in a real-world situation, and when there is a highly stressful situation how well does pepper-spray allow an individual to protect him or herself. This study starts the discussion on some of these topics.

1. Introduction

A violent crime classification includes rape or sexual assault, robbery, assault, domestic violence, stranger violence, and aggravated assault. According to the FBI's Uniform Crime Reporting (UCR) Program, in 2017, there were an estimated 1,247,321 violent crimes that occurred nationwide of which aggravated assaults accounted for 65.0% of violent crimes, followed by robbery offenses (25.6 percent), rape (8.0%); and murder (1.4%) (FBI, 2018). These types of crimes are often traumatizing for the victims, and therefore many keep self-defense devices to protect themselves from these crimes. According to a Gallop poll (2007) people reported using dogs (31%), burglar alarm in their homes (31%), mace or pepper spray (14%), a knife (12%), or using a gun for defense (12%) although many reported purchasing guns (23%). While dogs and guns may not always be available, a number of civilians use pepper sprays as a self-defense mechanism. Pepper spray can be found in many shapes and sizes. While the traditional design offers a canister with an aim and discharge trigger mechanism, some innovations include features with picture taking, alarm sounding and call for police all while spraying. The discharge also comes in various forms (such as a mist/spray form (aerosol), a single stream, a foam, or even a gel like material), with specific recommendations on proper use. For example, mist should be sprayed while moving the bottle to increase the spread of the irritant on the attacker as much as possible. For the stream form, users should try to focus the stream as much as possible on the attackers face and head area.

From a safety design, the two most common pepper spray designs feature either a side-slide safety or a spring flip top safety (Fig. 1). The side-slide safety requires the user to slide or push a notch located on top of the device to the right before using the spray. Pushing the notch to the right exposes the spray nozzle, when fully activated the nozzle will be pointing directly forward. The spray button can be pressed before the safety is completely pushed to the right, but it will not be accurate, and possibly blocked by the side of the bottle. The spring flip top safety consists of a spring loaded cover on top of the spray button. The user has to push the cover up and then push down on the button to spray. Users may be inclined to hold this spray with their index finger as the trigger

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https://doi.org/10.1016/j.ergon.2020.103059
Received 9 July 2020; Received in revised form 23 September 2020; Accepted 1 November 2020
Available online 7 November 2020

Fig. 1. Two common pepper spray designs.

finger. This puts strain on the wrist because it forces the users to keep the wrist held up, which may lead to strain and also cause the user to aim down instead of directly at the attacker. To the best of our knowledge, while there have been efforts on the chemical makeup of the spray itself (specifically focusing on the capsaicin in the sprays), no study has been conducted on the efficacy of the design of a pepper spray device. This potentially implies that there could be pepper spray device being sold that could actually harm a user due to poor usability and an unintuitive design.

Finally, in terms of instructions provided to users, most pepper-spray devices do come with some written instructions on the packaging, however it does not go into much detail on how to aim and hold the spray. Typically, they may provide illustration of the intended use in terms of how it should be held, but generally not much details or explanation are provided. Limited space also impacts the font size thus decreasing the chances of the owner carefully reading and comprehending the instructions. For other countries, pepper-spray is illegal to own or can be owned only for self-defense against animals (Pennoyer, 2016). In America, there are no restrictions on who may own pepper-spray. Any adult can go into a store and purchase pepper-spray. This leads us to wonder if the vast majority of pepper-spray owners have never used the device before, they may not be cognizant about where to aim or how to spray a target in a real-world situation.

Another reason for widespread use of pepper spray could potentially the concept of aim and fire which implies no training requirements to use the pepper-spray. However, a fact that might be overlooked may be the effectiveness of using these sprays as a defense measure. If a person owns pepper-spray but has never used it in the real world, they may be less likely to act decisively and know exactly how to use their pepper-spray on an attacker. A first-time pepper-spray user will have a much higher chance of misusing the product in the moment, often sudden and unexpected, leading to significantly negative results. Compounded with the extremely stressful situations in which pepper-spray is typically needed/used, an inexperienced user may cause more harm by using the spray. As a case in point, consider a pepper spray which requires the user to turn a tab completely to the left to expose the nozzle (safety feature). If the user does not know this, or does not turn it completely to the left, he or she will not hit the target, and can even lead to spraying him or herself. Since the form of the spray also varies (gel, single stream, and spray/mist), this potentially could impact the target (aim) and accuracy, which implies that user may not be effectively using the device.

Typically, a product is evaluated in terms of its usability, which the widely quoted ISO 9241-11 standard states as "The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (ISE 9241–11). Other researchers have added more attributes/dimensions and refined the definition of usability. For example, Nielson (2003) defined usability as a measure of the ease of use of an interface which can be assessed by 5 quality components, namely learnability, efficiency, memorability, errors and satisfaction. In the context of product design, it would be prudent to include measures (qualitative or quantitative) to assess some (if not all) of these components while testing the product/system. From a definition perspective, learnability inquires about the ease of use to accomplish basic tasks after first encounter with design, efficiency is related to how quickly the task can be performed once user has learnt the design, errors relate to user errors made, severity of errors and recovery from errors, while memorability refers to understanding about retention of task procedure after a period of non-use. The most frequent quality component used in studies is satisfaction, which seeks to quantify how pleasant the design is for use. All these qualities need to addressed while designing a product and if not addressed, we might get a product but not a "good useable design". Don Norman in his book "The Design of Everyday Things" suggested some simple rules for product designers including but not limited to making things visible, exploiting natural relationships that couple function and control, and making intelligent use of constraints (Norman, 2013). While these rules make sense, it is to be pointed that these rules and other considerations provided by practitioners yield the best results if

usability testing are employed in the early design stages to identify the use and user concerns.

While usability testing is not mandatory for all industries, there is abundant published literature for usability tests conducted on diverse products such as wearable fitness technology to assess effectiveness (Strath et al., 2011; Mercer et al., 2016), mobile technology applications to assess effectiveness and efficiency (Georgsson and Staggers, 2016), and medical devices such as infusion pumps to assess user-interface issues (Hicks et al., 2008), and lung ventilators to assess standard vocabulary (Minotra et al., 2017). Validated well-established questionnaires such as System Usability Scale (SUS) have been developed for end-of-test subjective assessments on usability (mainly websites and apps) for aspects such as system functionality, learnability, and ease of use (Brooke, 1996). However, to the best of our knowledge, a review of literature to understand three aspects - pepper spray usage by civilians from usability perspective, effectiveness of pepper spray as a self-defense mechanism, and design guidelines did not increase the knowledge on the design of the spray itself and actual usage by civilians. This leads us to ask some questions such as "what is the user's perception about pepper sprays?", "How might the pepper-spray design affect performance?", "how would first-time users would perform using pepper-spray on a target in a real-world like situation? and "How would these first-time users hold and aim the pepper-spray?".

Hence, this first part of the research endeavor was designed with the following objectives:

1 Understand general awareness of pepper-spray use and design, and
2. Conduct a lab based experiment to gain insights about intuitiveness of pepper spray safety designs.

The majority of events that involved pepper spray and civilian use that the pepper spray user is actually operating and using the spray for the first time. Unfortunately, when the critical moment arrives when they are being attacked these devices may not be readily available (either not on them or due to inaccessible location or lack of knowledge on how to use). This is a serious issue for which research is lacking, because situations where pepper spray is needed are often highly stressful, and require fast actions and precise movements. If a person cannot figure out how to use their pepper spray in the moment, the spray becomes useless and changes from a self-defense mechanism to a self-defense hinderer, distracting the user and likely leading to injury or worse. Furthermore, given the prevailing conditions and general self-defense awareness, more people are likely to carry non-lethal defense devices such as pepper sprays. Hence, this study to gain some insights about pepper-spray knowledge and use in general would be helpful to understand and then reduce the knowledge gaps and practice gaps. This knowledge could be used to design strategies for onboarding first time users, developing training manuals, and potentially assist manufacturers in redesigning the pepper sprays.

The first task undertaken for this endeavor was to consult with a subject matter expert to understand the use and user error about pepper spray (presented in Section 2) which was used to develop the user perception survey. The results of this survey was utilized to design a lab based experimental study for which an explanation of the methodology used, and the results obtained are presented in Section 4. A discussion of the overall results is provided in Section 5, followed by the conclusions (Section 6) from this exploratory endeavor.

2. User perception survey

2.1. Discussion with self defense subject matter expert

Prior to developing a survey, a local self-defense subject matter expert (SME), who also teaches a class on using pepper-spray usage, was contacted to learn more about correct pepper spray use regarding positioning and hand posture as well as how different devices should be ideally used. During the discussion, three concerns related to user error emerged. The first concern related to the use of the finger for accurate aim. It was pointed out that a common mistake made was using one's index finger as the trigger finger instead of the thumb. Holding the spray so that the thumb is on the trigger results in more accurate aim, better mobility, and makes holding the device less awkward. The second concern was related to the location of spraying. It was pointed out that a common mistake was users aim directly for an attacker's eyes. Ideally to be most effective, the pepper spray user should aim for the attacker's entire face area, to get the spray in his or her eyes, nose, and mouth. This is a much larger target than only the eyes, and will be more debilitating to the attacker. The third concern was that after spraying an attacker, many people make the mistake of freezing, or staying put and calling 911. In an ideal scenario, it is better for the individual to run away from the attacker and not call 911 until in a safe area. The insights from the discussion were considered in the survey design and the lab experiment design described in the following sections.

2.2. Survey design

The primary intent of the survey was to obtain information on the general public's perception of pepper spray, as well as how the public feels pepper spray is used/designed. To achieve this purpose, an online survey using Qualtrics software so that it could be widely distributed using email and social media. The survey contained 14 questions to solicit responses on general demographic information (age, and gender) on pepper spray users, their use cases, and type of pepper spray owned if any. Some questions included in the survey were: "How long do you think it takes to use pepper spray on an individual? This includes taking the pepper spray out, releasing the safety, aiming the spray, and spraying" with options of <3 s, 3–5 s, 5+ seconds, and "Where would you keep your pepper spray when going out during the day?" with options of bag/purse, pant pockets, jacket pocket, in my hand, don't bring it along, elsewhere. Another question inquired about the placement location when going out at night. The last question inquired about user action after spraying an attacker with pepper spray.

2.3. Survey results

71 individuals (47F/24M) completed the online survey. Fig. 2 represents the distribution by gender and age which indicates that approximately 48 individuals (29F/19M) constituting 68% of respondents were between the ages of 24–34, 10 (7F/3M) 15% between 35 and 44, and the rest were above 45 years old with six females over the ages of 65.71% (37F/19M) exercised up to 3 times a week while the remaining 16 respondents (10F/5 M) exercised between 4 and 7 times a week.

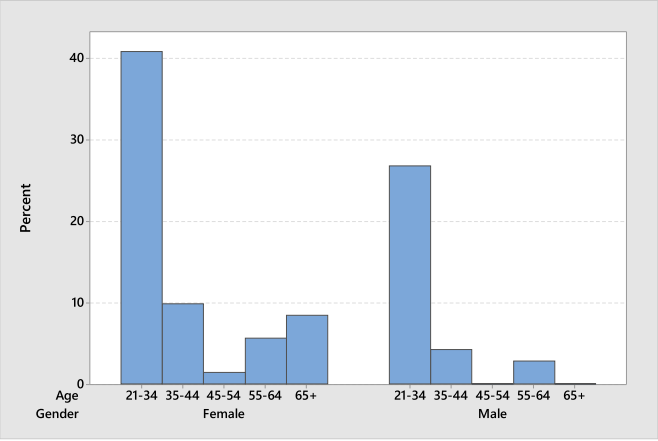

Fig. 2. Distribution of participants by gender and age.

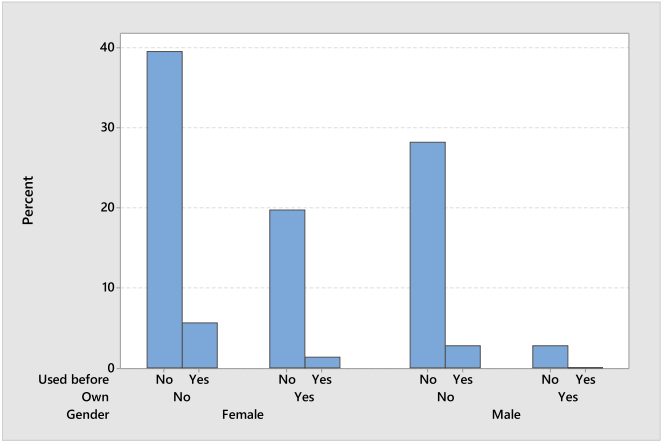

Fig. 3. Response to own pepper spray and prior usage by gender.

Table 1
Summary Responses to "Where would you keep your pepper spray when going out?" by time of day and gender.

Location	Day		%	Night		%
	Female	Male		Female	Male	
Usually don't bring my pepper spray when I go out	**14**	11	35%	10	9	27%
In a bag/purse	**24**	2	37%	14	0	20%
In my hand	**2**	0	3%	7	2	13%
Jacket pocket	**2**	1	4%	9	3	17%
Pants pocket	**1**	8	13%	6	6	17%
Somewhere else	**4**	2	8%	1	4	7%
Column Total	**47**	**24**		**47**	**24**	

2.4. Pepper spray usage

Of the 71 respondents, 76% (32F/22M) did not own a pepper spray but six respondents reported using one before. The remaining 17 respondents (15F/2M) owned a pepper spray and had bought it as a self-defense mechanism but only one respondent had actually used a pepper spray before (Fig. 3). A follow up question of "why they used a pepper spray" indicated that, 4 of these 7 experiences were related to training for their job, but surprisingly none had actually used it in a "live" situation.

2.5. Pepper spray location and general perception

Two questions to inquire about location/storage of pepper spray when carried was also asked in the survey. Specifically, response was sought for "Where would you keep your pepper spray when going out in the day? and "Where would you keep your pepper spray when going out at night? With options of bag/purse, pant pockets, jacket pocket, in my hand, don't bring it along, and elsewhere. It appears that 35% (25 respondents) do not carry the pepper spray with them while going out during day but reduces to 27% (19 respondents) during night, which could be interpreted that there is a perception of insecurity during the night time) (Table 1). Overall, during the day time, the primary location appears to be bag or purse (37% during day) followed by pants (13%). During the night, the primary location is still bag or purse (20% during day) followed by pants (17%), jacket (17%) and hand (13%). A closer look at the data indicated that 5 out of 6 respondents flipped their response from "Usually don't bring my pepper spray when I go out" during the day, to bag/purse or jacket as their response (Table 2).

Table 3
Summary for response time to the question "How long should it take to pepper-spray someone?"

Time	Female		Male	
	N	%	N	%
less than 3 s	5	7%	9	13%
3–5 s	19	27%	10	14%
5+ seconds	22	31%	5	7%

Table 2 also indicates that during night time, individuals considered hand, jacket, and pants as preferred location for the pepper spray, yielding to the hypothesis that closeness/proximity to body might be a factor while considering the location, which is in turn could be derived from their perception of time it takes to use pepper spray. Another result worth noting is that 41% of the respondents felt it would take between 3 and 5 s to pepper spray someone (Table 3). The question explicitly indicated that the response relates to time required to point the spray and de-activate the safety mechanism only. However, it is important to note that the total activity time comprises of summation of the time to undo the safety, look at safety when deactivating it, and the time taken to spray the target and not just the actual spraying. However, to the best of our knowledge, there is no literature that documents the response time.

Not surprisingly, only 58% (41/71 respondents) indicated that they would aim the pepper spray at the general face area of the assailant while others indicated eyes as the attach location. However, almost 75% (53/71) of the respondents indicated that they would run away from the location rather than call 911, which is the best option since it is better to create separation before calling 911 from a safe area.

3. Lab experiment

Based on the insights from the SME and the survey results, a lab experiment was designed with the intent to understand the intuitiveness of pepper spray safety designs and whether location affects a user's response time when using pepper spray. Four surveys were also presented to participants to understand knowledge and perception of usage of pepper sprays. The participants in this experiment were restricted to female only because they are more likely to carry a pepper spray on them when compared to males, as evidenced by the survey results. Also, a Gallop poll (2007) reported that 21% of females reported owning

Table 2
Tally of flipped responses for location preference from day to night.

	Location	Night					
		Usually don't bring my pepper spray when I go out	In a bag/purse	In my hand	Jacket pocket	Pants pocket	Somewhere else
Day	Usually don't bring my pepper spray when I go out	–	3	0	2	0	1
	In a bag/purse	0	–	6	3	5	1
	In my hand	0	0	–	1	0	0
	Jacket pocket	0	0	0	–	0	0
	Pants pocket	0	1	0	1	–	0
	Somewhere else	0	1	0	2	0	–

pepper spray compared to 7% of males, with younger age group more likely to carry than elderly. Ethnicity was not a concern for the study but applicants were included in the study if they had not used pepper spray in the past (i.e. novice users), no vision issues that cannot be corrected with prescription glasses, no night blindness, and ability to hold and aim pepper-spray. This study was approved by the University's Institutional Review Board.

3.1. Experimental design

A 2 × 2 randomized block design was implemented in this study. The two designs of pepper sprays (side-slide safety and flip-top safety as shown in Fig. 1) and the two starting locations for the pepper spray (purse or pocket) were the manipulated factors. While both designs are common, they require significantly different movements and actions to discharge. If someone had one of these devices and needed to use it in a real-world situation, there is a good chance that his or her performance may vary significantly depending on which device he or she had and prior experience.

Each participant performed all four possible combinations (two pepper-spray designs and two starting locations) in a randomized manner. The dependent measures included the time it takes to get the pepper spray out, time to disengage the safety, if and how long the participants looked at the safety after the attacker was displayed, overall response time, and self-reported perceived performance for each device and starting location.

During the experimental session, participants were asked to complete four surveys during the experiment: the first was presented before going through trials to assess their knowledge of pepper spray and how to correctly use one in a self-defense situation. Two more surveys were presented before the first trial of randomly selected pepper-spray design. These surveys focused on how the user perceived each device before using it. It asked questions about how participants expected it should be held, how accurate it is, and how long it will take to fire it. Lastly, after completion of all trials, a final survey was presented which asked the participant to compare both devices and starting locations, as well as their preferences for which device they felt was better. It also asked questions about their confidence with using pepper-spray in general, and whether they would be more or less likely to use pepper-spray after participating in the experiment.

3.2. Apparatus and materials

For the current study, the materials used included two commercially available pepper spray practice devices filled with an inert water-based substance; a purse and a "pocket" for the starting locations (pocket affixed on participant only if a participant did not have pockets of their own). In this study, the purse and pocket were empty, i.e. there were no other stuff to control the influence of time for searching and grasping/retrieving. Four security cameras set to record continuously while a participant ran through trials - The cameras were set to night-vision to capture the participants' movements for the time study analysis. Two 21 inch monitors set up close to shoulder height of participant were also used to present the stimuli. Each monitor was connected to a laptop running a PowerPoint Presentation of the attacker's image (image of a person with a screaming face). When the participant went through a trial, they walked towards the two monitors with one of the two sprays in one of the two starting locations. The researcher then randomly selected a monitor at a random time to display the attacker. When the attacker was displayed, a scream sound was paired with it to better simulate the real-world environment. Once displayed, the participants aimed and fired at the target as quickly and accurately as possible. Fig. 4 provides an illustration of the experimental setup.

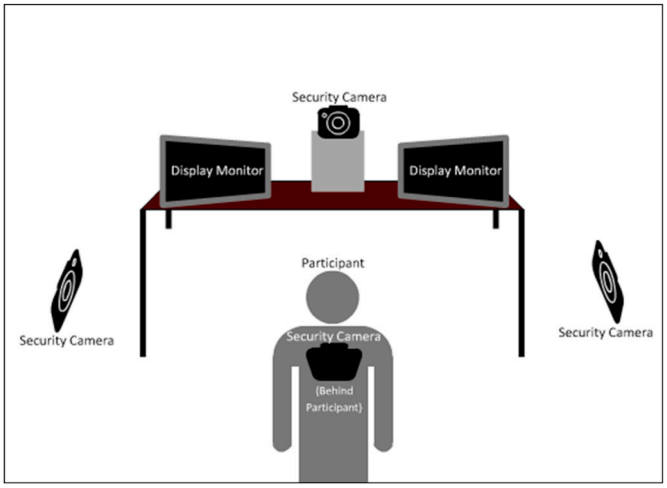

Fig. 4. Experimental design setup.

All the tasks were performed in a simulated light controlled walk environment. The lab environment illumination was made to match the outdoor night-time level, determined based on the lights levels, recorded using a light meter, outside the research building at around 9 p.m. over 2 days before the first trial.

3.3. Procedure

After obtaining the consent, the participants were shown the two pepper spray bottle designs (side-slide safety and flip-top safety) before going through the first trial. They were allowed to hold them and look at them but not actually discharge them. Once the participants have had a chance to hold and examine the two designs, a short survey to gather their impressions of the designs and their perception of the techniques to be used for spraying was administered. After completing this survey, the participant was provided with the instruction manual and any other material that come with the pepper spray. The rationale was that this should be a common occurrence for people who bought pepper spray. For this study, this self-review of the instruction manual will be

Table 4
In-lab experiment survey pre-trials (N = 11).

Question	Categories	Response Frequency (%)
Where should an individual aim pepper-spray at an assailant?	Eyes	64
	All over the face	36
	Nose	0
	Mouth	0
	Other	0
What should one do immediately after spraying someone?	Run away	73
	Call Police	27
	Check if assailant is breathing	0
	Keep spraying assailant	0
How far away should one be from an assailant to be most effective?	3–5 ft.	45
	<3 ft.	27
	As close as possible	18
	5+ ft.	9
To your knowledge, how many different types of pepper spray discharge is available?	3–5	55
	1–2	45
	5+	0
Which of the following discharges do you think is available?	Spray	36
	Stream	36
	Mist	18
	Foam	9
	Gel	0
How long should it take to pepper-spray someone?	1–3 s	55
	3–5s	36
	<1s	9
	5s+	0

considered as baseline training of the user (participant).

After the participant has reviewed the manuals and indicates to the researcher that they are comfortable with the product, one of the four conditions was randomly assigned and the data collection commenced. A hand bag and/or a side bag will be provided to the participant if they do not have either of these items on them. In order to account for light/dark adaption, participant was required to spend up to 3 min inside the alley condition before starting a trial. After completing the first trial, the participants repeated the experiment for the three other conditions with a 5-min break between trials.

3.4. Results

Eleven females between the ages of 21–44 from the local community participated in this study. None of them had used pepper-spray before nor had received any type of training. Due to the small samples size, non-parametric analyses were conducted to evaluate the differences with a significance level of 0.05.

3.4.1. Subjective preference ratings

A. Pre-Study In-Lab Survey

Each participant was presented a survey about general perception of pepper-spray devices, as well as knowledge about pepper-spray when they first arrived for the lab-based experimental portion of the study. The results of the survey are summarized in Table 4. It appears that, 64% of the respondents felt that they should aim only for the eyes when spraying a target, and that to be most effective one should be about 3–5 feet away. These are not correct, in fact the closer one can get to the assailant to pepper-spray them the better, as it will be more irritating to them. In addition, as mentioned earlier, one should spray the entire face of an assailant, as getting the spray in the mouth and nose will further inhibit the assailant. Another result worth noting is that 91% of the respondents felt it would less than 5 s to pepper spray someone and 73% of the respondents indicated that they would run away from the location rather than call 911.

B. Pre-Trial-Participant Pepper-Spray Perceptions

Before using each pepper-spray device, a survey was presented that asked questions about the participants' perceptions of each devices in terms of design, and effectiveness (in terms of time) as a self-defense device. The results from each of those surveys are presented in Table 5, which indicates that, participants exhibiting a preference for the flip-top safety which was also perceived as having a longer range for spray. This is interesting because these devices both claim to have a range of 8+ feet. Lastly, participants more frequently felt the thumb should be the trigger finger for the side-slide safety than the flip-top, however as shown in Table 5 they were just as likely to use the index as the thumb for the trigger finger.

Table 5
In-lab survey prior to side-slide & flip-top pepper-spray trials responses (N = 11).

Question	Categories	Response Frequency (%)	
		Side-Slide	Flip-Top
How do you think this design should be held while using?	Thumb on Trigger	73	55
	Index on Trigger	27	27
	Thumb on Safety	0	9
	Index on Safety	0	9
What would you estimate is the range of the spray for this design?	Definitely Yes	0	0
	Probably Yes	36	55
	Not Sure	55	36
	Probably Not	9	9
	Definitely Not	0	0
What spray type does this design fire?	Stream	55	45
	Mist	27	45
	Foam	9	9
	Gel	9	0

C. Post-Study Survey – Location and Device Preferences

After all trials, a final survey was presented comparing both devices (see Table 6). The participants rated the side-slide as being easier to use (73%), easier to deactivate the safety (64%), and faster to aim and fire (73% indicates flip top took longer) but not accurate (45%). Participants also rated having the spray in the purse resulted in a slightly worse performance, and rated the pocket starting location as a better performance most often. When asked about the trigger finger used for each device, participants showed no difference in their confidence that they held the device correctly.

The participants were also asked to state their confidence are you that you would be able to effectively use the pepper spray in a real-world situation using a 5 point Likert scale (1 –extremely confident and 5- not confident at all). The responses were not very encouraging with 10 out of 11 participants indicating that they were not very confident. Furthermore, 10 of the 11 respondents also indicated after experiencing using pepper-spray, they would much more likely to purchase and/or use it as their main self-defense method, which is a very encouraging outcome.

3.4.2. Video analysis results

The videos were used to extract data the time to undo the safety (after the attacker was displayed), the time looked at safety when deactivating it, the time it took to go from having the pepper-spray in hand to spraying the target, and the total overall response time after the attacker was displayed. The camera location, participant posture/movement, and the spray did not always provide the view and hence data for some participants was not included in some analysis. The data is summarized in Table 7, which indicates that the flip-top device resulted in a faster overall response time for both the purse and pocket starting locations. It also had a faster time to undo the safety and time from hand to spraying the target.

A Kruskal-Wallis H Test was conducted using SPSS v25 for both pepper-spray type and starting location. There was a statistically significant difference in overall response time between the two pepper-spray types (side-slide and flip-top) ($p = .046$) but no statistically significant difference was found for the time from hand to spray between the devices ($p = .817$), the time to undo the safety ($p = .636$), and the time looked at the safety ($p = .159$). For the Kruskal-Wallis test to compare starting location (purse and pocket) on response times, no statistically significant difference on overall response time ($p = .462$), time from hand to spray ($p = .563$), time to undo the safety ($p = .875$), and time looked at safety ($p = .949$) were obtained.

The next analysis was conducted to understand the use of trigger finger used by pepper-spray type. When trigger finger used was compared by pepper-spray type, it was observed that for all trials, the thumb (75%) was the most common trigger finger for the flip top but equally split between thumb and index for side slide design. The thumb resulted in faster overall response times for the side-slide device, but was actually slower for the flip-top (see Table 8). The thumb also resulted in a slightly longer time from hand to spraying target for the flip-top device. Other than these variables, the thumb was faster in all other categories for both devices.

A Kruskal-Wallis H Test with trigger finger and pepper spray type indicated statistically significant difference for overall response time for pepper spray type ($p = .011$), but no statistically significant differences were obtained for the other 3 variables, i.e. for time from hand

Table 6
Post-lab experiment survey (N = 11).

		Survey Question	Design type Ratings (%)	
			Flip-Top	Side Slide
Pepper-Spray Comparison on Performance by Design Type		Which design was easier to use?	27%	73%
		Which was more accurate?	55%	45%
		Which took longer to aim and fire?	73%	27%
		Which was easier to de-activate the safety mechanism?	36%	64%

	Survey Question-Effect of pepper-spray in LOCATION X on performance	Response Frequency (%)						
		Much Better	Moderately Better	Slightly Better	No Effect	Slightly Worse	Moderately Worse	Much Worse
Starting Location Performance Ratings	Pocket	36%	27%	27%	0%	0%	9%	0%
	Purse	9%	0%	0%	0%	45%	9%	36%

	Question in Survey	Categories	Response Frequency (%)	
			Side-Slide	Flip-Top
Pepper-Spray Ratings & Perception	How did you hold the pepper spray when presented with target?	Thumb on Trigger	63	100
		Index on Trigger	27	0
		Middle Finger on Trigger	0	0
		Other	9	0
	Did you feel you held it correctly when aiming & discharging?	Yes	55	55
		No	45	45

Table 7
Mean values for response times to spray target by pepper-spray type & starting location (N = 8).

	Purse		Pocket	
Average Response Times in Seconds	Side-Slide	Flip-Top	Side-Slide	Flip-Top
Time to Undo Safety	1.10	0.93	2.18	0.79
Time Looked at Safety	1.77	0.72	0.78	0.95
Time from Hand to Spraying Target	2.34	1.90	2.90	2.30
Total Response Time	4.88	3.13	4.83	3.89

Table 8
Mean values for response times to spray target by trigger finger and pepper-spray type (N = 8).

Average Response Times in Seconds	Side-Slide		Flip-Top	
	Index	Thumb	Index	Thumb
Time to Undo Safety	2.50	0.89	1.10	0.86
Time Looked at Safety	3.20	0.68	1.40	0.40
Time from Hand to Spraying Target	3.20	2.05	1.80	1.90
Total Response Time	6.48	3.22	2.16	3.20

to spray ($p = .991$), time looked at safety ($p = .099$), and time to undo safety ($p = .823$).

The videos were also reviewed to gather posture data for the upper extremities (trunk position), hand forearm orientation in space, and the distance when participants started spraying a target but did not get orthogonal views to do so and thus introduced a parallax error. While accurate quantification was not possible, it was observed that all participants started spraying at the target with completely extended upper and lower arms held between the shoulder and face (i.e. upper and lower arms were parallel to the ground). It was also observed that participants tended to lean forward at the waist (slight back flexion).

4. Discussion

The first objective of this study was to gauge perception of pepper spray itself and usage.

The survey indicated that majority of individuals (both gender) did not own a pepper spray and if they did, they did not receive any training on how to use pepper spray for self-defense. Quite notable is the fact that some individuals reported not carrying the spray on them when they went out, but for the others who did carry indicted either bag or purse would be their preferred location. Another result worth noting is that respondents estimated the response time to pepper spray someone to be between 3 and 5 s, which is collaborated by the time study results (average = 3.9 s, SD = 1.9). Overall, while mixed results were obtained from the survey, the main concern identified was that individuals did not realize that aiming for the face (not eyes) is the best target to get the desired effects. This is a concern since it is the exposure/inhalation of the spray that produces the intense physiological responses (nociception, temporary blindness, disorientation, shortness of breath, and choking) with temporary incapacitation of the victim with minimal long-term side effects and/or toxicity (Hyder, 1996; Hepburn et al., 1997). The eyes are a very small target and therefore users will be more likely to miss aiming at someone's eyes, especially if they are first time users. Even when aimed at an attacker's face, in general, issues still are present such as the attacker might dodge the spray if their reflexes are fast, which is why it is important to hold the spray bottle in the most appropriate position to be most effective and cover larger surface of the attacker as possible. On the bright side, the respondents also reported that the best response after spraying is to run away. This is the correct response since the primary purpose of pepper spray is to temporarily incapacitate the assailant and not paralyze the assailant, thus they still have the ability to continue their assault.

The results of this study indicate that the type of design has an impact on response and safety parameters. However, despite the flip-top performing consistently better, participants actually rated the side-slide pepper-spray as being easier to use, faster to aim and fire, and easier to deactivate the safety. This contradicts the lab-experiment findings, as the side-slide device resulted in slower response times for nearly all categories regardless of trigger finger and starting location. This was an interesting finding, and it is not clear why the participants found the side-slide device as the more effective device with one assumption being the force generation capability of the participants, specifically since data was collected on female.

In terms of location, it was expected that pepper-spray kept in the pocket would result in faster response times than keeping it in the purse due to additional actions of reaching for purse (accessibility) and unlatching purse, however the lab-based results showed no significant difference in response times, which is fact may be a good result to obtain since surprise attacks can happen quickly and without fore warning. Overall, the participants rated the keeping the pepper-spray in the purse as "Slightly Worse" most frequently while keeping the pepper-spray in

the pocket was rated as "Slightly Better" most frequently. Although there was no significance, the participants consistently preferred the pocket, and the results do show that the pocket location had total faster response times. With that said, some participants in the survey indicated that they hold the pepper spray in their hand especially at night, which may be a better location. This suggestion stems from two reasons – retrieval time can be eliminated, and from a psychological perspective, it is possible that a user holding a pepper spray may be more vigilant or have more situation awareness.

The researchers also analyzed the effect of trigger finger to fire the pepper-spray devices. There was a statistically significant difference in overall response time when using the thumb as the trigger finger compared to the index finger. This is particularly interesting, because the participants used their index for 50% of the trials when using the side-slide safety, which may indicate that the side-slide does not clearly afford holding so that the thumb is on the trigger. The recommended finger is the thumb as per recommendations from the self-defense expert and the pepper-spray packaging instructions. Holding the spray with the thumb leads to a higher likelihood of fully activating a device. An individual using their index finger to spray may not fully de-activate the safety, leading to significantly poorer accuracy and in some cases the sprayer may end up getting sprayed themselves. Also, from a force generation and ergonomics consideration, using the index finger as the trigger finger also puts unnecessary strain on the wrist, because the user must keep their wrist locked in an awkward posture to aim the spray.

While this study did produce interesting results and hopefully will start a conversation about the lack of pepper-spray design safety guidelines or more standardized and widely available training, the authors would like to acknowledge certain limitations that inhibit generalization of results, many due to needing to balance creating a real-world simulation and at the same time not causing participants undue stress or potentially triggering past traumatic events. The researcher did not and could not make participants feel anywhere near the level of stress an individual may be experiencing when being attacked and needing to use pepper-spray. This could have resulted in participants not being stressed at all and their state of mind did not at all match an individual's state in a situation where pepper-spray is needed. There was also the fact that the experiment was held in a lab and not outside or in a setting where an individual may want to keep pepper-spray handy in case of being accosted or attacked. From the survey results, it is very likely that one would hold a pepper-spray device in their hand whenever in a situation or environment that may require it for self-defense. This additional starting location could also have helped to highlight how the safety of each device affected performance. If participants are still having significantly more difficulty and taking significantly longer to spray when the starting location is in their hands, it could be claimed that the safety had an even larger influence on pepper-spray usability than the current study can show.

Because there is almost no previous research on first-time civilian pepper-spray users, the possibilities for future research are far reaching. Perhaps the clearest direction for future research is to focus on comparing pepper spray owners to non-owners. This would help to see if simply owning pepper-spray leads to significantly better performance when spraying a target. It will also increase awareness that owning a pepper-spray device may not necessarily lead to better protection if the owner has never used the device before. Another useful area to study is the effectiveness of pepper-spray training. The experiment would consist of running both owners and non-owners of pepper spray, but both with no actual pepper-spray experience, through the simulated lab trials. The participants would then receive professional pepper-spray self-defense training. After the training, the participants would repeat the trials to compare their performances. The results of this experiment will shed light on how training may affect performance in a real-world situation. The current study did not collect data on the accuracy of the participants. A study that focuses on comparing different device designs' accuracy may reveal issues related to the design that may decrease or increase accuracy. For example, if one design results in the user to think it should be held a specific (and not ideal) way, it may lead to poorer accuracy and longer response times. If a design does not lend itself to recommended grip, it will not matter how fast an individual can activate and discharge the spray because they are going to likely miss or not hit the desired target. During the experimental design process, an eye tracker was planned to be used to track accuracy and gaze, however, pilot tests did not inspire confidence in use of this instrument to correlate gaze and location of spray impact on the monitor screen (recall it was covered to protect from spray).

Lastly, future research should focus specifically on hand posture when holding pepper-spray. Using motion trackers and other materials to accurately assess hand posture and movement may reveal that certain designs affords the user to hold the device incorrectly, leading to poor performance and longer response times. An interesting result could be how performance is affected if their index finger is used to discharge the spray compared to using the thumb. Lastly, as convenience sampling was used in this exploratory study, it is recommended that future studies recruit more participants to create a larger sample size to determine whether these results are generalizable to the broader population.

5. Conclusion

The results from this exploratory study indicated that in general individuals regardless of gender did not own a pepper spray and if they did, they did not receive any training on how to use pepper spray for self-defense. Additionally, individuals reported not carrying the spray on them when they went out, which defeats the purpose of purchasing this non-lethal self-defense device. A knowledge gap identified in this exploratory study was that individuals did not realize that aiming for the face (not eyes) is the best target to get the desired effects. All users were able to complete the task assigned after a brief review of the instructions, which is a good positive indication for learnability and efficiency of the product. While effectiveness was not quantitatively measured, the results indicate that participants were not confident in their ability to effectively use the pepper spray in a real-world situation. A mismatch between knowledge and practice gap was also observed with participant's observed use of index for the trigger finger whereas they reported that the thumb should be the trigger finger for the side-slide safety than the flip-top. Regardless of this mismatch, it was also noted that participants showed no difference in their confidence that they held the device correctly, which alludes to requirement for a formal training prior to use. While it is recognized that not every individual would be willing to undergo a formal training (unless required by the job), it is recommended that manufacturing include a training video on their websites and provide the link in the instruction manual. The results also indicate that creating self-awareness might prompt users to purchase and/or use pepper sprays as their main self-defense method, which is a very encouraging outcome.

With respect to the device design. the results of the current study showed a significant difference in overall response time between the flip-top and side-slide pepper-spray devices. There was no significant difference in response time for the starting locations of purse and pocket. Participants rated the side-slide pepper-spray as being easier to deactivate the safety, being faster to aim and fire, and being overall easier to use, despite performing worse in the majority of recorded variables in the lab-based experiment.

Because there is no other research in the area of first-time pepper-spray users, let alone civilian pepper-spray users, there can be much learned about how well people can use these devices in a real-world situation, and when there is a highly stressful situation how well does pepper-spray allow an individual to protect him or herself. While it appears that these mistakes should be easy to correct with proper training, however because there are no training requirements for owning pepper spray as well as no requirements for an intuitive design, people will continue to make these mistakes.

CRediT authorship contribution statement

David Strybel: Methodology, Investigation, Formal analysis, Writing - original draft. **Anil R. Kumar:** Methodology, Conceptualization, Formal analysis, Resources, Validation, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ergon.2020.103059.

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