Human motor control, autonomic and decision processes under physical and psychological stress. Instinctive, reflexive and adaptive aspects.

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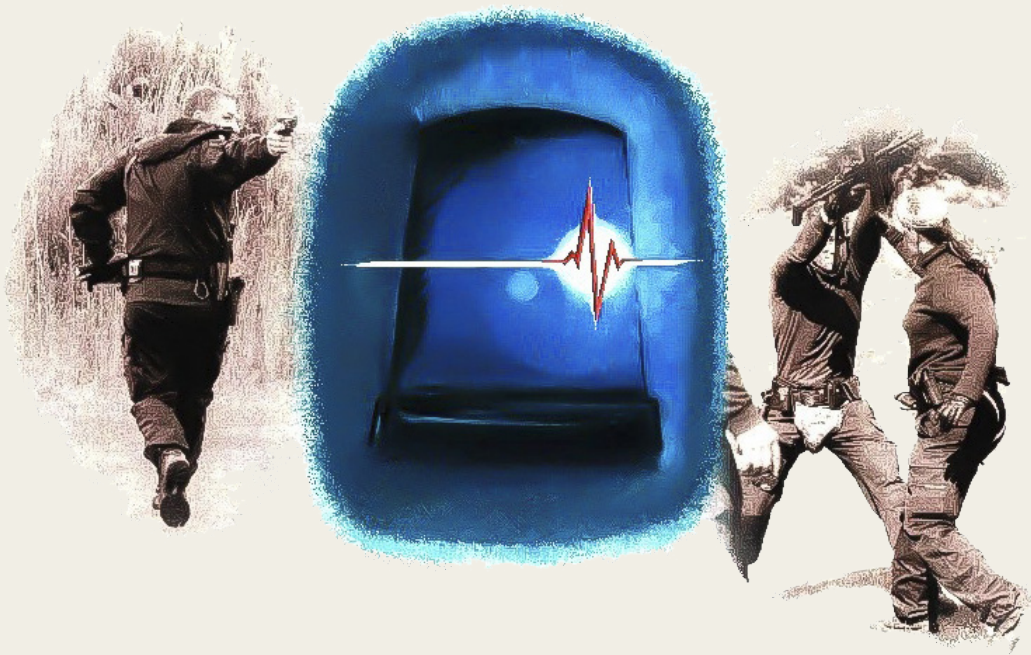

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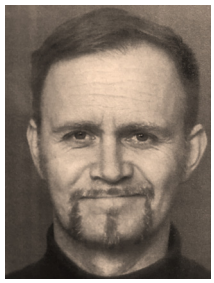

The stress response is governed by automatic neurological and hormonal processes that occur before we become consciously aware of a dangerous situation. If stress ensues for 15-30 seconds, the hormonal processes may have progressed so far that recovery takes an hour or longer instead of minutes. Stress can affect our behavior and in certain professions, such as the police force and emergency services, being in stressful situations is routine. When the stress imparted on an action is low, there may be little detriment to performance. However, when the stress imparted on an action is high, performance may be reduced and viewed as unsatisfactory.

This thesis has examined the situational characteristics and performance of police officers in stressful incidents where firearms and pepper spray have been used, and during training scenarios designed to induce stress. Pepper spray and firearms were often used differently in real situations, both operationally and technically, compared to the way they were used during training. When armed assailants were encountered in actual incidents, weapons were often used late on and at very short ranges. One real life event studied in detail showed that both police officers and civilian witnesses suffer from similar perceptual and memory distortions. When mimicking real situations for training through simulations, stress levels increased as evidenced by an increase in heart rate which may be used to ensure the closeness of training simulations to real events. When assessing the suitability of pupil dilation as a stress measure, the pupil underwent dilation in spite of large illumination increases, and the pupils also dilated when a threat emerged early in stress-inducing scenarios. Subjective assessments made by six experts separately, rated performance as being impaired in the simulated stress training in addition to poorer performance of a highly trained, complex, motor skill.

To conclude, stress can affect police officers during interventions and training, as it impaired perception and memory, cognition, decision-making and the motor skills necessary for equipment and weapon use. Hence, the consequences of stress responses should be considered when designing tactics, training and equipment so that tasks can be carried out well when stress is heightened. An increased understanding of physiological and behavioral changes to stressful situations in police officers will contribute to rationalizing outcomes and influencing policy based on scientific empirical and physiological grounds.

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Human motor control, autonomic and decision processes under physical and psychological stress

– Instinctive, reflexive and adaptive aspects

Johan Bertilsson

DOCTORAL DISSERTATION
by due permission of the Faculty of Medicine, Lund University, Sweden.
To be defended at Fernströmsalen, The Biomedical Centre, Sölvegatan 19, Lund University. Date Wednesday the 5th of June, 2019, at 13:00 pm.
All are welcome to attend.

Faculty opponent
Professor Stefan Holgersson
Politihøgskolen, Oslo, Norway

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Abstract

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Key words: Neuroendocrine stress response, Pepper spray, Police officer involved shootings, Memory distortions, Motor control

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Doctoral Dissertation Series 2019:57

“To understand the actual world as it is, not as we should wish it to be, is the beginning of wisdom.”
- Bertrand Russell

“Nothing in life is to be feared, it is only to be understood.”
- Marie Curie

“If you want to assert a truth, first make sure it’s not just an opinion you desperately want to be true.”
- Neil DeGrasse Tyson

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MADE IN SWEDEN

To
My wife Emma and my children Ida, Alvar and Vidar

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List of Publications

This thesis is based on studies reported in the following papers, referred to in the text by their respective Roman numerals.

I. Bertilsson J, Petersson U, Fredriksson PJ, Magnusson M, Fransson PA. Use of pepper spray in policing: retrospective study of situational characteristics and implications for violent situations. Police Practice and research. 2017;18(4):391–406.

II. Petersson U, Bertilsson J, Fredriksson P, Magnusson M, Fransson PA. Police officer involved shootings – retrospective study of situational characteristics. Police Practice and research. 18. 2017;3:306–321.

III. Dahl M, Granér S, Fransson PA, Bertilsson J, Fredriksson P. Analysis of eyewitness testimony in a police shooting with fatal outcome – Manifestations of spatial and temporal distortions. Cogent Psychology, 2018; 5: 1487271.

IV. Bertilsson J, Niehorster DC, Fredriksson PJ, Dahl M, Granér S, Fredriksson O, Mårtensson JM, Magnusson M, Fransson PA, Nyström M. Stress levels escalate when repeatedly performing tasks involving threats. (Submitted)

V. Bertilsson J, Niehorster DC, Fredriksson PJ, Dahl M, Granér S, Fredriksson O, Mårtensson JM, Magnusson M, Fransson PA, Nyström M. Towards systematic and objective evaluation of police officer performance in stressful situations. (Submitted)

VI. Bertilsson J, Patel M, Fredriksson P, Piledahl LF, Magnusson M, Fransson PA. Chapter 13. Efficiency of Simulated Realistic Scenarios to Provide High Psychological Stress Training for Police Officers. The Evolution of Policing. Worldwide Innovations and Insights. Eds. Melchor C. de Guzman, Aiedeo Mintie Das and Dilip K. Das; CRC Press 2013, Print ISBN: 978-1-4665-6715-3.

Other Publications

VII. Bertilsson J, Fransson PA. Innovative Possibilities: Global Policing Research and Practice. Invited review. Police Practice and Research, 2013, Vol. 14, No. 3, 268–272.

VIII. Bertilsson J, Fredriksson P, Piledahl LF, Magnusson M, Fransson PA. Chapter 9. Opportunities and challenges of research collaboration between Police Authorities and University Organizations. Economic Development, Crime, and Policing Global Perspectives. Eds. Frederic Lemieux, Garth den Heyer and Dilip K. Das; CRC Press 2014, Print ISBN: 978-1-4822-0456-8

IX. Bertilsson J, Fredriksson P. Chapter 8: Fire-arms and Self-Defense Training in Sweden. In Stanislas, Perry: International Perspectives on Police Education and Training, Routledge, Oxon and New York, 2014.

Abbreviations and definitions

Adaptation	Any change in structure, form or habits of an organism enabling it to function adequately in a new or changed environment
BPM	Beats per minute in heart rate
CNS	Central Nervous System
Decision time	Time to select an adequate response
EID	Electromuscular Incapacitation Device, e.g., a Taser®, where a delivered electric current disrupt voluntary control of muscles
FFE	Fire for effect, a firearm is used for incapacitating a subject
Habituation	The gradual adaptation to an environment, accompanied by an increasing feeling of certainty that a particular situation will produce a particular response
OC	Oleoresin Capsicum, the active agent in pepper spray
Perception time	Time to observe, locate (orient) identify (foe or friend), define threat
PNS	Peripheral nervous system
Proprioception	The sense of load, position or movement of one part of the body relative to another
Reaction time	Perception time + Decision time
Response time	Reaction time + Action time (Movement time)
Safe time	Response time + Time to effect
Stress response	Neurological and hormonal reflexive processes in response to a threat
Time constant	Time required for an exponential decay to reach 1/e of the initial value
Time to effect	Time for the action to make impact (immediate to none)
Warning shot	A shot fired in a safe direction to warn an aggressor that they will be fired upon if they do not comply with the police officer's instruction

Thesis at a Glance

Study	Question	Methods	Results	Conclusions
I	What are the situational characteristics, effectiveness and implications for violent situations when police use pepper spray (OC)?	936 incidents of OC use were investigated. Information was collected retrospectively as protocol.	OC was effective in stopping violent attacks. It was used against armed threats in 21% of incidents, which due to short range and lack of time was deemed unsafe.	OC is suitable for low threats, allowing 3-5 s of spraying from 2 m or less, but is not suitable for armed threats.
II	What are the situational characteristics and implications in police officer involved shootings?	128 police officers that used firearms 132 times in 112 incidents were interviewed using a structured questionnaire.	Firearms were often used at short ranges, with time constraints, and against moving threats. As officers were under stress, firearms where fired with one hand grips without use of aiming equipment.	Present firearm training is poorly adapted to real life situations. Better tactics for handling high threat should be trained.
III	Does the witness's perception and memory of a real life police officer involved shooting differ from the actual event?	13 witness statements, whereof 4 were police officers, were analyzed and compared to a filmed recording of the incident.	All but one witness did not recall the correct order of actions in the event. The distorted recollections were similar across witnesses.	Spatial and temporal memory distortions can be the same across witnesses, producing statements that can agree without being accurate.

IV	Do stress levels escalate when police officers repeatedly perform threatening tasks? Are heart rate and pupil size good stress biomarkers?	12 police officers performed 4 threatening police tasks in sequence. Their heart rate and pupil size were recorded and evaluated.	Heart rate increased mostly during the first task whereas pupil dilation responded poorly to large illumination changes	Repeated exposure to tasks containing threats initially increase heart rate. Pupil size changes were more unpredictable.
V	Can experts systematically assess police officers' skills? Can high stress levels impair complex motor skills?	12 police officers performed various threatening policing tasks while gaze, heart rates and actions were recorded, assessed and analyzed by experts.	Subjective assessments from 6 experts were consistent. High stress impaired extensively trained complex motor skills. Pupils dilated more if threats were presented early in the scenario.	Experts can systematically assess police officers' skills. Biomarkers may explain why performance sometimes deteriorates.
VI	Can simulated realistic scenarios provide high stress response levels in police officers? Can heart rate alone indicate an active stress response?	10 police officers performed the same scenario, first without and then with stressors, while equipped with devices recording heart rate.	Mean and peak heart rates were significantly higher (30 BPM) with active threat stressors.	Realistic scenarios can produce suitable stress levels for training. Heart rates objectively indicate stress.

Introduction

Experiences from the past and more recent

After about ten years of working with field duty service, I regarded myself as an experienced police officer, being able to handle also tougher situations. Then, one night, several years ago, when my colleague and I had just apprehended a drunk man for disorderly behavior, several men attacked us from behind. In retrospect, I had only fragmented memories from some events during this attack. One thing I remember is having trouble to control a very aggressive man I was grappling with. When he suddenly tried to put his fingers in my eyes. In rage, I threw him with unexpected force to the ground before pushing another man away from us. After that, I released my baton when I saw yet another attacker trying to pass a door attendant who was trying to help us. I hit the man on the upper arm with full force, but the baton seemed to move in slow motion. Finally, after about four minutes, backup police officers arrived. However, the incident felt much longer than four minutes, and we later found that our forearms and hands were bruised, although we did not experience any pain during the incident. We later had difficulty remembering the order of events. I also remember that a bit into the attack, I experienced that my eyesight became sharper and my attention was focused on constantly trying to view the hands of the attackers to see whether they had any weapons. I never thought of pressing the alarm button on my radio. It was my much more experienced partner who managed to do it, but it still took her two minutes. After the attack was over and the situation was under control, we found the apprehended man inside our patrol car, but had no recollection of putting him there.

Since that incident many years ago, several questions have been puzzling me. Why did we not remember parts of the incident or feel any pain? Why did we perceive the time of the incident as being longer than it actually was, and from where did I get my sudden increase in strength, strange sharpening of vision, strong attentional focus and slow motion perception?

From an evolutionary perspective, it is easy to imagine why survival of the human species would have benefited from moments of abnormal strength and faster sensory information processing in stressful situations. These evolutionary inherited stress

responses are not limited to the human species alone but can be found in most other mammals [1]. Genetically, we have not changed significantly since the Viking Age or even the collector-hunter-age. Thus, we are all influenced by the stress response to varying degrees in connection with threatening situations. However, what may come as a surprise to us living in a modern society is that these evolutionary super-human systems are still present in all of us but only seldom revealed because we rarely experience situations where these systems are activated. However, for emergency units like police officers, firefighters, and ER professionals, the situation is different, as these professions still are exposed to such threatening or dangerous events sufficient to evoke a strong stress response [2]. Without a stress response, we have limitations in terms of becoming aware of, localizing, identifying, defining and reacting to various problems or threats. Psychological stress is a natural human reflexive response evoked by threats. It can have both beneficial and negative consequences on our performance. Lower stress levels potentially correspond to better awareness, performance and improves chances of winning critical encounters [3,4]. Elevated physical and psychological stress is associated with poorer decision making [4], poor performance in shooting tasks [5] and a major cause of friendly fire in military operations [6].

There are ample examples of people having similar experiences as myself during situations of high stress. For instance, the effects of the psychological stress response have been known to be problematic through history, especially in conflict and war [7]. With varying success, psychological stress has been dealt with using armor, extreme training, discipline, alcohol, other drugs, religious fervor, punishments etc. Even the stress response itself in conflict has been used as a mean to overcome flight or freezing, by purposely turning fear into black rage. According to Näsström, the descriptions of the physical process of 'going berserk' in the Norse saga literature: "… *are almost identical in many of the sagas. The men began to tremble and then their teeth clapped loudly. Afterwards, they could tell about a cold that flowed through the body at this time. The cold was then replaced by a heat around the head, which eventually got its outlet in a powerful rage.*" [8]. When going berserk: "… *they felt neither pain nor fear but cut down everything that came in their way. When the rage ceased, they collapsed, exhausted to the limit of unconsciousness, and could hardly even defend themselves against attack. It also appears that when the rage has reached a certain stage, it was impossible to recall, even though the berserks ran a clear risk of being killed.*" [8].

The several centuries old descriptions above provide examples of the extreme effects of stress, with the automaticity corresponding to the activation of the autonomic nervous system. The autonomic stress response is initiated by the autonomic sympathetic nervous system through noradrenergic neurons, which subsequently initiates the release of the hormone adrenaline from the adrenal medulla (trembling, increased strength) including noradrenaline released into the blood system. The sympathetic stress response is characterized by glucose and fatty

acid release from stores, incipient constriction of peripheral blood vessels that diverts blood away from secondary tissues and to primary movers (cold flow, clapping of the teeth). Moreover, the stress response causes the release of endorphin from the pituitary gland and within the brainstem (pain insensitivity) and emotional rage (loss of impulse control and judgment) [7,9-11]. This is later followed by opposing parasympathetic actions (weakness and exhaustion). The negative effects, like diminished impulse control and an inability to function appropriately mentally, can remain for a substantial amount of time, which increases poor decision-making and in an extreme situation increases the risk of being killed. However, at the scene of a conflict, fleeing in panic, without being consciously aware of surroundings or other threats, poses a greater risk to one's life [7].

The autonomic response markedly affects sensory and perceptive functions, memory, cognition, decision-making and motor control [2,5,6,12-16]. These effects typically decrease task and motor performance and the ability to use several kinds of equipment. This thesis will start by presenting simplified descriptions of the most important neurobiological systems involved in producing a stress response. Moreover, it will describe how a stress response affects our sensory systems, the motor control and memory and how a stress response can induce psychological effects. The methods section will present the approaches used in the thesis to examine the real-life circumstances and effects of stress in medium and high threat situations (I, II, III). The stress response during test and training situations were evaluated with the biomarkers heart rate and pupil diameter (IV, V, VI). Furthermore, the reliability of using experts to assess performance was evaluated and after confirming their reliability, these expert reviews were then used to evaluate the performance of police officers when they performed repeated scenarios and tasks under different levels of stress (V). Lastly, the thesis evaluated the effectiveness of using artificial stressors to induce adequate levels of stress in police officers in order to desensitize the stress response (VI). The discussion section will address questions raised by the studies in the thesis, such as how the performance is impaired by stress and whether it is possible to improve performance under stress through training, despite the problematic effects of the reflexive neurobiological stress response.

Biology

The brain (CNS)

Although the entire width of the central nervous response in stress are not yet completely understood, science has revealed some of the mechanisms and have theories for others. The frontal lobes handle social behavior (personality), planning, selection of appropriate responses based on current stimuli including motor control. It is in operation when ethics, morals, reflection and emotions about self and

compassion are processed. The parietal and temporal lobes handle incoming sensory information, recognizing what a stimulus is and store information about it. The temporal lobes also play an important role for memory, hearing and emotions. The occipital lobes constitute the largest visual processing center in the brain [17,18]. The cerebellum is involved in balance control, movement coordination, fine motor control and when learning new motor tasks. The basal ganglia regulate simpler basic motor tasks. The thalamus is a relay station for sensory information to the cerebral cortex and it sends raw sensory information to the amygdala for early threat assessment. If a threat is recognized, the amygdala reflexively starts the stress response. The hippocampus is closely linked to the amygdala and is together with the amygdala important for both learning and memory [17]. The hypothalamus monitors the body's autonomous nervous system, where the sympathetic part promotes the stress response and the parasympathetic part counter-balance and restores the systems afterwards (see Figure 1). The brainstem controls amongst other things breathing, blood pressure, heart rate and maintains consciousness through an ascending network of adrenaline, noradrenaline, serotonin and dopamine neurons [17].

The brain processes information in several ways. One method is the rational thinking that we have access to in case of low emotional activation, i.e., lower stress levels. It involves reflection and delayed activity. Another information processing method is experience-based thinking that becomes prevalent in stronger emotional activation, higher stress levels, and which is focused on immediate action. This method is automated and takes over quickly if a dangerous situation arises [19]. During a stress response we tend to base our actions on past experiences and not on deliberate assessment of events in the decision-making process [19].

When a stress response is started, the brain itself is affected in several different ways depending on the strength of the stress response. The performance of different perceptive, cognitive and motor abilities follows an inverted U-function with increasing stress levels, i.e., the performance increases when the stress levels increase from low to moderate and thereafter decreases if the stress levels increase from moderate to high levels [20-22]. Parts of the frontal lobe involved in attention, memory, emotion and motor control, have shown to receive decreased blood flow when the stress response is activated, which causes an alteration of the neural activity [13]. Reduced blood flow to these brain areas is believed to impair judgement, ability to plan, impulse control, and decrease the ability to feel sympathy and to think with nuance. The stress response may also affect cerebellar motor control including cognitive functions dependent on cerebellum and other circuitry in communication with the cerebellum [14]. Acute stress has also been shown to impair sensory performance and motor control in rats [15] and other studies suggest that similar problems can be caused to human performance when affected by a stress response [5,6].

The autonomous stress response system

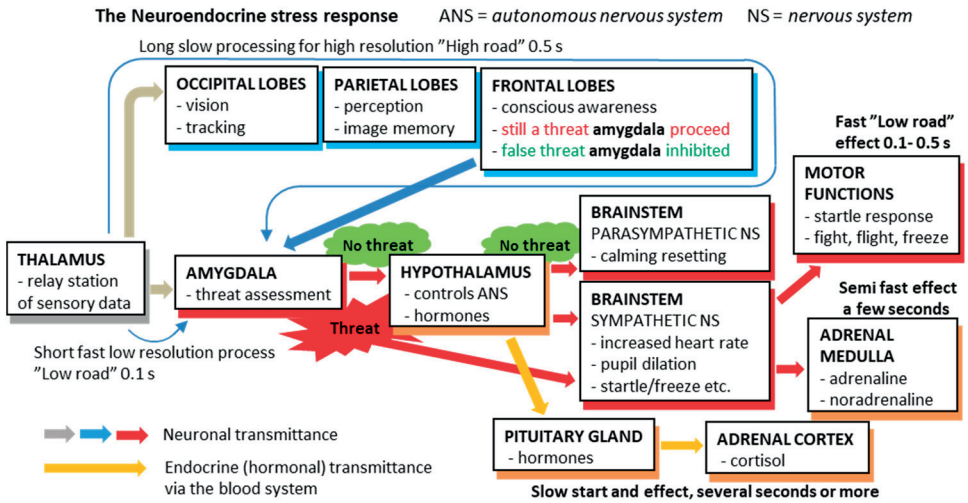

Figure 1. The "Low road" startle muscle contractions begin around 0.1 s after amygdala reacts to threat within low resolution data from the sensory system. The "High road" is slower but provides higher resolution of the threat and inhibits amygdala if the threat proves to be false. Adrenal medulla secretes adrenaline and noradrenaline to the blood within seconds and if not inhibited within 15-30 seconds will take an hour instead of minutes to recover. Adrenal cortex secretes cortisol to the blood within 15-30 seconds and if not inhibited within a minute the cortisol levels rise long after the threat is over, thus increasing the time needed for recovery to hours. However, all described timeframes are approximate estimates because they are affected by the strength of the stress response [23-26].

Activation and implementation of stress responses during threatening situations are built into human neurology. The efferent part of the peripheral nervous system (PNS) is divided into the somatic motor part connected to skeletal muscles, that can be consciously controlled, and the autonomic part, that functions reflexively and only on an unconscious level [17].

The autonomic nervous system's sympathetic part executes the stress response. The sympathetic activation results in increased attention, pupil dilation, dilation of airways, constriction of blood vessels, increased blood pressure, increased heart and breathing rate, which are all part of the fight and flight response [17,27,28]. However, the role of the parasympathetic nervous system is mostly to reverse the stress response by calming, relaxing and restoring, decreasing heart rate and breathing, constricting pupils, dilation of peripheral blood vessels and restart digestion [17].

Sensory information informs us of what is happening around us. From the sensory receptors, information passes to the thalamus before being processed in the appropriate area of the cortex. The thalamus also sends raw data of available

information to the amygdala for a first quick risk analysis. If the analysis of amygdala recognizes any part of the raw unstructured information as a possible threat, the amygdala starts the stress response [24,27]. This activation takes place before we become consciously aware of what the information consists of due to the time it takes for the information to be processed in the occipital, parietal and frontal lobes cortices. Thus, the visual information is processed in a slower but more detailed analysis to confirm if a threat is real or not [29] (see Figure 1). In other words, even if we immediately see the face of the person who surprises us when jumping out of a closet with a shout, we first realize with delay that it is someone we know. Then, we already suffer the effects of an early strong autonomous sympathetic stress response. Thus, it is not possible to avoid the initial reflexive fast sympathetic stress response from a sudden surprising threat. The same applies when the threat is perceived as catastrophic or when the threat is previously unknown to us [6]. A sudden threat stimulus evokes a startle reflex response. This is a fast bilaterally symmetric motor response causing blinking and muscle contractions that, if strong, may result in a crouching body posture [24].

The endocrine stress response system

When the amygdala detects a threat from sensory information, it starts and drives a stress response. If the threating stimulus does not stop or is incapacitated quickly, the endocrine adrenal medulla of the adrenal glands at the top of the kidneys will increase the blood concentrations of adrenaline increasing the body's sympathetic response [17]. When the amygdala starts the stress response yet another endocrine stress system is activated called the HPA-axis, where the hypothalamus signals to the pituitary gland to produce and release endorphins and hormones to the blood system making the adrenal cortex release other stress hormones like cortisol into the blood system [17]. However, the first part of a stress response is that the nervous system releases noradrenaline giving the first rush. This gives a very fast and strong response using electrical signaling to organs. Since these resources run dry within seconds, one of the most important sympathetic target organs is the kidney adrenal medulla, which starts to produce and secrete noradrenaline and release adrenaline into the blood system, thus reinforcing the stress response in the whole body. This process needs a few seconds to begin and then this process continuous to increase the concentration of these stress hormones in the blood as long as the threat signals continue. Hence, if we do not receive calming information within seconds, or the response is very strong, the stress hormone concentrations in the blood continue to build up, causing an augmentation of the stress response and its physical and cognitive implications. However, if the slower conscious perception of the event results in information that negates the threat within seconds, the stress response will be inhibited before the somewhat slower initiation of the endocrine adrenal glands

has increased the blood concentration of the stress hormones substantially. Thus, receiving calming information within a couple of seconds can make the stress response reset and make us recover from the stress response effects within minutes because the autonomous stress response reverses fast (see Figure 1). That said, if calming information has not been received within a minute, noradrenaline and adrenaline spread throughout the body and the recovery time from the stress response can increase from a couple of minutes to hours [12,23,25,26,30,31]. This increased delay in stress recovery is caused by a physical limitation in reabsorbing and disintegrating stress hormones already distributed in the body. A recovery process from a stress response can typically not start while the stressing event is ongoing.

The hypothalamic-pituitary-adrenal axis is slower than the sympathetic-adrenal medulla system, and it takes minutes to increase the levels of cortisol to measurable levels in the blood (see figure 1). Cortisol contributes to the increase of glucose concentration in the blood, which provides more accessible energy to the brain and muscles [32]. Cortisol in moderately increased levels in the blood has been shown to enhance memory, but very high levels of cortisol impair memory [12,33]. Adrenaline is less common as a transmitter substance but contributes to increased heart rate, increased strength in skeletal muscles, increased blood pressure, constriction of peripheral blood vessels in the skin and internal organs, and more fatty acids and glucose in the blood available as energy. However, as the transmitter substance, it also drives certain neurons in the brainstem to sharpen consciousness [32]. Noradrenaline is also used in the brainstem and is of importance for attention, alertness, sleep and eating habits. In the sympathetic ganglion neurons of the autonomic nervous system, norepinephrine is the major peripheral transmitter [17]. Noradrenaline is important for hippocampus memory functions and has an inverted U-shaped relationship for prefrontal cortex working memory functioning following different noradrenaline levels, thus impairing working memory during high stress [12,31]. Dopamine contributes to motor control and regulates feelings of motivation and reward. Higher levels of dopamine in the frontal lobe due to the stress response also impair cognition and even mild sudden stress can cause loss of abilities fast [12,34].

The endocrine stress response systems also function reflexively and are activated simultaneously but have somewhat slower activating processes due to the delivery via the blood system. However, when fully activated and with very high concentrations, the individual can have a very strong stress response for hours. However, when the activation has increased the concentrations of the stress hormones in the blood, it will take much longer to reset the system and for one to recover from the effects. As adrenaline is a hormone and circulates in the blood, it will affect the sympathetic nervous system long after the threat disappeared, thus affecting and impairing several different physiological, psychological, cognitive and motor control functions [12,30,31].

Internal processes

The stress response affects several internal processes directly through the sympathetic nervous system and more indirectly through the endocrine stress response system. This results in a widened (dilated) pupil for increased light infusion, inhibited saliva secretion, contraction of superficial blood vessels and blood vessels in internal organs (vasoconstriction), which contributes to increased blood pressure, the airways widen with better oxygen perfusion as a result, the heart rate and breathing rate are elevated. The sweat glands are activated which, in combination with cold pale skin due to vasoconstriction, are perceived and described as 'cold sweat'. The digestive tract in the stomach stops digestion, the insulin secretion in the spleen is slowed down by glucose secretion and the liver begins delivering glucose and fatty acids to the blood for increased energy supply. The strength, tension and blood supply to the skeletal muscles increase. The blood flow in the skin and internal organs decreases and vascular resistance increases peripherally with increased blood pressure as a result [32]. Bowel activity is slowed down and the bladder becomes slack and in extreme stress situations involuntary emptying of colon and bladder is effectuated [17]. The hair on the body rises with the help of hair-raising muscles, which on a dog look more imposing [32].

When the stress response is stopped, the parasympathetic nervous system is activated and contributes to pupil constriction, salivation, constriction of the airways, suppressed heart rate, stimulated digestion, dilation of peripheral and intestine blood vessels and contraction of the bladder [17].

Stress effects on the sensory systems

The visual system

Already without a stress response, it is difficult to detect a sudden change in our field of view if it occurs when we actively focus our attention on something specific or look away for a brief moment [35]. This phenomenon is called change blindness. We can only focus on a limited part of our visual sensory input. Changes in the visual field that occur during a blink or a rapid reflexive eye movement (saccade) can also pass unnoticed. If the change is unexpected, very large visual changes can pass unnoticed [36]. Another related well-documented phenomenon is inattentional blindness, which means that we only notice what we are actively expecting to see, thus, everything else in our visual field passes unnoticed. We therefore observe and remember only the objects and details we devote focused attention regardless of whether the object is close or far away from our visual point of focus [37].The same applies to complex activities and events that may pass unnoticed in dynamic processes [38]. However, the memory of activities within the peripheral visual field

might be more impaired than memories of activities within the central visual field due to attentional narrowing [39].

A psychological stress response entails a number of neurological and perceptual consequences, where not least vision is affected. Experience of extra visual clarity or sharpness of eyesight is common during high stress situations [2]. Another effect is strong attentional locking on the threat if such is visible and especially on weapons if these are presented (the weapon focus effect) [40-42]. This phenomenon may increase the effect of inattentional blindness or perceptual load. Other common high stress effects are tunnel vision [2], increased blinking frequency (reinforces change blindness) or no blinking at all [43]. Typically, the pupil dilates during stress from an autonomous sympathetic nerve reflex [17]. The eye's depth of field is thus very short, which means that everything in front of and behind what is in focus becomes blurred [44]. Another factor to consider during stress is that a very strong stress response can lead to perceptual narrowing, which may increase the cognitive uncertainty and anxiety, which in turn can increase the stress response in a vicious spiral [21]. Extreme stress even impairs perceptive cognitive processes and may create false memories [2].

The auditory system

Stress increases our inability to perceive a change of voices [45]. In shooting incidents, police officers often experience diminished sound, sometimes to the degree that they do not hear their own gunshots. Typically, the loud sound from a close distance gunshot produces a ringing in the ears if the ears are unprotected. However, in high stress situations this residual effect may not appear. Less frequently, during a stressful event police officers experience regular sounds as extremely loud [2].

The tactile sensory system

The nature of the sensory information from skin and muscles is largely influenced by the properties of the various types of receptors and their distribution throughout the tissue. Touch, pressure, vibration, the position of the limbs in relation to the environment constitutes different types of sensations that we can perceive. The speed of somatosensory information in nerve fibers varies from 2 m/s to 120 m/s depending on type of neuron. These differences are substantial, and affect how fast we can become aware and respond to different stimuli. Large parts of the autonomous sensory information that underlie the everyday regulation of a variety of autonomic body functions are never (secretion, vascular resistance, etc.) or rarely consciously perceived [17]. It is governed by an autonomous network in the brain where the hypothalamus is one of the most important components.

Pain is one sensation that in itself may induce different levels of the stress response depending on the strength, if it is sudden or unexpected, persistent or

unfamiliar. When nociceptor impulses reach the brain, the information is sent to several different parts. Via the thalamus, impulses reach the somatosensory cortex, where space, surface and kind of pain are noted. Cerebellum mainly gets information to the cerebellar cortex to inhibit ineffective activities [46]. A second "parallel" task and path for pain impulses with multiple pathway offshoots affects, among other things, the sympathetic part of the autonomic nervous system and emotions. The parallel pathway reaches parts of the brainstem associated with initiating pain relief mechanisms and protective motor functions and for motor feedback from the cerebellar cortex [17,47].

Stress effects on motor control

Motor skills can be defined in several ways. Schmidt et al. describe movements as discrete events with beginnings and ends (throwing), sustained cyclic (walking, running) and as a sequence of discrete movements (playing the piano) [48]. They also define the term ‘closed skills’, where the environment is predictable (write, target shooting), and the term ‘open skills’, where the environment is unpredictable (street fight, battle) with a descending scale with semi-open skills connected to a semi-predictable environment (driving a car in regulated traffic). In addition to these terms the terminology of fine, complex and gross motor skills are also defined [48]. Typically, the fine and complex motor skills start to become affected already at low to moderate stress levels whereas the gross motor skills might benefit from a stress response. Our own experiences from police training are that the fine motor dexterity becomes decreased at moderate stress levels during training scenarios while complex tasks are performed well under moderate stress. However, a seemingly simple skill like a straight punch, i.e. fast triceps extensor action with relaxed biceps, might be less effective during a strong stress response due to the adrenal increased skeletal muscle strength and tension [49] also affecting the biceps, which counteracts the triceps action, and slow down a straight punch but not a swing. Hence, the present separation of movement patterns into fine, complex and gross motor skills may not properly reflect to what extent a stress response influences the ability to perform all individual tasks defined within each motor skill category [21].

Fine motor skills

Fine motor skills are important for the ability to use smaller muscle groups, e.g. fingers or hands combined with eye coordination, and especially for the ability to perform precise and complex hand and finger movements and precise motor control positioning. Examples of tasks that require fine motor skills are to perform surgery, handle the safety lever on a firearm, precise aiming using sights, and using a pepper spray canister [21,48]. It becomes increasingly more difficult to perform fine motor

skills and tasks demanding large cognitive effort when the heart rate starts exceeding 115 beats per minute (BPM) due to a stress response [21].

Complex motor skills

Complex motor skills encompass the ability to use different muscle groups in a composite sequence with accurate timing to produce a specific outcome or an asymmetrical static posture involving more than three independent constituent sequence parts or muscle groups, e.g., dancing, martial throws or asymmetric stances. Other examples of complex motor skills are the ability to adapt and respond to a continuously changing environment using tracking, timing and multiple techniques [21,48,50]. The ability to perform complex motor skills and tasks demanding moderate cognitive effort typically becomes increasingly difficult to perform when heart rate exceeds 145 BPM [21,22].

Gross motor skills

Gross motor skills refer to the ability to use large muscle groups in simpler tasks such as maintaining and stabilizing our upright position, locomotion and powerful lift, push, pull or jump activities. Gross motor skills have been described to become more effective when heart rate increases to between 175 and 220 BPM due to a stress response [21]. This enhancement of performance can be explained by the fact that increased adrenaline levels during a stress response not only increase the heart rate but also increase the skeletal muscle tonus and strength [17]. Gross motor circuitry and programs are situated in the spinal cord and brainstem, and are not, in contrast to the fine and complex motor skills, dependent on the cerebellum for motor control implementation. The functioning of the cerebellum can become affected at high stress levels [14].

Heart rate

The stress response can affect cognitive and motor control performance. The relationship between heart rate and performance is commonly described with an inverted-U shaped function. Consequently, performance is typically poor at low and high levels of heart rate, whereas somewhat higher levels of heart rate than normal are associated with higher levels of performance. The optimal performance is achieved at a specific heart rate level, which depends to a part on individual skills or abilities [21,22]. For fine motor control the optimal heart rate commonly lies between 80 and 115 BPM and for complex motor control between 115 and 145 BPM. Thus, to assess arousal or activation level of the stress response, heart rate has commonly been used [3]. However, more recent studies have argued that heart rate alone does

not fully account for the variation in performance, since the performance is also influenced by factors such as previously developed stress habituation 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 [3,48]. Hence, if the heart rate indicates a high stress level without a decrease in performance, this may be because the shape of the inverted U-function is different for, e.g., an experienced individual [22].

Stress effects on memory

Memory can be categorized as long-term memory, that uses many parts of the brain, and short-term memory, that is part of the function of the frontal and parietal lobes. However, our senses also store information for very brief moments in what is called the short-term sensory store (STSS). The enormous flow of sensory information is thus temporarily available, for a fraction of a second in the STSS, for our working memory, which is a part of our short-term memory, where certain parts of the sensory information can be stored for processing. The working memory can also retrieve and store parts of information from the long-term memory for processing and integration with the latest information flow of highest interest. The working memory has unconscious functions and is part of how we consciously process the information [48,51]. Hippocampal functioning is necessary to store short-term memory content in the long-term memory. One explicit, consciously available part of the long-term memory referred to as the semantic memory, represents our ability to store and retrieve facts, meaning, concepts and ideas [52]. The other part of the long-term memory's explicit memory function termed episodic memory refers to our ability to store what-when-where information of previous experiences and retrieve it to adapt behavior in new situations. Episodic memory likely has a long evolutionary history and is shown in birds, rodents and primates including humans [53]. Negative cue (even fear) conditioning and spatial (where) memory consolidation are improved by moderate stress, but explicit memory retrieval becomes impaired [54]. Fear conditioning to normally neutral objects, smells, places or training situations, can later activate the stress response when experiencing the neutral cue, and thus, can become a problematic part of PTSD [12].

Inattentional blindness and several other factors may affect our conscious perception of an event. A stress response initially increases our focus of attention and sharpens our senses, improving our ability to perceive and recognize important patterns when comparing them with old previously stored or inherited patterns of sounds, weapons, behaviors and patterns of events to assess and select required responses. However, if the stress response becomes very strong, dilated pupils and other effects cause perceptional narrowing. Thus, the ability to process information starts to deteriorate which also causes impaired memories. However, cortisol in

itself affects memory positively at moderately increased levels, and negatively at high levels [33,55]. Stress also leads to impaired working memory connected to parts of the frontal and parietal cortex [16,30,56]. Common effects of high stress on perception and memory of police officers in shooting situations are experiences of slow motion, loss of memory for parts of own behavior or the event. Some police officers experienced memory distortions or fast motion time, e.g., when time seems to pass faster, than it actually does [2].

Psychological stress effects

The cognitive impairment connected to the stress response [2,16,56] may result in several psychological effects ranging from no perceived emotions and absence of thoughts to shear fear or panic [2,7]. Extreme survival stress with hormone-induced heart rate between 185 and 220 BPM can cause hyperactivity in the sympathetic nervous system, which can trigger panic reactions with behaviors and motor responses in the form of irrational flight, fight, freezing, submission and hyperventilation, motor symmetry effects, and repetitive movements [7,22,57]. What is perceived as 'freezing' in retrospect might have different causes. One reason might be that the recollection of the slow passing of time may make a person believe they have frozen. The freezing response is due to temporary activation of the amygdala in preparation for fight or flight. The amount of information to process might become overwhelming or the information too malevolent to allow a rational analysis due to increased stress activation or feelings of dissociation, 'this is not happening…' causing inactivity, which in retrospect might be perceived as freezing even if there was no real 'freezing of movements' taking place.

The stress response may not cause any particular emotions when in effect. One explanation for this differentiation of emotions and the physiological stress response might be that this is an effect of inattentional blindness obstructing visual awareness or that it is due to two separate circuits processing the physiological stress response and the emotional content. Whatever the neurological explanation, still the occurrence of the sometimes separated effect is undisputed [58,59]. Still, feelings of fear and panic are not uncommon in police officers involved in shootings. However, one study regarding officer-involved shootings showed that three out of four police officers went into an "automatic pilot" mode with little or no conscious thought, two out of five experienced dissociation, sense of detachment or unreality, and one out of four experienced intrusive distracting thoughts [2].

Aims of this thesis

I. To investigate the situational characteristics and the effectiveness of pepper spray to address violent behavior and to evaluate factors associated with operative and tactical limitations with pepper spray during real policing situations.

II. To perform a systematic evaluation of the situational characteristics during high threat shooting incidents and the police officer's actions taken to handle them, including analyzing signs of human physical and psychological limitations.

III. To analyze whether perceptual distortions occurred in eyewitness testimonies, by comparing the testimonies with films of the event, when watching a real life event where police officers were involved in a shooting incident with lethal outcome.

IV. To determine whether repeatedly performing moderately threatening policing tasks, executed in a rapid sequence with only a brief rest between tasks, cause an altered stress response as assessed by the biomarkers heart rate and pupil diameter.

V. To investigate how executing policing tasks at different levels of threat and repeatedly with only brief rests between tasks influence the perceptual, cognitive and motor skill performance and physiological measures.

VI. To evaluate whether a realistically simulated active shooter scenario effectively can produce high levels of psychological stress in experienced police officers.

Methods

The methods used in the investigations were selected with the purpose of objectively measuring the performance of police officers conducting various policing tasks under different levels of stress; from a situation eliciting no stress to life threating events. One limitation in some of the studies is that the real life, high threat events, are so rare in Sweden that they are not practically feasible to monitor, e.g., heart rate recordings. Hence, the situational characteristics had to be determined retrospectively from questionnaires and interviews of the police officers involved, which might introduce errors since the subjects involved may not be able to remember all details.

Evaluated parameters

Heart rate

Heart rate was measured using two different devices. Heart rate in study IV and V was recorded with a Zephyr Bioharness® 2.0 (Zephyr technology cooperation, Annapolis, USA) which sampled the ECG activity at 250 Hz. In study VI, a Polar Team System™ equipment (Polar Electro, Sweden) was used. Both devices stored the heart rate data on a computer memory integrated in the recording device.

Pupil diameter

In studies IV and V pupil diameter was recorded with eye tracking glasses from SensoMotoric Instruments (SMI), Berlin, Germany. Pupil diameter was recorded at 30 Hz and the recorded data were stored on a portable computer to which the glasses were connected. A problem with using pupil size as a biomarker is that factors other than a stress response may produce alterations of pupil diameter. For example, changes between illumination levels affect pupil diameter via the pupillary light reflex [60,61].

Scoring made by experts in police training

In study V, the performance of each participant during each of the tasks was rated by six experts in police officer training. The experts reviewed performance using a

front-facing camera on the SMI eye-tracking glasses, displaying a participant's gaze overlaid on the video. The experts also reviewed video recordings from three Go-Pro™ 3.0 cameras. These cameras recorded sound and displaying an overview of the scene from different viewpoints, see Figure 2. The experts were allowed to watch the participant's performance as many times as they wanted. The order in which the experts rated videos from the different participants and tasks was randomized. The experts scored the participants' performance using a custom questionnaire, targeting seven different aspects of the performance. These categories were; I - perception, II - verbal contact, IIIa - verbal voice control, IIIb - general motor control, IIII -spatial and V - temporal tactical implementation, and VI - overall situational control.

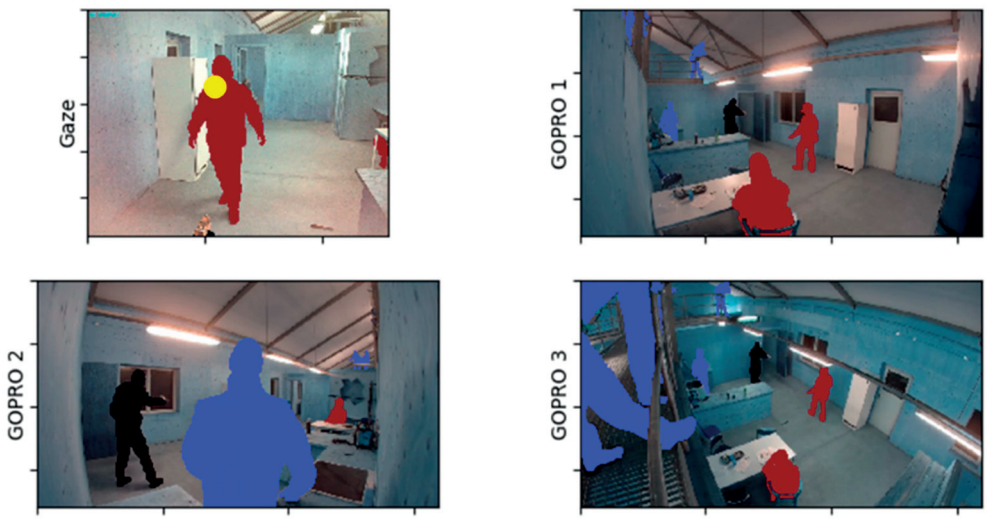

Figure 2. Experts in police training scored the participant's performance using information from the front-facing SMI camera (top left), presenting a first-person view and the participant's gaze location (yellow dot). The three go-pro cameras monitor the scene from different viewpoints. The study participant is marked in black, the scenario figurants are marked in red and the scenario instructors are marked in blue.

Questionnaires and interviews

Information from real life police intervention incidents were collected in studies I, II and III, by using combinations of questionnaires and interviews. In study I, characteristics of the pepper spray (OC) incidents were determined from the standardized protocols used by the police when reporting OC incidents. The questionnaire information was sorted and analyzed into three categories: scenario information, factors influencing the effectiveness of OC spray, and longitudinal changes of how OC spray was used in the context of present crime rate, see Table 1.

Table 1. Pepper spray (OC) incident 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 of use. OC incident frequency variations over the Years, Months, Day of the Months, Day of the Week and hour of the Day.

In study II, the situational characteristics during real life shooting incidents with police officers were obtained using both questionnaires and interviews. To minimize the possibility for misinterpretation of the written questions, all police officers that had used their firearm during an incident were interviewed using a predesigned questionnaire. The same study investigator performed all but a few interviews with the police officers involved in the incidents. The information collection was performed after the legality of the shooting incident had been determined, which was usually completed within a few days after the incident. The incident information collected and analyzed during the interview are presented in Table 2.

Table 2. Firearm incident information collected.

Assailant and police officer profiles	Evaluation of (1) Age; gender and armament of the assailant; (2) Age; gender; work experience of the police officer and kind of police unit involved.
Scenario conditions	Evaluation of (3) Perceived time from threat emerged till shots fired (police); (4) perceived distance to assailant when shots were fired and relationships between shooting distance and assailant armament. (5) Assailant actions; (6) Police officer actions; (7) Police force on site and active in the incident; (8) Incident locations, risks for bystanders and ricochets; (9) Visual conditions.
Other incident details	Evaluation of (10) Initial police assignment; (11) Initial encounter phase; (12) Implications of affected motor skills from psychological stress; (13) Circumstances at accidental shots.

In study III, four police officers and nine civilian witnesses observed a real life shooting incident. These thirteen witnesses were interviewed by twelve different police officers and all interviewees read and confirmed the correctness of their statements. The interviews included questions about presence of weapon, numbers of shots fired, what did persons involved say, what happened and in what order etc.

Analysis of parameters

Heart rate

In study IV, heart rate was analyzed both as mean values and as rate of change with a regression analysis within four time windows, see Figure 3. The **Onset** time of each task was defined as when the door between an anteroom and a scenario room was opened, and thus, when the scenario was revealed to the participant. The **Offset** time of the task was defined as the moment when the scenario instructor terminated the task with a verbal "abort" command. For both heart rate and pupil diameter, analyses windows were defined as a 5-second period before the task **onset** (denoted **Pre Onset**) and as a 5-second period after the task **onset** (**Post Onset**). Additionally, analyses windows were defined as a 5-second period before the task **offset** (denoted **Pre Offset**) and as a 5-second period after the task **offset** (**Post Offset**). These analysis windows are illustrated in Figure 3.

In study V, the average heart rate during each of the tasks was analyzed, see Figure 3. The **Onset** time of each task was defined as when the door between the anteroom and scenario room was opened, and thus, when the scenario was revealed to the participant. The **Offset** time of the task was defined as the moment when the scenario instructor terminated the task with a verbal "abort" command.

Finally, in study VI, the heart rate was determined at three states: 1) Start heart rate (steady state heart rate in beats per minute (BPM) before the start of the exercise); 2) Maximum heart rate (maximum heart rate recorded during the exercise, in BPM); 3) End heart rate (steady state heart rate after the end of the exercise, in BPM). Values were also calculated illustrating the time (in seconds) taken to reach the maximum steady state heart rate level and recover from it. Lastly, the heart rate change over time (in BPM/seconds) was calculated to illustrate the gradual increase and decrease in heart rate during the activation phase and recovery phase respectively during the exercise.

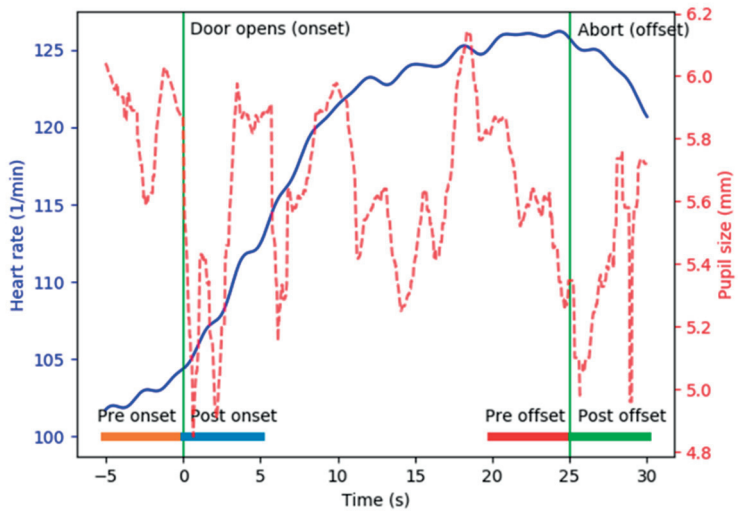

Figure 3. A participant's heart rate (blue) and pupil diameter (red) when performing a task. The 5-second analyses windows submitted to detailed analyses are marked by the horizontal bars denoted Pre onset, Post onset, Pre offset and Post offset.

Pupil diameter

In study IV, the pupil diameter (mm) was analyzed both as mean values and as rate of change with a regression analysis, within four time windows, see Figure 3. For details of the windows see the Heart rate section above.

In study V, the average pupil diameter during each of the tasks was analyzed. The **Onset** time of each task was defined as when the door between the anteroom and scenario room was opened. The **Offset** time of the task was defined as the moment when the scenario instructor terminated the task with a verbal "abort" command.

Questionnaires and interviews

The data from the questionnaires in study I were analyzed with the aim of determining if the four properties Response to OC, Reduction of violence, Dosages and Distance were affected by the factors Gender, Species, Intoxication, Mental Illness, Armed assailant, Indoors/Outdoors location, Windy condition and Age. Additionally, analyses were performed to determine longitudinal changes in how OC was used during the incidents.

In study II, the collected information were partly analyzed by performing a systematic presentation of all findings. A detail statistical analysis was performed to determine whether relationships could be found when shots were fired as a warning or for effect.

Finally, in study III, the degree of consistency between the statements and the actual related event was evaluated by two of the authors independently. The witness statements were organized along a timeline based on timing of the actual event, as revealed by films of the event. However, the witnesses did not give any estimates of the duration between, for instance, the shots fired.

Statistical analyses

In study IV, the heart rate and pupil diameter during the four repeated tasks were analyzed using repeated measures ANOVA. The main factors and factor interactions analyzed were: 'Repetition' (Task 1…4; d.f. 3); and 'Window' which were evaluated for three different pairs of analysis windows (door opening: Pre Onset vs. Post Onset, task execution: Post Onset vs. Pre Offset, and abort command: Pre Offset vs. Post Offset, d.f. 1).

In study V, the seven questionnaire categories (I-VI), the average heart rate, and the average pupil diameter during the four repeated moderate threat tasks 1-4 were analyzed using repeated measures GLM ANOVA. The main factor was 'Repetition' (Tasks 1, 2, 3, 4; d.f. 3).

The repeated measures ANOVA method was used in both studies IV and V after ensuring that all dataset combinations analyzed in the study with this statistical method produced model residuals that had a normal or close-to-normal distribution [62].

In study I, Mann–Whitney between-groups test were used to determine if specific factors, e.g., gender of target, distance to target etc., influenced the effect of OC spray.

In study IV, Wilcoxon matched-pairs signed-rank tests (Exact sig. 2-tailed) were used for within-group post hoc comparisons, i.e., analyzing the accumulated changes from task 1 to task 4. Moreover, the same test was used in study V, for within-group post hoc comparisons, i.e., analyzing the differences between tasks,

and in study VI for analyzing the parameters recorded during (1) the dry-training exercise and (2) the police officer team exercise.

In study I, the longitudinal changes and distribution profiles were analyzed with linear regression except in three stated cases where an exponential regression model better matched the profile. Moreover, in study IV, the best fitting dynamic patterns and time constants describing the changes in heart rate and pupil diameter during the four time windows (Pre Onset, Post Onset, Pre Offset, Post Offset) during each task were determined by using regression models after evaluating different regression models for best fit. A linear regression model was found to describe best the changes in heart rate whereas an exponential regression model was found to describe best the changes in pupil diameter over time.

In studies I and II, the collected data were analyzed using the non-parametric Spearman's Rank correlation test to determine the presence and strength of systematic relationships, e.g., if the effectiveness of OC spray changed with the age of the subject targeted with OC spray.

Nonparametric statistical tests were used in all studies as the Shapiro–Wilk test revealed that the dataset were not all normally distributed, and normal distribution could not be obtained with log-transformation. In all analyses, the p-value considered significant was set depending on the number of comparisons made, in line with Bonferroni correction procedures [62]. All statistical tests were performed using SPSS™ versions 21.0 - 24.0 software (SPSS Inc., Chicago, IL, USA).

The Investigations

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

The aims were to investigate the situational characteristics and the effectiveness of pepper spray (OC) to address violent behavior and to evaluate factors associated with operative and tactical limitations with pepper spray during real policing situations.

Subjects:

During the period investigated, between years 2006 to 2012, data was collected from when 457 police officers (80 % males) used pepper spray in 936 incidents. The subject exposed to the OC spray involved a male (*M = 31* years, 94 % of the cases), a female (4 %) or a canine (2 %). In 16 % of the incidents, more than one subject was active or threatening when the OC spray was used.

Study design:

Information about OC incidents was collected from 936 standardized protocols used by the police when reporting OC incidents. The protocol was typically filled in by the police officers the same day the OC event occurred.

Results:

In 43.9 % of the OC incidents, the police officers defended themselves or others against attacks. In a large proportion of the incidents (21.1 %) the OC spray was used to address subjects armed with objects that could potentially be lethal if used. In 10.7 % of the incidents, the subject was armed with a sharp object (e.g., knife, axe) and in 6.5 % a blunt object (e.g., flask, iron pipe, stick). Furthermore, in 19.9 % of the encounters, the subject was presumed to be under the influence of drugs or alcohol and in 10.0 % of the cases, the subject was presumed to be mentally ill.

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. 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.

The factor evaluation suggests that larger dosages were applied on mentally ill and these were sprayed at significantly longer distances than healthy subjects were. Furthermore, armed assailants were sprayed with significantly larger dosages of OC and at significantly longer distances than unarmed subjects were. Alcohol/Drug intoxicated subjects were sprayed at significantly shorter distances than healthy subjects were.

The OC spray had a perceived effect in 35.7 % of the cases after 1 dose (corresponding to 1 second of spraying), which cumulatively increased following an exponential pattern to 68.7 % after 2 dosages and to 85.1 % after 3 dosages, see Figure 4A. Of note, the dosages (or time) until reaching a perceived effect on the subject targeted include both dose used until achieving a hit on the target and dosages used until 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 the bystander affected.

In most encounters (58.2 %) OC spray was used at distances shorter than 1 meter, see Figure 4B, and in 22.3 % at distances between 1-2 meters. The distance distribution profile of OC spray matched an exponential pattern. The dosages used increased significantly with increasing distances to the target.

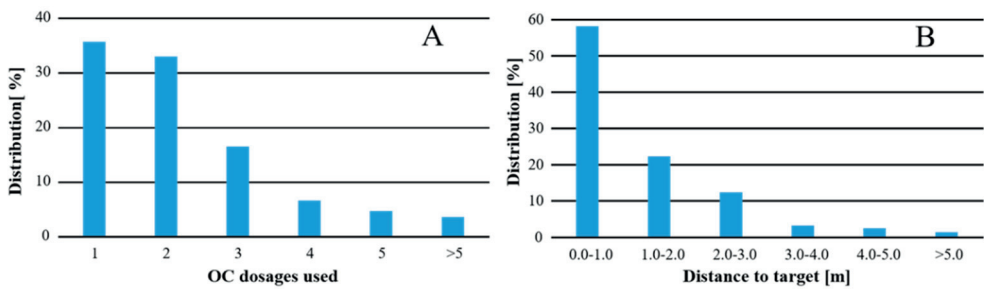

Figure 4A: Dosages applied until perceived effect. The dosages scale correspond to 1 dosage = 1 second of spraying. Figure 4B: Distance to target when spraying.

Conclusions:

- 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.

- 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 24.4 % of the incidents, whereof 89.8 % 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.

- The design of the OC canister could be improved by providing better aim and by being equipped with a safety release that is simple to use during severe physical or psychological stress.

Study II: Police officer involved shootings – retrospective study of situational characteristics.

The study objective was to perform a systematic evaluation of the situational characteristics during high threat shooting incidents and the police officer's actions taken to handle them, including to analyze signs of human physical and psychological limitations.

Subjects:

During the period investigated, between years 1984 to 2012, 128 police officers within the Skåne (Scania) County Police Department used their firearm 132 times in 112 incidents. The typical police officer was on average 35.0 years old (*SD = 6.1*) with a work experience of 10.4 years (*SD = 6.5*). The police officer was in the majority of cases male (93 %). The gender distribution followed the overall distribution among police officers working in field service during the assessed time period. The assailant(s), when identified, involved males (76 %, *M = 30* years), females (1 %), canines (9 %), and crowds (14 %).

Study design:

Data were collected by detailed interviews of all police officers that had used their firearm in the line of duty. The same person performed all but a few interviews with the police officers using a predesigned questionnaire. The interviews were performed after the legality of the shooting incident was determined, usually within a few days.

Results:

The most common armament of the assailant was firearms (26 %) or sharp objects such as knives (27 %). Vehicles were also used (14 %), whereas attacks with blunt objects (10 %) or by dogs (9 %) occurred more rarely.

In 39% of the cases, the threat was regarded so imminent that a shot was fired within ≤3 s from the time the threat was presented. In 27 % of the cases, the time frame between emerged threat and response was estimated between 3 and 10 s. The emerged threat was regarded a reaction between 10 and 30 s afterwards in 13 %, whereas in 21 % of the cases the threat resulted in a shooting after more than 30 s.

In 42 % of the cases, the distance was estimated to be ≤3 m and in 65 % of the cases ≤7 m. The assailant was in motion during 76 % of the shootings. The attacker moved towards the police officer in 52 % of the cases, away from the officer in 8 %

of the cases, and in parallel to the officer in 16 %. The attacker was standing still in 24 % of the encounters.

The police officer responded in 40 % of the cases with fire for effect (FFE) shots (aimed or pointed); in 12 % with a combination of FFE shots and warning shots; in 40 % with warning shots and in 8 % with an accidental shot. The police officer was in motion during 27 % of the warning shots fired and during 33 % of the FFE shots fired.

The hit rate could be estimated to some extent for 39 of the 69 FFE shootings performed during the investigated period. The estimated hit rate was about 72 % for pistols whereas about 6 % for submachine gun (MP5).

The initial reason for police presence rarely gave an indication that the event could evolve into a shooting incident. About 70 % of the initial assignments concerned tasks usually performed un-dramatically on a daily basis such as house search warrants, handling brawls, burglaries or handling mentally ill subjects. The remaining 30 % of the cases concerned more serious offences such as handling robbery, pursuit of criminals and kidnapping.

The police officers fired warning shot(s) without using gun sights in 91 % of the cases and in 55 % of the cases FFE shots without using gun sights. Moreover, when firing warning shots the police officer held the gun with one hand in 48 % of the cases, whereas while firing FFE shots the gun was held with one hand in 24 % of the cases.

The risk of panicking was reduced when there was time to prepare mentally for the upcoming situation. The officers tended to feel more mentally prepared and feel less panic when the assailant was armed with more obvious lethal weapons.

Conclusions:

- The concept of “safe distance” is poorly viable to real-life scenarios, e.g., an assailant armed with close range weapons cannot from 10 meters inflict any harm, however, can move the distance of 10 meter to perform an attack within 2 seconds. A concept of “safe time”, i.e., within what time frame is an assailant able to harm or kill someone, may add a more versatile measure of imminent risks to determine suitable tactics. An attacker can reach a person standing at 7 meters distance within 1.5 s, meaning that knives and blunt objects pose an imminent life threat at this distance.

- An uncertain threat caused in the reviewed incidents more stress than a clear and severe threat did, e.g., the discovery that the assailant had a firearm.

- The situational characteristics in many shooting incidents (32 %), e.g., the numerical superiority, no firearm threat, available time and distance, might

have allowed attempts by the police officers to incapacitate the assailant using medium to long range less-lethal weapons, e.g., a Taser.

- Police officers in field service should in general receive high threat incident training. In 80 % of the incidents, it was the first officers arriving to the site that addressed the situation. Only 8 % of the violent confrontation phases exceeded a minute in duration.

- Firearm training aimed to mimic real-life shooting incidents should include practicing firing at threats for various distances, on threats that are in motion and include training to fire without using sights, using one hand and while in motion. The common practice to fire warning shots in the air is hazardous, given that most incidents occurred in densely populated areas.

- A clear legal framework detailing how police officers are allowed to handle violent assailants with certain armaments may markedly support designing better tactics, customize training and support design and introduction of suitable less-lethal weapons able to address these situations.

Study III: Analysis of eyewitness testimony in a police shooting with fatal outcome – Manifestations of spatial and temporal distortions.

The aim was to analyze whether perceptual distortions occurred in eyewitness testimonies, by comparing the subjective testimonies with objective video recordings of the event. In this real-life event, police officers were involved in a shooting incident with lethal outcome.

Subjects:

Four police officers and nine civilian witnesses.

Study design:

The preliminary crime investigation protocol that included all the interviews with the witnesses, constituted the basis for this study. The accuracy of the interviews was evaluated by comparing them with the video recordings. Witnesses' statements were organized along a timeline based on timing of the actual event, as revealed by the video recordings. The degree of consistency between the statements and the actual related event was evaluated by two of the authors independently.

Results:

Six of the 13 witnesses claimed that five shots (the correct number) were fired while the others reported numbers ranging from three to six. All 13 witnesses reported observing the knife, and several were even more specific, using terms like "kitchen knife", "stainless knife", or "a big silvery knife". Furthermore, all 13 witnesses reported hearing the police shouting "drop the knife". All but one of the 13 witnesses reported seeing the perpetrator advancing toward the police officer. All 13 also reported that the police officer fired warning shots into the air and the perpetrator ignored these warnings shots and continued to advance toward the police officer. To this point in the timeline of events, the testimonies were mostly consistent and in accordance with what the video showed. However, the testimonies then began to diverge from the actual course of events; 12 of the 13 witnesses, including the police officers, reported that the perpetrator was hit by the third or fourth shot, but with very limited effect. The perpetrator was reported to have "flinched", "staggered", "continued limping", or simply "been unaffected". Nine of 13 witnesses reported that the perpetrator continued to advance, and an additional shot was then fired that stopped the perpetrator and made him fall to the ground. Only one witness correctly

reported a shot being fired when the perpetrator was lying down or was standing on his knees. All witnesses then reported that the perpetrator was approached by the other police officers and incapacitated, described with various degrees of detail.

Conclusions:

- There were obvious differences between the video recordings of the event and the statements made by the witnesses.

- The witnesses did not correctly report the actual progression of the event. However intriguingly, the bias in perception and memory of the event was similar in almost every witness statement even though the type of involvement in the incident varied (some were passive bystanders while others were active police officers). This consistency of inaccuracy indicates the presence of general biases rather than biases connected to a particular witness or from which position the event was viewed by the witness during the incident.

- From a legal point of view, systematic biases in perception and memory of events are of marked importance because eyewitness statements are common and often considered to have a high-probative value. In this case, 12 of 13 witnesses state a similar version on some of the crucial parts of the progression of the incident, a level of witness agreement that most likely would lead most courts to believe that truth is established beyond reasonable doubt. Still, the video recording shows that the agreement across these 12 witnesses was inaccurate.

Study IV: Stress levels escalate when repeatedly performing tasks involving threats.

The study objective was to determine whether repeatedly performing moderately threating policing tasks, executed in a rapid sequence with only a brief rest between tasks, cause an altered stress response as assessed by the biomarkers heart rate and pupil diameter.

Subjects:

Twelve male subjects (*M = 30.7, SD = 3.2* years) participated in the study. All participants were experienced police officers with at least five years prior experience of field duty work. All participants had normal or corrected-to-normal vision (with contact lenses).

Study design:

Four different tasks, all involving policing a moderate threat, were performed by the participants in a fixed sequence. All tasks started when participants opened a door and quickly entered the scenario room where a specific scenario started to play out immediately. When a scenario instructor judged the policing task to be completed, he terminated the task with a verbal "abort" command, and the participant returned to the anteroom for a brief rest lasting about 33 seconds (*M = 33.2, SD = 9.4* s) before the next task commenced. The subject received no detailed instructions about the scenario to address, but was merely asked to deal with the situation.

Results:

Repeatedly performing moderately stressful tasks significantly increased the heart rate during door opening across the four tasks, see Figure 5. Moreover, the heart rate was significantly faster post onset (after door opening) than pre onset (before door opening) for all tasks. Furthermore, the heart rate pre onset was slower than post onset at the initial tasks but the differences decreased during the last tasks. The heart rate values recorded at scenario pre offsets (before task aborted) were significantly slower than the heart rate recorded after receiving the command "abort". However, this difference decreased significantly over repeated tasks.

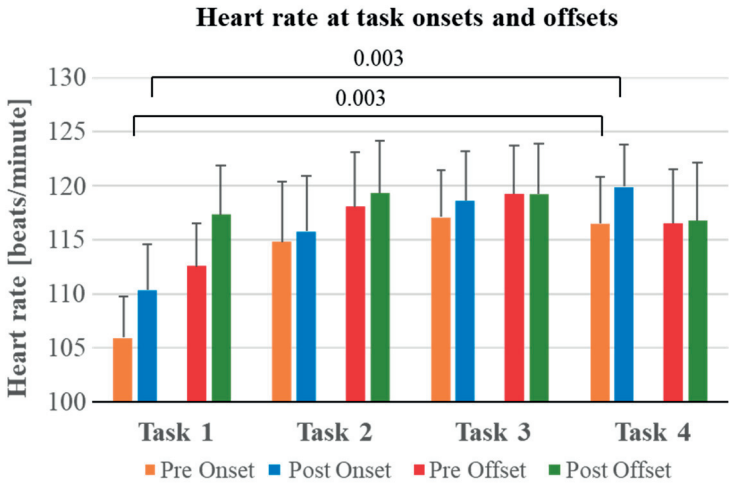

Figure 5. Heart rate before and after task onsets and offsets. The heart rate became increasingly larger at task onset by each test performed. The heart rate continued to increase until just before task offset, but primarily while performing the first tasks in the series.

Regression analysis of the heart rate time series revealed for task 1 significant heart rate increases during the pre onset and the post onset windows. A similar significant heart rate increase was found during task 4 pre onset and post onset windows.

Repeatedly performing tasks significantly changed the pupil diameter at the door opening (pre onset and post onset) in a complex pattern, i.e., the pupil diameter reached a minimum during task 2 and increased again during tasks 3 and 4. During task execution (post onset and pre offset) and during the abort command (pre offset and post offset), the pupil diameter changed in the same complex pattern of reaching the smallest pupil diameter while performing task 2 followed by an increase during tasks 3 and 4.

Regression analyses of pupil diameter dynamics revealed a significant decrease in pupil diameter during pre onset before task 1, before task 2 and before task 4, whereas the pupil diameter increased significant pre onset before task 3. However, a significant pupil diameter increase was detected during post onset of task 1, task 2 and task 3, whereas a pupil diameter decrease was detected during post onset of task 4.

Conclusions:

- Stress levels escalate when repeatedly performing stressful tasks, manifested mainly as a higher heart rate at the onset of the tasks. This said, after the initial escalation in heart rate during the first tasks, the heart rate seems to

approach a new higher steady state level at task onset and offset already while performing task 3 and task 4. One practical implication of this finding is that one should avoid repeatedly performing sustained stressful tasks without allowing enough deescalating rests between tasks.

- The 'abort' command, which terminated a scenario, was also associated with an overall increase in heart rate across the repetitions. This heart rate response was more marked during the initial tasks but declined when reaching the last tasks 3 and 4, suggesting that response might be a startle effect from that the instructor intervening in the scenario.

- The interpretation of pupil activity was in general more complex compared to heart rate, with rather unsystematic variations from task to task, where the smallest pupil sizes were recorded during task 2.

- The pupil diameter did not change during the scenarios to the extent expected in response to the changes in illumination. A possible explanation of our findings could be that the parasympathetic pupillary light reflex was overpowered by a stronger sympathetic nerve response, causing the pupils to dilate in spite of the participants entering a room with much higher illumination.

Study V: Towards systematic and objective evaluation of police officer performance in stressful situations.

The aim of this study was to investigate how executing policing tasks at different levels of threat and repeatedly with only brief rests between tasks influence the perceptual, cognitive and motor skill performance and physiological measures.

Subjects:

Twelve male subjects (*M = 30.7, SD = 3.2* years) participated in the study. All participants were experienced police officers with at least five years prior experience of field duty work. All participants had normal or corrected-to-normal vision (with contact lenses).

Study design:

Six different tasks were performed by the participants, including no threat, moderate threat and high threat scenarios. Tasks 1- 4 were performed in a sequence with a brief rest between tasks of about 33 seconds (*M = 33.2, SD = 9.4* s).

The effects of repeatedly performing stressful tasks at moderate threat levels were evaluated by comparing questionnaire scores from six independent experts in police officer training, recorded heart rate and pupil diameter. The effects of performing tasks under different levels of threat were determined by comparing expert review scores of motor performance when executing the identical firearm jam-clearing drill at no threat (task 6) and at high threat (task 5). Moreover, a more detailed comparison between performances under moderate (tasks 1-4) and high (task 5) threat was done by comparing expert review scores, recorded heart rate and pupil diameter. Additionally, it was also determined if any of the parameters used to assess performance were influenced by whether a threat appeared immediately at the onset of the task or after a delay.

Results:

The correlations between the six individual expert evaluations, as manifested by the scoring form, revealed a strong consistency between the ratings of the individual experts.

When repeatedly performing tasks that induced a moderate threat in a sequence, performance significantly increased over tasks for the perception, motor control of voice, general motor control and temporal tactical implementation categories. However, statistical findings for perception suggest that tasks, where the threat

appears immediately, produce a poorer visual perception than tasks with a delayed threat. Repeatedly performing tasks under moderate threat had no significant effect on the average heart rate. However, the average pupil diameter during the tasks decreased significantly by repetition. Moreover, a pattern emerged in the pupil diameter, suggesting that the pupil diameter was significantly larger if the threat appeared immediately compared with if the threat appeared with a delay.

Having to handle a high threat task caused a significant decrease in general motor control performance and in overall situation control compared with the average performance during moderate threat tasks, see Figure 6. Finally, when comparing expert review scores for performing a firearm jam-clearing drill during high threat with performing the same task during no threat it was found that the motor control performance was rated significantly poorer in the high threat situation.

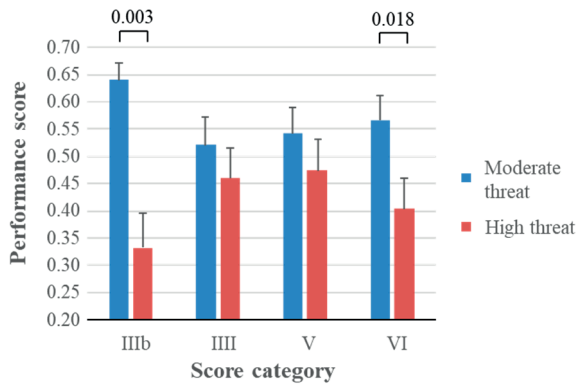

Figure 6. Having to handle a task with higher threat caused a significant decrease in motor control performance (IIIb) and in overall situation control (VI).

Conclusions:

- Systematic and quantitative judgements from experts provide valuable and reliable information about the performance of participants in realistic and stressful policing scenarios. A novel and appreciated tool by the experts was the SMI eye-tracking glasses that displayed the participants' gaze overlaid on the video, and thus revealed continuously where the participants looked while performing the tasks.

- Repeatedly performing tasks have potential to improve some of aspects of performance more than others do. The predominant aspects that improved with repetition were perception, motor control of voice, general motor control, and temporal tactical implementation. Hence, when exposed to a sequence of scenarios with different objectives and required actions there is still potential to make improvements and adaptations.

- Having to handle a high threat task caused a significant decrease in general motor control performance and in overall situational control compared with the average performance during moderate threat tasks. The level of stress may affect also an extensively trained complex motor skill when under the influence of a strong stress response.

- The pupil diameter was systematically larger during scenarios where the threat appeared at the start of the task compared with a delay. Moreover, the experts also scored a significant lower perception performance score when the participants had to address an immediate threat. Hence, the pupil diameter may reveal how participants respond to details in the scenarios they are exposed to.

Study VI: Efficiency of Simulated Realistic Scenarios to Provide High Psychological Stress Training for Police Officers.

The study aim was to evaluate whether a realistically simulated active shooter scenario effectively can produce high levels of psychological stress in experienced police officers.

Subjects:

Ten healthy experienced police officers (seven males; M = 38 years).

Study design:

The scene was set in an abandoned, three-level building unfamiliar to all participants, where each level had 20 rooms. The attacker(s) were positioned hidden in one or two of these rooms with three to four victims. The aim of the police officer team was to find the room(s) of the attacker(s) and work together to arrest or shoot the attacker if necessary. Both police officers and attackers were armed with guns loaded with Simunition® paint cartridges and allowed to fire at each other. Being hit with a Simunition paint bullets produces a short sensation of intense pain.

The participants first performed the scenario as dry-training 2–5 times without any attackers or victims present. Thereafter the participants performed the scenario as a police officer in a realistic setting with both active attackers and victims. Since all participants performed the dry-training and police officer team exercises, they constituted their own controls regarding the different cardiovascular outcomes.

Results:

The heart rate was already before the start of the police officer exercise significantly higher compared with the dry-training, see Figure 7. Moreover, during the exercise the peak heart rate during the police officer exercise was significantly higher (143 BPM) than during the dry-training (113 BPM). After the exercises, the mean steady-state heart rate recovered to was significantly higher compared with the heart rate recovered to after the dry-training.

The time to reach maximum steady-state heart rate at the onset of the exercises were almost identical (45 s) for the dry-training and the police officer team exercise. However, the recovery to a steady-state level of heart rate after the exercises took significantly longer time after performing the police officer team exercise (59 s) compared with the dry-training (41 s).

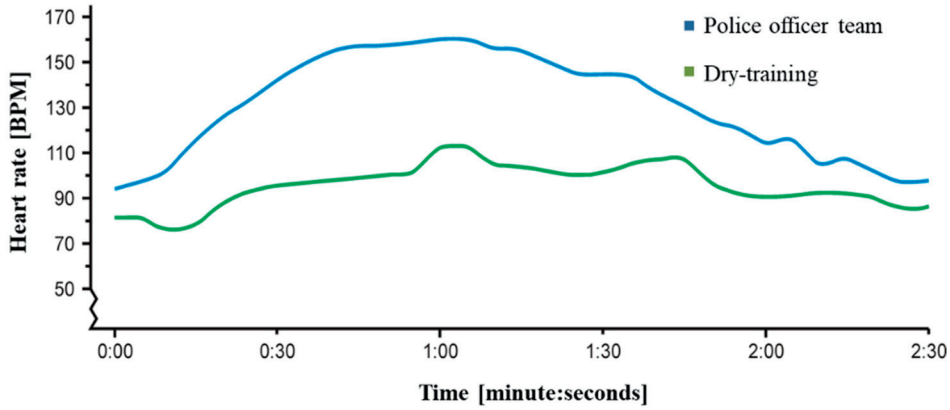

Figure 7. Recorded heart rate in a police officer performing the dry-training and the police officer team exercise. The physical strain performing the exercises was identical. Both exercises started at 0.0 min and were complete at about 1:10 min. Already before performing the police officer team exercise the heart rate was slightly higher, and the start of the exercise produced a fast increase in heart rate.

Conclusion:

- Performing realistic scenarios may induce high psychological stress.
- The heart rate activation pattern enabled the identification of physiological and psychological stress in the exercise, see figure 8, given that the physical tasks performed were identical.
- Real-time monitoring of cardiovascular activity during the exercise might be used as a mean to control the training scenario, by allowing the training instructors to add more stressful elements to the scenario during the exercise, if necessary, so the psychological stress aimed for is achieved.
- Recording heart rate may reveal the properties of dynamic processes, such as latency between event and recorded stress response, rate of increasing reaction, duration of reaction, and recovery rate.

General Discussion

The police are one of the most important, and sometimes the single institution allowed to use force against citizens to enforce the law. In most societies, the law constitutes the most important framework for defining the ethical limitations of treating one another in a civilized manner. However, the obligation to enforce the law inherently increases the risk of police officers encountering threatening and violent situations. Such situations may activate the reflexive stress response that affects the police officer's perceptive, cognitive and motor performance. However, a failure to act or act appropriately by a single police officer may, not only seriously affect the involved individuals physically and mentally, but may also be seen as proof that the police force in general are unprofessional or untrustworthy. Hence, society will benefit if scientific research can determine objective outcomes when humans are in threatening and violent situations and what we can do, in terms of training, operative tactics and by providing appropriate equipment features to minimize the risks for unnecessary injuries among all people involved.

Two aspects might be particularly problematic when addressing the subject of psychological stress. First, the stress response is a vital part of the evolutionary toolkit that has enabled humans as a species to survive and evolve. From an evolutionary perspective, it is easy to imagine why survival of the human species would have benefited from moments of abnormal strength and faster sensory information processing in life-threatening situations. These evolutionary stress responses are not limited to the human species alone but can be found in most other mammals [1]. However, what may come as a surprise to us living in a modern society is that these evolutionary super-human systems are still present in all of us but only seldom revealed because most of us rarely experience situations where these systems need to be activated. For emergency units like police officers, firefighters, and ER professionals, the situation is different, as these professions are still commonly exposed to such threatening or dangerous events [2]. However, the fact that the stress response is reflexive in nature and initiated subconsciously may mean that it is produced in inappropriate settings. The view could then be taken that this feature is a flawed remnant in human design, because any lack of conscious control is perceived negatively in a modern society.

Second, one's own experience of threat or "street-awareness" will determine a person's perception of threat, response and necessary training to avoid untoward situations. A person with little experience may begin to develop malformed ideas [7,22]. Thus, films may create widespread incorrect perceptions among general society

about laws of physics, human neurology and physiology, psychological stress effects and limitations including actual effects of violence [63]. The hero is often portrayed as calmly performing fine motor tasks after choreographed critical encounters and stressed people are portrayed as weak and as cowards. Moreover, the hero can also revoke any stress response in seconds and make people "come to their senses" by performing a patriotic speech. Thus, popular culture likely enforces the common stigma, guilt and shame about poor performance from stress, even in professions where working under stress is common [64]. However, the reflexive and universal nature of the stress response means that even the best trained and experienced special unit operators will initially face the full stress response effects, if the threat is surprising, unknown or catastrophic to their nervous systems early warning circuitry [65]. The stress response will take effect before they become aware that they are stressed at all and before they consciously realize what the threat is, if the threat is clear enough [6,30,66].

Extreme stress can cause chronic illness known as post-traumatic stress disorder (at the time called 'shell shock'). The natural effects of extreme situations started to become evident to the military, and medical and scientific communities during world war one. The military soon realized that trench warfare produced psychiatric problems among so many soldiers that these casualties, exceeded the number of soldiers suffering from physical injury toward the end of the war [7]. One intriguing finding from the early research was that the conflict component in having to harm other humans was the most psychologically devastating. The non-combative medical personnel did not at all suffer the same amount of psychological 'shell shock' effects in spite of being killed and wounded even more often [7]. Thus, it is essential that society officials, legal system and the public understand the roles that human neurobiology and physiology play in extreme situation. In that respect, no education can make police officers and special unit operators resilient to their neural reflexive responses, but they will be equally affected by stress when it occurs, as the rest of the population. However, adequately adapted education and real life experience can make them better prepared and raise their stress thresholds to some extent [3,5,22].

Physiological and psychological effects of stress

The initial stress response is purely reflexive and activates an array of subconscious physiological effects, see figure 1. The more apparent reactions like the startle response, increased heart rate, pupil dilation, and conscious and emotional reactions, takes about 0.5-5 seconds to become noticeable. If the stress response is not inhibited quickly enough, increasing concentration levels of adrenaline and noradrenaline in the blood will be too high to prevent a fast recovery of the perceptual, cognitive and motor control systems affected by the stress response. The

stress effects may increase faster after the threat has been confirmed by both subconscious and conscious processes. If this state is reached, the slow inhibitory function of the endocrine stress systems and the long time they need to break down the stress hormones means that the recovery from a marked stress response will be in the order of one to several hours [67]. Hence, the nature of the physiological endocrine process makes it difficult to "…come to ones senses…" in a threatening situation and be able to think logically and make sophisticated decisions.

A stress response can have very different influences on performance, and lead to both improvement and impairment, related to the levels of stress. For example, in study V it became apparent that handling a high threat task resulted in a significant decrease in general motor control when the subject had to unexpectedly perform a firearm stoppage drill, which the same subject could perform perfectly just hours before. Hence, the high stress response level was also found to affect a complex motor skill trained to a high level of proficiency. This finding concurs with reports describing deteriorated fine and complex motor performance when under the influence of a strong stress response [21,68,69]. The difference in average heart rate levels between the moderate threat and the high threat was large, however not significantly different in study V, mainly because one individual was sleepy when performing the high stress task, and was hardly affected by stress when performing the physical task. Intriguingly, this individual was also the only one performing the firearm stoppage drill without deteriorated motor performance, e.g. without mistakes. The induced stress produced an average heart rate of 142 BPM in study V, which was likely too low to reveal the more dramatic effects of very high and extreme stress response levels.

Study IV revealed that heart rate systematically increased when repeatedly performing stressful tasks, which suggests that a stress response may include accumulating and preemptive properties. Moreover, when entering a stressful situation the pupils dilated instead of an expected constriction when police officers entered a more brightly illuminated room. The pupillary light reflex would normally constrict the pupils when exposed to a higher illumination level. However, the sympathetic stress response effect on the pupil is to dilate it. If a dilation becomes very large, it may have detrimental effects on vision, e.g., by reducing the 3D-space that can be kept in focus [44]. Another finding of great interest was that the pupil diameter was systematically larger if the threat appeared immediately at the start of a scenario compared to a delayed threat (V). Hence, the pupil diameter may reveal how participants respond to specific events within the scenario. Pupil diameter and heart rate can thus be used separately or in combination as reliable physiological stress markers.

Eyewitness statements are commonly considered credible when the witnesses are confident and have no reason to lie. However, the findings in study (III) suggest that the perception and episodic memory might be vulnerable to distortions in witness testimonies. The scenario context in study (III) also suggests that some witnesses

were likely affected by a strong stress response whereas others probably did not perceive a threat towards themselves. Intriguingly, however, we found not only distortions but also a seemingly systematic bias in all but one of the 13 witness testimonies. This was possible to examine since the incident was also filmed and the witnesses were interviewed before they saw the film. The main aspects of the shooting incident were well described; however, the order was altered or disconnected from the actual course of events. Specifically, the witnesses' perception of the assailant's movement and posture seems to have been distorted. All but one witness said that the perpetrator continued to advance toward the police officer after being hit with limited effect while the assailant, as revealed by the film, fell to the ground after the first FFE shots and thereafter continued to drag himself towards the police officer while still holding the knife. Both the police officers and civil witnesses displayed similar distortions of perception and memory. This indicates that the stress response affects perception and memory in a similar way, despite the, most likely, very different experiences and received training among the witnesses. One potential factor for the systematic error might be that witnesses are more prone to present a testimony supporting a police officer than an armed aggressive assailant. However, if the high levels of consistency in the specific details the testimonies were biased, it would have required coordinated discussions between all the witnesses as a group. The documentation from the case gave no indication that witnesses were allowed to talk to each other, but typically, the interrogations were performed individually on the same day of the event.

One explanation to a systematic memory bias may be that high noradrenaline and dopamine levels impair working memory and thus cognition, creating attentional locking or the weapon-focus effect causing inattention to other aspects [12,40-42]. However, this explanation cannot explain why witnesses probably not effected by a strong stress response still reported the same perceptual distortions, but instead implies that the processing of detailed visual information may be limited to the content perceived as most relevant. These results emphasize the necessity to be careful with witness statements, and when possible to complement legal procedures with forensic investigations by, e.g., determining bullet trajectories.

Whether stress improves or impairs memory is debated. In some cases, the recollection is enhanced and sometimes the effect is detrimental. Moderate stress levels commonly predict improved memory performance [70]. Deffenbacher et al. [71] state, however, that stress always impairs memory for, at least, details. A difference in stress response levels may be part of the explanation to the mixed results due to both the cognitive effects regarding attention but also depending on the concentration of noradrenaline and cortisol in the blood system. One possible reason for the mixed results is the known effect of the stress hormone cortisol on memory. A moderate increase of cortisol in the blood improves memory but a high concentration of blood cortisol impairs memory [12,33].

Equipment

The situational characteristics and effective outcome when using various equipment for policing may serve as an important information source when determining if the properties of the equipment used may have had a role that affected the operational implementation during high stress encounters (I, II, III). Such information may enable improvement of equipment use but also the related tactics. Hence, if stress levels change, the ability to use the fine or complex motor skills necessary for operating equipment are altered and we might not be able to use the recommended equipment as effectively. Understanding whether the design of existing equipment meets the pressures of a high-stress environment is essential and this may result in the development of new equipment designs or tools.

Real-life experiences of using pepper (OC) spray

Study (I) showed that subjects' responses to pepper spray were strong in 82 % of the incidents, moderate in 12 % and no noticeable in 6 % (3% misses). This finding suggests that pepper spray is often an effective tool in many situations. However, the 82 % efficiency means that pepper spray often fails to produce the effect expected, which can easily make events more dangerous for the people involved. Moreover, due to the properties of pepper spray, where even a strong effect does not restrict physical strength or ability to move, an assailant may still be capable of inflicting harm. Another important situational characteristic is time to effect. The time to effect for pepper spray used in real life situations showed that one second of spraying only sufficed in 35.7 % of the cases; another second of spraying was needed for the cumulative effect to reach 68.7 %; but it was not until after 3 seconds of spraying that the cumulative effect reached 85.1 %. One reason for this problem is that pepper spray will only cause an effect if it hits the eyes. Even under normal conditions is it difficult to hit such a small target with a liquid stream that has a complex trajectory that change with the distance to the target. Moreover, the intended target of the pepper spray is often moving. Another issue detected was that the pepper spray canister used by the Swedish police during the period investigated included no targeting device, which likely also was a contributing factor to the short distances used and long spray times needed before an effect was reached. Noteworthy, in 24.4 % of the times when pepper spray was used, it resulted in hitting a non-intended target who, in 89.8 % of cases, was another police officer. Furthermore, the collateral contaminations increased significantly in windy conditions.

Even though the possible range for the pepper spray canister was about 5 meters, 58.2 % of the incidents occurred from 1 meter or less and in 22.3 % of the incidents the distance was between 1-2 meters. Consequently, the real operative range of pepper spray is likely not close to the theoretical limits. The short distance in itself

does not have to be a problem. However, pepper spray was used against people armed with sharp and blunt objects in 21.1 % of all incidents.

Finally, study (I) also highlighted the design of the canister attachment to the weapon belt. To remove the pepper spray canister from the holster, position it properly in the hand and put the thumb under the protective lid may be increasingly difficult to perform depending on the strength of the stress response. The cylinder formed pepper spray canister used during the investigated period provided no tactile cues for pointing the muzzle in the intended direction, increasing the risk of missing the target, delaying speed and instead hitting an unintended person. It is also problematic to put the thumb under the protective lid when stressed, since this task requires fine motor control. These things could be improved by instead using a different lidless holster, a lidless higher threshold release button or a dead man's grip, and an oval canister or attached grip.

Real-life experiences of using firearms

One marked situational characteristic in the officer-involved shootings (II) was that in 39 % of the cases the threat was regarded so imminent that a shot was fired by police 3 seconds or less from when it emerged. Moreover, in 42 % of the cases the distance was 3 meters or less when the first shot was fired. Thus, in many shooting incidents the limited timeframes and distance did not allow any detailed analysis of the conditions at the site. Moreover, the conditions were probably worsened because the police officer involved presumably started to feel the initial effects of a strong stress response. The police officers themselves reported feelings of panic at some point in 36 % of the cases. Furthermore, in 76 % of the cases, two or more police officers were at the site of the incident but in 86 % of the cases, only one police officer used the firearm. All police shootings in study (II) was deemed legal in retrospect, which raise questions why not more police officers made the same analysis of the situation and made the decision to shoot. One reason might be that using a firearm has a much higher human thresholds than, for example, using pepper spray. Another unexpected finding was that the police officer firing FFE shots felt more mentally prepared doing so when they had determined that the assailant were armed with a lethal weapon (II). This and other findings suggest that a reluctance to use a firearm, may have produced a delay allowing the assailant to move closer, i.e., that the opportunity to fire immobilizing leg shots earlier during the event was lost. Hence, one of the primary fears reported seems to have been to use the firearm for the wrong reasons.

An unexpected finding in the situational characteristics was the difference found between the trained firearm procedures and the ones used during real life incidents. Almost all police officers were exclusively trained to fire on static targets, use aimed (sighted) fire, to stand still and to use two hands while firing. In real life, the assailant

was in motion during 76% of the shootings and the police officers adjusted to the situational characteristics by shooting using one hand, without using sights and shoot while both themselves and the assailant were in motion. That the police officers did not use their aiming equipment likely depends on the short time frames available, the weapon focus effect and due to tunnel-vision distortions common in real life situations [2,40-42,68,69]. To fixate the threat and not relocate attention to your own sights, as commonly trained, might improve threat assessment, decision making, speed and accuracy when using firearms [72]. The combination of using one hand, no ability to use sights and experiencing a high to extreme stress response may have serious consequences unless addressed.

The missed FFE shots using the service pistol was 28 % among the 57 % shooting events where this could be deduced. However, a part of the shots reported as warning shots might also have been missed FFE shots, partly because a warning shot is less questioned in retrospect than a missed FFE shot due to the Swedish regulations. One possible explanation for some of the missed shots is that a strong stress response causes a much stronger clenching of the pistol grip locking the wrist in a certain position. If the pistol grip is too large for the individual police officer's hand size, the barrel will thus point to the right (for right-handed individuals), due to the high stress convulsive grip's locking of the wrist. The same will occur if the pistol is not gripped correctly using one hand. These physical effects can make a police officer miss a human target from as close as 1 or 2 meters. Hence, adequate pistol grip sizes are crucial [68,69,73]. However, the situational characteristics must also be addressed in training. Hence, the firearms training should better reflect real life situational characteristics by having to practice to shoot under training at various distances, at various target areas, at moving threats, fire while in motion and while using only one hand and no sights [68,69,73] .

Of all investigated shooting incidents recorded, 8 % were classified as accidental shots (II). Two circumstances were common during accidental shots, 1) in 80 % of the cases reported the police officer was in motion. 2) in the majority of the cases the firearm was in single-action with 1.8 kg trigger pressure. Hence, a contributing factor to several accidental shots might have been the safety regulation in effect during the period. The regulation stated that a pistol is not allowed to be loaded when holstered, thus, to make the pistol operational during an incident the police had to perform a two-step procedure to first load the pistol and then to activate the pistol's built in safety mechanism setting the trigger force to about 5-6 kg. However, firearms instructors soon noticed that the second step in the loading procedure, (de-cocking) setting the trigger force from 1.8 kg to 5–6 kg, often was forgotten under stressful situations. Hence, a likely reason for an accidental shot might have been an unexpectedly low trigger force setting [76]. After the end of study (II) the safety regulations were changed so that the pistol now can be carried loaded in the holster.

Operative aspects

Performing evaluations of operative aspects and tactics based on the situational characteristics compiled from real life incidents are useful in many ways. First, it enables us to find out how often certain incidents occur and how often certain characteristics in these events occur. Some incidents or characteristics may be so scarce that they should not be given much attention or time within the limited training provided to police officers. Moreover, performing training on handling rare events may bias and remove focus from training for the kind of events that occur more often. However if the outcome of a scarcely occurring incident or characteristic is very dire, risking lives or serious injury if not handled adequately, it may still need attention regarding the tactics, training and equipment provided [74] (II, III, VI). Moreover, it is important to include the relevant differences between the more common use-of-force encounters, with low to moderate threat levels, and the rare high threat encounters that would only be experienced once or twice, if at all, in a police officer's career. Thus, the police officer would only be able to rely on artificial experience, tactics and use of equipment gained from given training. Hence, the tactics, training and equipment used by the police should be based on as many real life experiences and investigations as possible, minimizing the possible bias of basing general operative decisions on a few non-representative incidents (I, II, III).

Operative role of pepper (OC) spray

When pepper spray was introduced, it was feared that the spray would be used too liberally. However, study (I) shows that 80.1 % of the police officers that used pepper spray during the seven-year period only used it once or twice. The more surprising finding was that in 43.9 % of the situations, pepper spray was used in association with self-defense or defense of others due to attack or imminent threat. Even more surprising was that in 21.1 % of the encounters pepper spray was used against armed individuals. This finding suggests that pepper spray is commonly considered as a viable alternative to firearms, though the short range and the unpredictable "time to effect" properties seems not to have been considered or was unknown to most police officers in study (I). As it only takes 1.2 seconds from standstill to reach someone 5 meters away (i.e., the maximum range of pepper spray), an armed assailant within that range poses a severe threat. It is important to know that if someone starts running from standstill from distances up to about 6 meters, one will not be able to escape contact even if trying. This is due to the response time needed [75].

Hence, the operative role that pepper spray serves today is unlikely to conform to its planned use or with what is being taught in basic training. The present training stipulates that pepper spray should be used early in a confrontation or before

intervening with close contact techniques to reduce the risk of injury, for example, when arresting a comparatively stronger or more skilled non-compliant person. The usefulness of less-lethal weapons as pepper spray in such situations should not be underestimated. However, collateral hits/contaminations were noted in 24.4 % of the incidents, whereof 89.8 % were other police officers. Hence, from a tactical perspective, pepper spray cannot be recommended for acute life threatening encounters. The average effectiveness of pepper spray use of only 82.1 %, 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 pepper spray.

Operative role of firearms

Several findings suggest that the operative use of firearms, at least in Sweden is in an awkward position. Acceptance of firearm use by the police is low in parts of the society and media, while others can accept its use under exceptional conditions [76]. On the other hand, the properties of the criminality have undergone a change during the last decade, and it is today much more common that criminals use firearms in urban areas, often disregarding the presence of civilians. In the future, the police force might be assigned equipment like EIDs able to handle short to contact range weapons with less-lethal weapons with equal or better efficiency than firearms. However, presently there exists no proper alternatives to firearms to address assailants armed with firearms, because of factors like range, follow up capacity etc.

One operative problem with firearms is that the "time to effect" factor is largely random, e.g., one can miss the target altogether and even lethal injuries may not cause an imminent effect, especially if the assailant is affected by drugs or in a mental state making the subject insensitive to pain (III). If the assailant shows no sign of response to shots fired, more shots would likely be fired until an apparent effect can be discerned, i.e. the imminent threat is perceived to end. Moreover, the commonly recommended action to aim for and hit the legs is not a simple task to perform when the target is moving as they most commonly were in real life as documented in study II.

Finally, in 84% of the cases, the police shooting occurred in urban areas, and the risks for ricochets were regarded as elevated at 82% of the shooting sites (II), which highlight the risks for bystanders. In this context, firing warning shots may not either be regarded as risk free as the bullets might pass through windows and fragile walls. Hence, the operative characteristics of firearms are far from perfect, however, in a number of the situations investigated in study II, using firearms offered at the time the only available solution.

Operative tactics

One of the most critical situational characteristics of police interventions is the reflexive autonomous hormonal stress response and its repercussions. Since the response is reflexive, it is not possible to prevent the unconscious initial activation if the triggering threat is sudden, unfamiliar or perceived as catastrophic. In 39 % of the police officer involved shootings in study II, the threats emerged without previous cues and emerged so suddenly that no tactics or conflict reducing techniques would have had the ability to be implemented, let alone affect the outcome. Hence, a vital operative factor (I, II, III) is the importance that police officers are well informed about the conditions they will face in advance, e.g., reports of prior incidents of violence, alcohol and drug abuse, mental illness etc.

When police officers used their firearm, 70 % of the situations emanated from regularly uneventful tasks, first responders acted in 80 % of the cases and 83 % of the events played out before a special unit or SWAT-team could be summoned (II). An elite SWAT unit fills a critical role in minimizing the risks of injuries among police officers, the civilian population and the perpetrators alike while resolving anticipated or protracted high threat situations. However, the systemic pattern in that the best-trained police units are so rarely involved in the most dangerous events, does raise questions if operative enhancements are possible. Hence, the real effectiveness of a few national elite units might be low if they arrive after the event has been resolved by local, less specialized, units. Noteworthy, in one of the deadliest events present, e.g., school shootings and terrorist attacks with only a few assailants, the attacks tended to stop when the assailant became aware of that the first responder unit had arrived to the scene. In the active shooter events is USA between 2000 and 2010 the first responder reached the scene before the situation had ended in about 51% of the incidents, out of which the perpetrator then was stopped by the first responders in 51%, committed suicide in 35% or surrendered in 14% [77]. However, due to the often very fast kill rate, any delay in intervention, as for waiting on the arrival of an elite special unit, can have dire consequences [78].

An operative problem is that the number of patrolling (and investigating) police officers in duty all over Sweden, has diminished drastically since the 1980s at least until the early 2000s due to reorganizations [79]. This may create a deceptive lower crime rate because there is no one to report the crime to [79]. This may also cause the public less prone to report crimes (VIII), and thus, cause the police officer presence to be reduced even further in a silent degrading process where in the end the ability is lost to intervene when serious crimes are committed. Thus, a major factor for the police to be efficient also regarding handling small or large extreme violent situations, is that there are patrolling police officers out in numbers working in the societies at all times and that there are criminal investigators prepared to investigate what the patrolling officers' find (I).

Finally, to know possible repercussions of different levels of stress is of importance for the operational tactics. For example, when we investigated the effects of being repeatedly exposed to stressful tasks, we found that repetition in itself could escalate the levels of stress. This suggests that deescalating rests between stressful tasks would be a way to avoid sustained exposure to stress (IV, V). This may also prevent unnecessary functional impairment due to entering a new situation already with a stress response activated (IV, V).

Using the "Safe time" definition as a tool for objective risk evaluation

In operative tactics, the situational characteristic "distance" is often used to determine what is safe or not in different situations. However, a novel concept of "safe time" would be much more versatile as it does not depend on one situational characteristic alone, e.g. distance, but considers all known factors in the response process (I, II, III). The definition of "safe time" is the shortest possible time for a human to have a realistic ability to affect the outcome of a possible attack, based on all situational characteristics at hand. The calculated "Safe time" should thereafter be compared to within which time the threat in question could cause harm to the police officer, e.g., what time would be required for an armed assailant to move 10 meters and inflict lesions. Objective risk evaluations including all factors and a presentation of the outcome in easily understandable parameters, i.e., available time in seconds to respond to a sudden attack, may introduce forensic, ethical and legal implication where verdicts are required to consider physical limitations realistically, e.g., in self-defense criminal cases. Moreover, the "Safe time" concept might also serve as a tool to determine the risks of different operative tactics and use of equipment.

The first factor to be included in "safe time" is "perception time", i.e., the time required to identify a threat (awareness), e.g. time to observe, locate (orient), identify subject (foe or friend), and define the threat. The second factor is "decision time", e.g. time to select an adequate response to the threat detected. The two factors, perception and decision times, added together are commonly known as "reaction time". To the "safe time" we also have to add "action time" which is the time required to physically perform the selected movements to respond to a threat, e.g., remove the firearm from the holster, raise it, aim and fire a shot. The "reaction time" and "action time" added together is commonly called "response time" [48]. Finally, to the "safe time" we also have to add the "time to effect" which is the time for the action taken to make impact, which may range from immediate to no effect produced. In general, there are two means to obtain an almost instant incapacitating effect; 1) by causing neural damage or block neural communication by lesions or by causing nerve blockades (e.g., use EID) of vital movement control sites; or 2) by causing lesions to essential skeletal structure [63]. Other, lethal or severe lesions may

not be incapacitating on a time scale of seconds, especially not if the subject is affected by drugs or medication or is in a psychological state restricting sensations of pain.

Empirical data of real life situational characteristics may give important knowledge about what to expect in terms of "reaction times" and in "time to effect" and by showing limitations not revealed in artificial tests (I, II, III). Continuous research will expand the empirical base from which we can adapt resources to the most common and important situational problems. As an example, the inherent risks using a short range less-lethal weapon against an armed person at short distances (I), would indisputably be revealed and easily understood if the concept of "safe time" would be implemented. Thus, there is a necessity to fill the tactical less-lethal range gap exposed with a longer distance less-lethal weapon. The result would prevent police officers from having to continue taking great personal risks nor to increase the use of firearms in those situations.

Possible incentives to introduce EID (Taser®)

The risk-taking behavior found when police officers use pepper spray from close ranges with uncertain "time to effect" against violent or armed assailants (I) could be changed if police officers had access to long-range EIDs. This could also significantly reduce the use of firearms against aggressive and/or armed assailants if other conditions (e.g., assailant armament, time and distance) allow attempts to use alternative approaches first (II, III). As Swedish police officers work in pairs to reduce the risk of assault and injuries [80], at least one in the patrol could be equipped with an EID and assigned beforehand to the role of being the first to act to address unarmed but physically superior, aggressive, assailants or assailants armed with short-range weapons. In a two-man patrol, the officer primary assigned to using the EID can be protected by the partner, who can use an EID too against unarmed or use a firearm from a distance, to handle those armed with short to contact range weapons, as backup if the EID fails. Due to the short time needed to move several meters from standstill (a healthy subject can move 7 meters from standstill in 1.5 seconds [75]), the necessary range of an operative EID device should be no less than 7 meters but preferably up to 12 to 15 meters. Thus, longer operational EID range would enable more than one EID shot to be fired before the threat levels would become imminent. Moreover, most EIDs can be used at short-range encounters as the two electrodes at contact deliver currents disrupting voluntary control of muscles, thus, offering an easier to use tool than pepper spray that requires the eyes to be hit to produce an effect. However, caution must still be taken since a hit in an eye with an EID dart might cause permanent blindness, and falling might cause injury. An EID do not work if one of the darts miss, and several of the present EID

models are poorly able to handle thick clothing. However, more modern EIDs are better at handling thick clothing.

Learning and training

When personal experiences from real-life situations become scarcer, for instance due to periods of peace time or in communities with low crime rates, assumptions and myths begin to spread about what threatening situations look like, how we respond to them and what constitutes adequate training, possibly due to films and media [7,22]. Analyzing many real-life incidents may then offer one of few proper alternatives to quantify which and how often different threats or attacks appear and how the police officers actually respond when under moderate to extreme stress levels [69] (I, II, III). Shanghai's international settlement in the early 1900s counted about a million inhabitants and 2000 police officers (i.e., about the same size of the police force and inhabitants as in the county investigated in studies I and II). Several police officers were killed annually (9 were killed in 1919). A police officer and instructor of the Shanghai Municipal Police, Fairbairn, had already in 1910 started to participate in dangerous missions, conducting forensic investigations and interviewing survivors after every officer involved shooting. After the lives lost in 1919, he could show that the training was not adapted to the effects of stress. He modified the training accordingly and reduced the losses of lives by more than 50 %. Fairbairn's work showed consistent patterns and differences in how people reacted under real-life stress, in contrast to what was, and still often is, presumed [21,69,73] (II, VI).

Who needs to train for what kind of problems? As 80 % of shootings with police officer involvement were handled by the first responders and 70 % of the shootings emanated from uneventful situations, the regular patrolling police officers are the ones that are commonly exposed to critical encounters (I, II). One may argue that the events that result in shootings are relatively rare in Sweden (4-5 per year in the district investigate with about 1.2 million inhabitants)(II). However, the high threat events that resulted in use of pepper spray were not uncommon (about 200 per year, same district) (I) when counted for in a representative Swedish police district. The police officers ability to handle the more threatening situations will always be affected by a reflexively activated stress response to some level. Thus, these police officers need to be prepared to address sudden, critical and even previously unknown high threats causing an immediate, strong, stress response (I, II). In 39 % of the officer-involved shootings, the characteristics included properties like very short time frames (< 3 s) and in 42 % of the cases very close ranges (< 3 m) (II). The use of firearms by a police officer is very uncommon and the use of pepper spray on individual police officer level is also rare, so the only previous experience most police officers will have will be artificial, i.e., from basic and in service

training. Hence, it is important that any training given is adapted to the real-life situational characteristics of these incidents (I, II). However, high threat situations (armed assailants) are almost five times more commonly addressed with pepper spray (II) than firearms (I). Thus, the police officers also have to train to handle moderate threats and stress levels, which are much more common and can still induce high levels of stress, as shown in the pepper spray study (I).

According to the situational characteristics (I, II, III) the necessary training should include handling high to extreme threat situations, e.g. short range (< 3 m) to medium range (3-7 m) threats/attacks with firearms, sharp and blunt objects, and firearms threats/attacks from longer ranges (> 7 m), i.e., no "safe time" available initially. Moreover, the officer should train handling high threat situations, e.g. armed with sharp or blunt object or several unarmed attackers, from long range (> 7 m) with a small initial window with "safe time" available. Finally, the training should include handling moderate to high threat situations, e.g. unarmed threats/attacks with the threat level determined by available "safe time" or number of attackers compared to resources.

To handle high to extreme stress, sudden attacks and threats from close ranges, the choice of responses to train is crucial. A defense or counter response adapted to a specific high threat stimulus would be appropriate [21,69] (I, II). For example, 55 % of the fire for effect (FFE) shots were fired without the use of sights and 33 % of the FFE shots were fired while the police officer was in motion where none reported using two hands when firing. However, almost all training received stipulated that a police officer should stand statically, using sights and two hands while firing. Hence, the situational characteristics of short time frames, short ranges, moving threats and high to extreme stress response levels, force police officers to use the firearm in ways not previously trained [21,69] (II). Thus, to decrease the risks for police officers and bystanders, these situational characteristics should be trained for. As fine motor skills and even highly trained complex motor skills deteriorate during high stress response levels [69] (I, II, V), the selected equipment, techniques and responses for high to extreme threats also need to be resilient to stress. Hence, a stress resilience evaluation should include the entire equipment handling process from detachment of the weapon and weapon holster, handling of safety mechanisms, means for aiming and means for actually producing an effect on the target with as short a "safe time" as possible.

Theoretical abstract knowledge, i.e. information gained from lectures, reading, discussions or after training reflection are not available to us during a stress response. Hence, theoretical education or after action reflection has no effect on future ability to perform when under stress. Thus, practical procedural training is necessary to improve ability during stress, since it creates experiences accessible during a stress response [19,81]. Techniques and responses need to be learned as stimulus-response open skills in a low stress environment immediately followed by repetition and training at systematically increased stress levels. This approach can

be utilized as varied short scenario training (VI, V, VI). Heart rate was shown to be a very useful stress biomarker in ensuring that the training reaches stress habituation levels (IV, V, VI). The heart rate monitoring might also protect from fear conditioning during tests and stress training (VI). To determine whether the training given or received improved the police officers ability to handle the most common high threat and stress situations, the test scenarios can be filmed (IV, V). The performance can be subsequently reviewed by experienced instructors, using a predesigned systematic protocol, examining factors like general motor control, verbal content and tone, spatial and temporal tactical implementation and overall situational control (V). If eye-tracking equipment were available, filming the direction of gaze makes it possible to assess the perceptive abilities of the trained too (V).

Limitations

One limitation is that the police officers in studies I and II self-reported the situational characteristics during the events. Thus, one risk is that the police officers that participated might have rationalized or described their actions as better than they really were. However, the reported details are based on 128 (II) and 457 (I) involved police officers' individual experiences and perceptions collected over a 7-year (I) or 28-year period (II). Thus, the risk for systematic biases across the collected material is low. Moreover, at the time, the information was collected anonymously, and no legal issues remained, which should have provided as accurate a report as possible. Another risk is that all reports are based on subjective recollections that likely to some degree contain biases connected to the stress response (III). Here, the perceived time may likely be more prone to bias than the perceived distance. However, the most common bias regarding time is slow motion [2], which indicates that the actual time frames are likely shorter than perceived, emphasizing the risks found in studies I and II even more.

Another limitation is the somewhat unsystematic collection of information due to many different interrogators (12) used in study III, that may not have followed identical procedures, e.g., not used the same questions or asked the questions in the same order when interviewing the witnesses (13) (III). Thus, some details might have been omitted where certain questions were not put forward to some witnesses. However, as the interrogators did not use identical questions, systematic bias may be avoided as the individual interrogator introduced a randomness that would prevent groups creating a picture based on the questions asked or to the order in which they were asked.

Some of the studies (IV, V, VI) were performed in artificial environments and settings with an audience, like in a laboratory. Hence, the scenario simulations lacked many of the elements of uncertainty that would be present in the real life

situations, and thus, the heart rate levels recorded during many scenarios suggested that the scenarios induced only moderate stress. NATO developed a method to evaluate the use and functionality of less-lethal weapons [82]. However, this method of using simulated scenarios gave limited knowledge about responses to less-lethal weapons, and the circumstances around police officers' use of less-lethal weapons in real life [83,84]. That said, artificial tests can still give important information regarding effects of stress and training if using real life situational characteristics and when examining specific trained responses to known problems, threats and attacks.

Another difficulty is to differentiate when physical activity induced an increased heart rate from a psychologically induced increased heart rate (IV, V, VI). In studies IV and V, the participating police officers took a few slow steps into the scenario environment. The heart rate then rapidly increased from about 105 BPM to 120 BPM when the scenario included psychological stressors. However, taking a few steps would normally not cause a major increase in heart rate in healthy subjects. For comparison, in study VI, the participants were assigned to searching 20 rooms in a fast succession (≤ 60 seconds) without psychological stressors and that caused a mean heart rate of 113 BPM.

When examining pupil diameter as a physiological stress biomarker in studies IV and V, we noted that the pupil rapidly changed in diameter and the pattern and complexity varied compared to heart rate. Although pupil diameter can be affected by gaze or shadows e.g., a light source may temporarily distort the pupil diameter measurements, the pupil still showed to be a useful stress biomarker. The pupil was dilated even though participants entered a brightly lit room (approximately 100x brighter) and dilated further when a threat appeared early in the scenarios.

Implications

- The findings in the thesis revealed systematic situational characteristics in real life police interventions and in artificial scenarios that may affect perception, memory, cognition, decision-making, and motor ability to use weapons, depending on the strength of the reflexive neuroendocrine stress response.

- Pepper spray is effective, however, lacks key properties for use in high threat and high stress situations, e.g. against armed individuals. This contradicts current and common risk taking use in real life police interventions, which indicates a gap in the less lethal use-of-force continuum.

- Firearms training, both basic and in service, currently do not meet the needs of real life situational characteristics when police officers are forced to use their firearms. This was especially reveled when the police officers in real life

incidents were exposed to sudden armed attacks from close ranges that offered only short time frames to respond. The situational characteristics described, e.g., that police officers have to shoot using one hand, without using sights and shoot while both themselves and the assailant are in motion, are not part of the present training programs. Moreover, some findings suggest that a reluctance to use the firearm altogether, may have produced a delay allowing the assailant to move closer, i.e., that the opportunity to fire immobilizing leg shots earlier during the event was lost.

- Access to longer range, simpler to use and shorter "time to effect" less-lethal weapons, e.g. EIDs, may improve safety for intervening police officers, perpetrators and bystanders alike.

- The new term "Safe time" defines the shortest possible time for a human to have a realistic ability to affect the outcome of a possible attack. The calculated "Safe time" should thereafter be compared with the time it takes for the threat in question to cause harm to the police officer, e.g., what time would be required for an armed assailant to move 10 meters and inflict injury. The term "Safe time" considers and includes all known time affecting factors in the response process such as distance, body position, obstacles, type of weapons involved, response time and time to effect. Objective risk evaluations including all factors and a presentation of the outcome in easily understandable parameters, such as the available time in seconds to respond to a sudden attack, may have ethical and legal implications where verdicts are required to consider physical limitations.

- Biomarkers can be used to determine if optimal stress levels for stress habituation are reached by the training conditions designed, as evidenced by recordings of heart rate, and to some extent pupil size. Heart rate, if continuously monitored in real-time, may also help to prevent too extreme stress levels that create fear conditioning, i.e., increased stress sensitivity.

Conclusions

From the findings in the studies upon which this thesis is based, the following conclusions may be drawn.

I. Situational characteristics were obtained from 936 incidents where police officers used pepper spray. Pepper spray was found to be effective by often preventing or stopping violence. However, in 21 % of all incidents police officers took great personal risks by using pepper spray against armed persons. People armed or perceived as mentally ill were sprayed with larger dosages from longer distances, whereas unarmed, those perceived as healthy or intoxicated were sprayed at significantly shorter distances. In 24 % of the incidents, non-intended people were hit or contaminated, whereof 90 % were police officers. The average effectiveness was of only 82 %, the operative range less than 2 m and it took up to 3-5 s until 'time to effect'. Consequently, this enables an assailant to reach the spraying police officer and to inflict harm before the effect of pepper spray has commenced. Hence, tactical use of pepper spray cannot be recommended for acute life threatening encounters. Moreover, the pepper spray canister could be enhanced for better tactile aim and simpler safety mechanisms to improve functionality. The short ranges used, the long spray intervals needed, the very common unintended contamination of other police officers all indicate that the required fast tracking precision and fine motor skill required for handling pepper spray deteriorate during stress.

II. Situational characteristics were collected from 128 police officers that used their firearms 132 times in 112 incidents. The first police officers at the scene were in 80 % of the incidents forced to handle the situation, and the incident was typically over before a SWAT-team arrived. The initial reason for police presence rarely gave an indication that the event could evolve into a shooting incident, but about 70 % of the initial assignments concerned tasks usually performed un-dramatically on a daily basis. In 39 % of the cases, the threat was regarded so imminent that a shot was fired within ≤3 s from the time it emerged and in 27 % of the cases between 3 and 10 s from the time it emerged. In 42 % of the cases, the distance was estimated to be ≤3 m and in 65 % of the cases ≤7 m. The assailant was in motion during 76 % of the shootings. The findings suggest that patrolling police officers should receive high threat incident training. Moreover, the firearms training should better reflect real life situations

by including shooting at various distances, at various target areas, at moving threats, fire while in motion and while using only one hand. The situational characteristics in 32 % of the shooting incidents would have allowed initial attempts to use long-range (7-15 m) EID, to neutralize the assailant.

III. When witnessing a shooting with lethal outcome, the temporal and spatial distortions or biases were similar in almost all the witnesses' statements. All 13 witnesses reported observing that the assailant was armed with a knife and heard the police shout; "drop the knife". All of the witnesses reported that the perpetrator moved toward the police officer, and that the police officer first fired warning shots into the air, which the assailant ignored and continued to advance toward the police officer. However, the testimonies then began to diverge from the actual course of events; 12 of the 13 witnesses reported that the perpetrator was hit by the third or fourth shot, but with very limited effect. However, the video revealed that the third or fourth shot made the assailant fall to the ground to thereafter try to drag himself towards the police officer without dropping the knife. The similarity of the perceptive and memory distortions, in spite of the obvious individual differences in training received, experiences and role in the incident, indicate that the biases can be general and systematic. Thus, trustworthy eyewitness statements, even when many are in consistency, must be treated with caution, especially if the witnesses were likely affected by stress. Hence, the perceptual, temporal and spatial biases from stress are very important to consider during the forensic investigation, witness interviews and in the legal aftermath.

IV. Performing threatening tasks in a sequence can escalate the stress response, and the stress can be initiated even before being exposed to a task. The findings highlight the benefit of avoiding sustained exposure to high stress by allowing deescalating rests between stressful tasks. Many policing actions, training and evaluation often include sequential tasks, thus these results may have implications when developing training and planning at different levels. The knowledge can also be of use in after-action reviews of stressful police interventions. Heart rate was found to change systematically with repetition during moderately stressful tasks. Pupil diameter indicated a stress response at the onset of the tasks by dilating instead of constricting when the police officers entered an almost 100 times brighter illuminated scenario room. Hence, both heart rate and pupil size seem to be reliable biomarkers of the stress response, though displaying different kinds of information.

V. Expert instructors' systematic and quantitative assessments provide valuable and reliable information about the performance of police officers in realistic and stressful scenarios. Furthermore, objective physiological measurements of

heart rate and pupil diameter can help to explain why performance sometimes deteriorates. For example, the pupil diameter tended to be influenced by the scenario, e.g., by a delayed or immediate threat presentation. Since even well trained complex motor skills deteriorate during higher stress situations, it is important to evaluate the training curriculums used, to categorize different skills in fine, complex or gross motor respectively. A high threat problem should not be addressed with a solution that requires fine motor skills.

VI. When police officers performed an active shooter exercise without active stressor stimuli, the average heart rate increased from 83 BPM (resting) to 113 BPM, most likely mainly due to the physical activity. However, when the same police officers performed the same exercise, this time with the active stressor stimuli, their heart rates increased significantly to 143 BPM. Hence, given the similar level of physical activity, it was possible to identify physical and psychological reasons for changes in heart rate. Hence, heart rate is a reliable biomarker of the stress response providing detailed analyses of dynamically changing scenario effects, e.g., latencies between an event and recorded stress response, rate of increasing reaction, duration of reaction and recovery rate.

Svensk populärvetenskaplig sammanfattning (Summary in Swedish)

I vissa yrken, som polis och räddningstjänst, riskerar man oftare än människor i allmänhet att råka ut för starkt stressfyllda situationer. Stressreaktioner påverkar flera viktiga neurologiska funktioner som vid låga stressnivåer ofta, men inte alltid, är till en fördel. Vid låga stressnivåer blir perceptionen (varseblivning) först bättre med ökad vakenhet och uppmärksamhet och vår tanke- och beslutsförmåga växlar från en långsammare, analyserande aktivitet till ett snabbare mer erfarenhetsbaserat beslutsfattande. Vid hög stress försämras perceptiv och kognitiv förmåga med avskärmat synfält och trögare beslutsfattande som följd. Vid extrema stressnivåer kan effekterna bli tunnelseende och att man upplever sig som ”tom i huvudet”. Andra extrema beteenden inkluderar kamp-, flykt- och frysningsreflexer och känslor som panik, raseri, ångest, eller att man inte har några känslor alls. Vår förmåga att utföra även väl inövad finmotorik blir sämre redan vid låga stressnivåer men vid högre stress börjar också komplexmotorisk förmåga avta samtidigt som förmågan till grovmotorik blir oförändrad eller bättre på grund av ökad muskelstyrka. Det är viktigt att notera att en stressreaktion styrs av reflexiva neurologiska och hormonella processer som initieras redan innan vi med vårt medvetande uppfattat en farlig situation. Stressreaktionens reflexer är mycket snabba, en farlig situation uppfattas av interna centra inom 0.1 sekund och dessa aktiverar i sin tur en rad processer som stärker vår förmåga att hantera farliga situationer. Först efter 0.5 sekunder uppfattar vårt medvetande situationen. Om man inte inom 15-30 sekunder får lugnande information (t ex att man såg fel) så hinner så starka hormonella processer aktiveras att en stressreaktion inte längre kan bromsas inom minuter utan återhämtningen tar en till flera timmar. När stressresponsen väl pågått en kort stund finns således ingen möjlighet att snabbt besinna sig eftersom blodets stresshormoner tar lång tid att reducera biokemiskt genom upptag och nedbrytning. Alla angivna tidsramar är dock ungefärliga eftersom styrkan i stressreaktioner och hur snabbt stressprocesserna arbetar moduleras av hur farlig man uppfattar situationen.

Målet för avhandlingen har varit att undersöka de akuta perceptiva, kognitiva och motoriska effekterna av reflexiva neuroendokrina stressreaktioner vid polisiära

situationer och ingripanden i verkliga livet, samt under olika tester och övningar. Forskningsstudierna syftar till att nå en bättre förståelse och därigenom bättre kunna anpassa taktik, träning och utrustning så att poliser ska kunna fungera och lösa sina uppgifter bättre vid polisiära ingripanden trots en oundvikligt pågående reflexiv, men olika stark, stressrespons.

De aktuella studierna

I sex olika arbeten har vi undersökt omständigheter och stresseffekter i samband med polisingripanden i verkliga livet och under övningar. I tre studier har vi empiriskt undersökt vilka konkreta faktorer som påverkar vid verkliga polisiära hotfulla och våldsamma situationer när pepparsprej och skjutvapen använts. Dessa undersökningar syftar till kartlägga omständigheter och pepparsprejens effektivitet samt analysera dess operativa och taktiska begränsningar vid polisingripanden. Målet var också att utvärdera de konkreta faktorerna som påverkar under de ofta extremt hotfulla situationer när skjutvapen använts, hur poliserna har agerat och om händelsemönstret visar tecken på mänskliga fysiska och psykiska begränsningar (I, II). I en studie undersökte vi perceptions- och minnesförvrängningar hos vittnen till en verklig händelse där polis använde skjutvapen med dödlig utgång (III). För att närmare kunna analysera effekten av stress genomförde vi också tre studier där vi under kontrollerade tester och övningar undersökte effekterna av olika stressande hot och störningar. Vi mätte under dessa studier då också de fysiologiska biomarkörerna puls och pupilldiameter för att undersöka hur väl dessa markörer fungerar som indikatorer för en aktiverad stressrespons. Målet var då även att se hur puls och pupillstorlek varierande när poliser i en snabb följd genomförde flera hotfulla polisuppgifter med endast en kort vila emellan (IV). Vi undersökte också om erfarna instruktörer systematiskt kunde bedöma testade polisers perceptiva, kognitiva och motoriska förmågor med objektivt utfall (V). Studierna användes också för att undersöka om förmågan att utföra en väl inövad komplexmotorisk färdighet påverkades av om den utfördes under påverkan av en stark stressrespons jämfört med om den utfördes under lugna förhållanden (V). Slutligen undersökte vi om man genom att använda artificiella miljöer av simulerade våldsscenarier, kunde skapa en psykologisk stressreaktion hos deltagarna (VI). Detta är viktigt eftersom övning under stresspåslag ger tillvänjning och ökar förmågan att hantera framtida stressfyllda situationer. Å andra sidan är det viktigt att man kontrollerat kan öka stresspåslaget stegvis, t ex genom pulsmätning under övningarna, för att undvika att starkt betinga ett obehag kopplat till det stimulus som man vill få poliser att hantera bättre. En sådan stark negativ betingning försämrar istället den framtida förmågan att hantera det aktuella hotet eller till och med andra faktorer betingade till hotet.

Slutsatser

Pepparsprej visade sig vara ett effektivt verktyg för att förhindra eller stoppa våld, och därmed minska risken för skador på alla inblandade (I). I 21 % av incidenterna tog dock poliser stora personliga risker genom att använda pepparsprej mot personer som var beväpnade med vassa eller trubbiga föremål. Vid 24,4 % av incidenterna blev andra än de ämnade för pepparsprejen träffade, varav 90 % var poliser. Vi fann att pepparsprejens egenskaper gör den taktiskt farlig att använda mot beväpnade, eftersom den hade god effekt bara i 82 % av fallen, dess faktiska operativa räckvidd var mindre än 2 m och att den hade en ”tid till effekt" på upp till 3-5 s, vilket gör det möjligt för en angripare att nå och skada eller döda den spejande polisen. Designen på pepparsprejens behållare är dåligt anpassad för att användas under en starkare stressrespons, på grund av att behållaren är svår att ta loss från vapenbältet, den runda formen inte ger någon indikation om spraymunstyckets riktning samt säkerhetsmekanismen kräver finmotorisk förmåga. Sammantaget demonstrerar studie (I) värdet av att empiriskt analysera erfarenheter och omständigheter från verkliga incidenter eftersom informationen ger bättre taktiskt och objektivt underlag från att stresseffekter i verkliga situationer inte går att återskapa fullt ut i laboratoriemiljöer. Dessutom visar datan från verkliga situationer vilka händelser och tillhörande omständigheter som faktiskt är vanligast vid hotfulla och våldsamma situationer. Dessa mer objektiva metoder kan i kombination med kunskap om hur vi fungerar fysiologiskt vid olika stressnivåer göra det lättare att avgöra om de vidtagna åtgärderna var säkra och rimliga ur forensiskt och juridiskt perspektiv.

Undersökningsresultaten av både polisernas bruk av pepparspray och skjutvapen visar att poliser i yttre tjänst har ett stort behov av utbildning i att hantera mycket kritiska situationer (I, II). I 80 % av skjutincidenterna tvingades första polispatrull på plats hantera situationen själva och händelsen var oftast över innan en specialenhet som insatsstyrkan kunde nå platsen. Övning med tjänstevapen bör varieras och innehålla träning på att skjuta från olika avstånd, mot olika målytor, mot hot som är i rörelse, att använda vapnet med en hand, i rörelse och att skjuta välriktade skott utan riktmedel. Varningsskott upp i luften bör begränsas starkt eftersom kulor i de flesta fall är dödliga när de slår ner. Bruket av termen ”säkert avstånd” är i taktiska sammanhang delvis problematiskt. Exempelvis kan en knivbeväpnad person inte orsaka någon skada från 10 m avstånd, men efter en rusning som bara tar 2 s så är förhållandet det motsatta. Att istället bruka ”säker tid” = den minsta rimliga möjliga tid som behövs för att ett angrepp ska upptäckas, ett beslut om adekvat motåtgärd fattas, hinna utföras och få effekt - kan vara mer användbart för att kunna bestämma lämplig taktik där många fler faktorer än avstånd påverkar risknivån. Vår andra studie (II) visade att vid 32 % av tillfällena när polisen använde skjutvapen skulle de istället kunnat använda ett mindre dödligt vapen med

litet längre räckvidd. Den svenska polisen saknade vid studiens genomförande lämpliga mindre dödliga vapen som kunde verka inom 2-15 m.

En troligen starkt stressresponsaktiverande händelse när en person med kniv skjuts av polis analyserades i studie (III). Av 13 vittnen, varav 4 poliser, hade alla utom en uppfattat händelseförloppet felaktigt med samma typ av minnesförvrängningar. Detta förhållande framgick av att det verkliga förloppet under händelsen hade dokumenterats på film. Det tydde på att perceptionen och minnet påverkats likartat trots individuellt stora skillnader mellan vittnena vad gäller övningsbakgrund, erfarenheter samt den varierande delaktigheten i situationen.

Att utföra stressande uppgifter i en snabb följd kan i sig själv eskalera stressresponsen (IV). Redan strax före genomförandet av tester kunde vi se att stressresponsen varit aktiverad med hjälp av pulsmätare. Pupilldiametern gav mer varierade utslag än puls på stress. Pupillen ökade t ex i diameter när de kom in i scenariorummet trots att scenariorummet var en faktor nära 100 gånger starkare upplyst än förrummet de kom ifrån. Normalt borde det få pupilldiametern att krympa på grund av den pupillära ljusreflexen. Mätning av pupilldiametern kan således komplettera pulsmätningen för att se kortare reaktioner på stressorer inom ett scenario. Testscenarierna i studie IV framkallade pulsnivåer på omkring 120 slag per minut, vilket tyder på att en måttlig stressresponsnivå inducerades under denna övning. Den stressnivån kan potentiellt påverka vissa kognitiva funktioner och är problematisk för förmågan att utföra finmotoriska uppgifter.

Erfarna instruktörers systematiska kvantitativa bedömningar visades ge värdefull och tillförlitlig information om polisens prestationer i realistiska och stressiga scenarier (V). Vidare kan objektiva fysiologiska mätningar av hjärtfrekvens och pupilldiameter hjälpa till att förklara varför prestation ibland försämras. Pupilldiametern var t ex signifikant större om ett hot presenterades tidigt i ett scenario än om det presenterades sent. En väl inövad komplexmotorisk förmåga, för att åtgärda ett eldavbrott på tjänstevapnet, försämrades drastiskt när den utfördes under en stark stressrespons.

När poliser utförde en övning i pågående dödligt våld utan stressorer, ökade hjärtfrekvensen från i genomsnitt 83 slag per minut till 113 slag per minut, troligen främst på grund av den fysiska aktiviteten (VI). Men när samma poliser utförde samma övning med aktiva stressorer, i form av hotfulla figuranter och risk för att bli träffade av smärtsamma färgmarkeringsskott, ökade deras hjärtfrekvens betydligt till i genomsnitt 143 slag i minuten. På grund av den identiska fysiska aktiviteten i tid och aktivitet var det möjligt att identifiera från pulsaktiveringsmönstret, om träningen endast var fysiskt belastande eller om övningen även orsakade en stressresponsaktivering.

Sammanfattningsvis visar studierna att stressresponsen kan påverka poliser under skarpa polisingripanden och övningsscenarier som kan inverka på perception och minne, kognition och beslutsfattande samt motoriska färdigheter som behövs för att

använda utrustning och vapen. Följaktligen bör konsekvenserna av stressresponsen beaktas vid val och utformning av taktik, träning och utrustning så att uppgifter kan utföras väl även vid starkare stressresponsaktivering. En ökad kunskap om hur verkliga hotfulla och våldsamma situationer ser ut, samt en ökad förståelse för fysiologiska och beteendemässiga förändringar i dessa situationer, kan bidra till att forensiska utredningar och juridiska bedömningar kan utföras mer systematiskt och vara mer konkret baserat på vetenskaplig empirisk och fysiologisk grund.

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Appendix: Publications