THE HEALTH EFFECTS OF CONDUCTED ENERGY WEAPONS

The Expert Panel on the Medical and Physiological Impacts of Conducted Energy Weapons

Council of Canadian Academies
Conseil des académies canadiennes

Canadian Academy of Health Sciences
Académie canadienne des sciences de la santé

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THE COUNCIL OF CANADIAN ACADEMIES & THE CANADIAN ACADEMY OF HEALTH SCIENCES
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Library and Archives Canada Cataloguing in Publication

The health effects of conducted energy weapons / The Expert Panel on the Medical and Physiological Impacts of Conducted Energy Weapons.

Issued also in French under title: Effets sur la santé de l'utilisation des armes à impulsions.

Includes bibliographical references and index.

Electronic monograph in PDF format.

Issued also in print format.

ISBN 978-1-926558-64-6 (pdf)

1. Stun guns–Health aspects. 2. Nonlethal weapons–Health aspects.

I. Council of Canadian Academies. Expert Panel on the Medical and Physiological Impacts of Conducted Energy Weapons, author

HV7936.E7H43 2013a 363.2'32 C2013-905595-9

This report should be cited as: Council of Canadian Academies and Canadian Academy of Health Sciences, 2013. *The Health Effects of Conducted Energy Weapons*. Ottawa (ON): The Expert Panel on the Medical and Physiological Impacts of Conducted Energy Weapons. Council of Canadian Academies and Canadian Academy of Health Sciences.

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Printed in Ottawa, Canada

Council of Canadian Academies
Conseil des académies canadiennes

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Canada This assessment was made possible with the support of the Government of Canada.

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Letter from the Chair

Although relatively new to modern policing, conducted energy weapons (CEWs) have become widespread tools used by law enforcement and public safety personnel in all jurisdictions across Canada. Because of this widespread use and current scrutiny in both scientific and public spheres, all Canadians have a vested interest in determining what is known and not known about the physiological and health effects associated with CEW use.

The Expert Panel on the Medical and Physiological Impacts of Conducted Energy Weapons is deeply appreciative of the opportunity to explore this important question and for the input and assistance it received throughout the course of its work.

Several individuals and organizations provided very helpful advice and assistance early in the process. In particular, Len Goodman, Head (acting), Individual Behaviour and Performance Section, Defence Research and Development Canada-Toronto, and Donna Wood, Project Manager, Conducted Energy Weapons Strategic Initiative (CEWSI), Defence Research and Development Canada-Centre for Security Science, provided excellent background on the work of the CEWSI more broadly and guidance related to the scoping of the assessment questions. Sergeants Steven De Ville and Greg Borger of the Ottawa Police Service in Ontario also generously provided their time and experience to guide the Panel through a hands-on demonstration of CEW devices and their uses in policing use-of-force models.

The Panel also wishes to acknowledge the staff of the Quality Engineering Test Establishment research facilities of National Defence and the Canadian Forces, who were very helpful in providing a tour of their research testing facilities in the initial stages of the assessment and instrumental in providing testing data related to their work with CEWs for use in the report. The Panel also appreciates the reconnaissance work of Public Safety Canada and its important consultation activities into the use of CEWs in Canada.

Finally, the Panel is most grateful for the outstanding support it received from the staff members of the Council of Canadian Academies, whose names are listed below.

The Honourable Justice Stephen T. Goudge
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Report Review

This report was reviewed in draft form by the individuals listed below — a group of reviewers selected by the Council of Canadian Academies and the Canadian Academy of Health Sciences (CAHS) for their diverse perspectives, areas of expertise, and broad representation of academic, industrial, policy, and non-governmental organizations.

The reviewers assessed the objectivity and quality of the report. Their submissions — which remain confidential — were considered in full by the Panel, and many of their suggestions were incorporated into the report. They were not asked to endorse the conclusions nor did they see the final draft of the report before its release.

Responsibility for the final content of this report rests entirely with the Expert Panel on the Medical and Physiological Impacts of Conducted Energy Weapons, the Council, and CAHS.

The Council and CAHS wish to thank the following individuals for their review of this report:

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The report review procedure was monitored on behalf of the Boards of the Council and CAHS and the Joint Scientific Advisory Committee by **Dr. Jean Gray, C.M., FCAHS,** Professor of Medicine (Emeritus), Dalhousie University. The role of the Report Review Monitor is to ensure that the Panel gives full and fair consideration to the submissions of the report reviewers. The Boards of the Council and CAHS authorize public release of an expert panel report only after the Report Review Monitor confirms that the report review requirements have been satisfied. The Council and CAHS thank Dr. Jean Gray for her diligent contribution as Report Review Monitor.

Elizabeth Dowdeswell, O.C., President and CEO
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Executive Summary

Conducted energy weapons (CEWs) are devices that use electrical energy to induce pain or to immobilize or incapacitate a person. The broad use-of-force continuum used by law enforcement and public safety personnel ranges from the physical presence of an officer through to use of deadly force. CEWs are one of several options on this continuum. They are typically used to facilitate arrests of uncooperative individuals who are resisting. The induced loss of voluntary muscle control causes subjects to fall to the ground, where they may be subdued and taken into custody. Subjects are not meant to experience any lasting effects after application of the device.

CEWs are used by law enforcement agencies around the world. They were first adopted by some Canadian law enforcement agencies in the late 1990s. Currently, there are approximately 9,174 CEWs in use in Canada and although the number varies based on jurisdiction, all federal, provincial, and territorial jurisdictions use the device in some capacity. Decision-making about the protocols for selecting, acquiring, and using CEWs is undertaken by local agencies and varies across geographies. The decision to deploy a CEW resides not only at the institutional and management levels, but also in the field and in the moment. In any policing scenario, the officer on the scene decides whether and how to use force by following protocol, weighing options and outcomes, and estimating risk within the limitations of information available in real time.

CEWs are intended to be safe and potentially injury-reducing compared to alternative interventions, but they are not necessarily risk free. Scientific research and public forums have discussed and debated the potential risk, harm, and appropriateness of CEWs as a use-of-force option. Based on media reports and documented inquest processes alone, to date at least 33 deaths have been proximal to CEW use in Canada, but were not necessarily results of CEW deployment. There is no synthesized body of evidence documenting the number of deaths related to all other use-of-force encounters to confirm or compare with this number. Given current scrutiny, a scientific consensus on what is known and not known about the physiological and health effects associated with CEW use is essential.

In 2010, the Centre for Security Science at Defence Research and Development Canada (DRDC) began undertaking the Conducted Energy Weapons Strategic Initiative (CEWSI), in partnership with the Director General for Policing Policy at Public Safety Canada. One of the CEWSI objectives was to convene a panel of medical experts to conduct an independent evaluation of existing research aimed at examining the medical and physiological impacts of CEWs. To fulfill this objective, DRDC (the Sponsor) asked the Canadian Academy of Health Sciences (CAHS) to conduct an independent, evidence-based assessment of the state of knowledge in this area. CAHS established a partnership with the Council of Canadian Academies (the Council). Working collaboratively with CAHS, the Council acted as the secretariat for the science-based exploration of the evidence.

The Council and CAHS were asked to answer the following three main questions:

1. What is the current state of scientific knowledge about the medical and physiological impacts of conducted energy weapons?
2. What gaps exist in the current knowledge about these impacts?
3. What research is required to close these gaps?

To address the charge, the Council and CAHS assembled a 14-member multidisciplinary panel of experts from Canada and abroad (the Panel). This report is based on the consensus reached by Panel members through their review and deliberation of the evidence: major evidence syntheses, reviews, and books; peer-reviewed primary research; other relevant literature on broad topics such as research ethics, electrophysiology, and electrical engineering; technical documents outlining testing results established by DRDC; and a hands-on demonstration of CEW deployment during a site visit to the Quality Engineering Test Establishment (QETE) research facilities of the Department of National Defence Canada and the Canadian Forces.

THE FINDINGS

The Panel identified five key findings that serve to answer the charge put forward by DRDC. The following is a description of those findings; a more detailed discussion is contained in the Panel's full report.

1. CEWs are based on the principle that the electrical discharges delivered by the device are powerful enough to effectively stimulate motor and sensory nerves, causing incapacitation and pain, but too brief to directly stimulate other electrically excitable tissues. Because the electrical characteristics of CEW devices are variable and evolving, each CEW device must be tested on its own merit to assess performance as well as the ability to induce incapacitation and potential adverse health effects.

CEWs deliver short, repeated pulses of electricity to the skin and subcutaneous tissues through two metal probes. They can be used in two operating modes: probe mode and drive stun mode. In probe mode, a pair of metal darts deploys from the CEW, spreads apart, and penetrates and attaches to the subject's clothing, skin, and soft tissues. The darts are connected to thin electrical wires that conduct the electrical discharge from the device. If the two darts are spaced widely enough across the body, the resulting effect is incapacitation. In drive stun mode, the device is pressed directly against the subject, causing localized pain. Probe mode is more likely to result in current flow through the tissues in the chest — including, potentially, the heart — and carries the most risk of unwanted cardiac or other health effects.

In addition to causing pain, CEWs influence the peripheral nervous system in a way that causes temporary, involuntary, and uncoordinated skeletal muscle contractions. Along with factors specific to the individual and context, the response of the human body to a CEW depends on the strength, duration, and waveform of the electrical discharge, as well as on the timing of the applied electrical current in relation to the natural electrical activity occurring in the body. The ability of CEWs to stimulate some tissues (e.g., nerve cells) and not others (e.g., heart cells) is dependent on these characteristics. Nerve cells have waveforms that are much shorter than those produced by the heart muscle. The duration of electrical stimulation required to exceed the threshold in a cardiac muscle cell is about 10 to 100 times longer than in a motor or sensory nerve cell. Therefore, the principle guiding the functioning of CEWs is that the short-duration electrical discharges it delivers are highly effective in stimulating nerves, causing incapacitation and pain, but are much less effective in stimulating the heart muscle and thereby inducing potentially fatal disruptions to the heart's rhythm and pumping ability. Specifications between CEW devices are variable, however, and may change with use and under different conditions. CEW devices and the variations between them are also constantly evolving, so knowledge based on any particular model does not necessarily translate to other devices, and the characteristics of newer devices are unknown. Evaluating the intended and unintended effects of a CEW requires testing each device on its own merit and understanding the context and conditions under which it is used.

2. Certain physical injuries such as superficial puncture wounds are common as a result of CEW discharge, but rarely pose serious medical risks. Although it is difficult to state any firm conclusions on the neuroendocrine, respiratory, and cardiac effects of CEWs due to an absence of high-quality evidence, available studies suggest that while fatal complications are biologically plausible, they would be extremely rare.

The Panel identified a range of CEW-induced physical injuries. Superficial physical injuries resulting from CEW probes are common, while more severe injuries resulting from CEW probes, muscle contractions, and falls associated with incapacitation occur much less frequently. The Panel concentrated on acute, short-term physiological and health effects resulting from the electrical current of CEW devices and having the most potential for sudden unexpected death. Because sudden unexpected death is likely the end result of a variety of intersecting factors that involve the neuroendocrine, respiratory, and cardiovascular systems, the Panel focused on physiological changes in these systems, including activation of the human stress response and build-up of related levels of stress hormones such as catecholamines; mechanical impairment of breathing, changes in blood chemistry, and resulting acidosis; and changes to heart rhythm and rate and the potential for arrhythmias. The Panel also examined a range of co-factors that individually, or in combination, could increase the risk or severity of these effects and increase the risk of sudden unexpected death. From the Panel's review of the available literature, the majority of which focus on cardiac effects, several findings emerged:

- Although limited studies suggest CEW exposure can induce the stress response and increase hormone levels, these increases are of uncertain clinical relevance. It is also unclear to what extent the discharge of a CEW adds to the high level of stress already being experienced by an individual in an arrest scenario.

- Studies of animals subjected to prolonged or repeated CEW exposure indicate the potential for respiratory complications (e.g., pronounced acidosis). Although published experimental data identify respiratory changes in healthy human subjects typical of vigorous physical exertion, studies involving more heterogeneous groups or humans subjected to prolonged or repeated exposure have not been conducted.
- Some animal studies suggest CEWs can induce fatal cardiac arrhythmias (abnormal heart rhythm) when a number of discharge characteristics, either alone or in combination, are in place: probe placement on opposite sides of the heart (i.e., current is delivered across the heart), probes embedded deeply near the heart, increased charge, prolonged discharges, or repeated discharges. These studies indicate the biological plausibility of adverse health outcomes following CEW exposure.
- A small number of human cases have found a temporal relationship between CEWs and fatal cardiac arrhythmias, but available evidence does not allow for confirmation or exclusion of a causal link. If a causal link does exist, the likelihood of a fatal cardiac arrhythmia occurring would be low, but further evidence is required to confirm the presence and magnitude of any risk.
- The roles of co-factors common to real-world CEW incidents (e.g., intoxication, exertion, restraint) and other co-factors (e.g., body type, existing health complications) that may increase susceptibility to adverse effects have not been adequately tested to properly establish an understanding of increased vulnerability in humans.

These conclusions are limited by a number of challenges presented by the available laboratory-based experimental research studies, including translation of findings from computer and animal model studies to humans, human studies with mainly healthy subjects who do not represent the varying populations involved in CEW events, the absence of adequate control groups, lack of diverse and robust experimental designs and monitoring, and small sample sizes. Large-scale population-based studies that better capture the complexity of real-world CEW deployment scenarios, along with a range of potential co-factors, are lacking.

3. **Sudden in-custody death resulting from a use-of-force event typically involves a complicated scenario that includes multiple factors, all of which can potentially contribute to a sudden unexpected death. This makes it difficult to isolate the contribution of any single factor. Although the electrical characteristics of CEWs can potentially contribute to sudden in-custody death, given the limited evidence, CEW exposure cannot be confirmed or excluded as the primary cause of a fatality in most real-world settings.**

Sudden in-custody death refers to rapid, unexpected death during detention of individuals by law enforcement or public safety personnel. These fatalities typically occur during a complicated scenario, which may include agitation, physical or chemical restraint, disorientation, stress or exertion, pre-existing health conditions, and the use of drugs or alcohol, all of which can potentially contribute to the death. This makes it difficult to isolate the contribution of any single factor. Although evidence shows the electrical characteristics of CEWs can potentially contribute to sudden in-custody death, no evidence of a clear causal relationship has been demonstrated by large-scale prospective studies. In a few coroner reports, however, CEWs were ruled as the primary cause of death in the absence of other factors when excessive exposure was present. Conversely, it has been argued that CEWs could potentially play protective roles in terminating situations that might otherwise culminate in sudden in-custody death. Given the limitations and scarcity of the evidence, a clear causal relationship between CEW use and sudden in-custody death cannot be confirmed or excluded at this time. In addition, there is insufficient evidence to determine whether the use of CEWs increases or decreases the probability of sudden in-custody death in the presence of co-factors such as mental illness or excited delirium syndrome (a highly controversial classification denoting a state characterized by signs and symptoms such as agitation, elevated body temperature, disorientation, and aggression). If a causal relationship does exist, the likelihood that a CEW will be the sole cause of a sudden in-custody death is low. The extent to which the device would play a role in any death is unclear and dependent on the co-factors involved. Further research is needed to better define these relationships.

4. **There are a number of overarching challenges in funding, conducting, and interpreting CEW research, which create knowledge gaps related to the health effects of CEWs across varying populations and across the operational settings in which CEWs are deployed.**

CEWs have been studied in the laboratory, with computer or animal models and human subjects, and in the field, with real-world incidents. Animal models allow for more intensive experimental interventions, which can clarify the various parameters required to predictably achieve physiological and health effects following CEW exposure. Despite the potential advantages of these studies, their applicability and generalizability to real-world CEW exposures is unclear. The Panel concluded that prospective large-scale population-based field studies involving detailed and consistent collection of information on the characteristics of the subjects and the events surrounding CEW incidents are essential for improving the quality of evidence. However, low injury rates and lack of standardization, among other challenges, make it difficult to establish meaningful associations. Because of the challenges present in the current evidence, the Panel concluded that key issues have not been fully explored across varying populations or in the operational settings in which CEWs are actually deployed, thus pointing to several priorities for future research:

- To what extent can the electrical characteristics of CEWs cause cardiac arrhythmia and sudden in-custody death in humans when deployed in real-world operational settings?
- Are certain groups or individuals with particular conditions at increased risk for adverse outcomes related to CEWs, and if so, what are the key co-factors?
- What CEW design and deployment features could minimize the risk of adverse health effects?

The Panel further identified five overarching gaps in health-related CEW knowledge:

Establishment of causal relationships – Establishing causality is not a simple task. While some research indicates an association between CEW exposure and certain health effects, other research does not, and in many cases there is simply not enough research to make any definitive conclusions. The effects of confounding factors may provide a number of possible explanations for those relationships, or the lack thereof. Thus, the Panel considered it difficult to establish the extent to which CEW exposure could act as the primary cause of severe adverse health effects in real-world settings, largely due to the challenge of weighting the contribution of multiple factors.

Establishment of time necessary for probability – There are no guidelines to specify the length of time needed between CEW discharge and the development of a health effect that would allow one to conclude the CEW was responsible for that effect. It may be beneficial to consider a continuum where, as the time of a health effect moves farther away from the time of deployment, the probability that a CEW was directly responsible for that event diminishes.

Understanding of varying populations – Laboratory-based experimental CEW research on human subjects typically involves healthy, physically fit volunteers. There is therefore a paucity of knowledge of the health effects associated with CEW use outside controlled settings and within varying, potentially vulnerable populations. Large-scale population-based field studies involving detailed and consistent collection of information on the characteristics of the subjects and the events surrounding CEW use hold promise for addressing ethical constraints and identifying health effects across a range of populations.

Lack of standardization – The ability to carry out adequate surveillance and population-based study is hindered by lack of standardization and inconsistent reporting and record-keeping practices related to use-of-force events. There are few central registries with standardized recording of CEW incidents by both law enforcement and medical personnel. The lack of standardization hinders the ability to conduct population-based studies and to form evidence-based conclusions about the relationship between CEW use and adverse health effects.

Transparency and independence of research – Many research studies of CEWs appear to be affiliated with, or receive support from, CEW manufacturers or individuals with perceived conflicts of interest (e.g., paid medical experts), and funding sources are not always transparent. Although these studies may be scientifically robust, there is a perceived conflict of interest that limits their widespread acceptance. Independent research by organizations without financial or other ties to CEW manufacturers or others with perceived conflicts is desirable.

5. **Filling gaps in the state of evidence on the physiological and health effects of CEWs can best be achieved through a series of integrated strategies that focus on better surveillance, monitoring, reporting, and population-based epidemiological studies.**

The Panel was challenged with identifying research activities and mechanisms that might address the knowledge gaps related to the physiological and health effects of CEW use. The Panel determined the need for a series of integrated strategies underpinned by surveillance, monitoring, reporting, and population-based epidemiological study. The following considerations could form the basis of this integrated response:

Standardizing and centralizing the recording of CEW incidents – Establishing common definitions of use-of-force and CEW use, and implementing a standard method of reporting to enable police and medical personnel to record a minimum level of information, would make it possible to compare various parameters at the population level. This process would be supported by the creation of a central repository for information about use-of-force in Canada.

Enabling comprehensive medical assessment following CEW exposure – When subjects are brought to hospitals following CEW incidents, health care professionals would benefit from guidance on relevant co-factors and specific physiological changes and injuries to assess for proper patient care. With this knowledge, health care professionals could more routinely perform medical examinations relevant for evaluating CEW effects. Innovative technologies could also be integrated into CEW devices to allow for the instant and automatic recording of health and circumstantial information.

Improving access to, and sharing and integration of, knowledge across fields – Researchers could benefit from improved access to law enforcement and medical records, based on what is ethically and reasonably possible. Respecting privacy concerns, a process could be established to anonymously share and link this information across disciplines, institutions, and jurisdictions. Improved access and linking of information could encourage investigation of a range of relevant phenomena and increase the number of high-quality publications that examine various associations.

Supporting large-scale, multi-site, population-based studies – Our body of knowledge would benefit from robust multi-national, prospective population-based studies in which a broad range of health care professionals are trained in the nature and breadth of CEW injury and conduct consistent, comprehensive, and detailed medical examinations of individuals exposed to CEWs. To enable scientific analysis and reliable comparisons across events, research protocols would benefit from dynamic evidence-gathering methods allowing for the capturing of any unforeseen events (and their characteristics) that may arise during data collection.

Improving understanding of CEW risk relative to other use-of-force interventions – CEWs exist alongside (and can be used in conjunction with) many other possible interventions. To assess the risk of CEWs in relation to other interventions, future studies should consider comparing sudden in-custody deaths both related and unrelated to CEW incidents. Future studies would benefit from exploring the risks of not using a CEW in a given situation and accounting for jurisdiction and context, the use-of-force techniques and protocols in place, and the related adverse health effects that include morbidity, its severity, and mortality.

Understanding specifications of CEWs manufactured by a range of companies – By studying and comparing a broad range of devices, researchers could better understand how distinct outputs (e.g., waveform specifications and deployment modes) from CEWs are associated with physiological effects that vary in type and severity. Properly defining and articulating testing protocols for CEW devices would impose standard methods for assessing device performance over time. Enhancing knowledge in this area would help establish more robust information around safety parameters and technical specifications.

Furthering ethical, laboratory-based CEW research – Future computer modelling and animal studies would benefit from the application of novel approaches and larger sample sizes with proper comparison and control groups. Human studies would benefit from mimicking certain characteristics typical of subjects in the field (with appropriate ethical and safety constraints in mind), using more heterogeneous and larger study samples, and exploring extrapolation techniques.

CONCLUSION

The conclusions reached by the Panel are based on its interpretation of the best available evidence provided throughout the report. The Panel recognizes there are gaps in the literature and undoubtedly this poses challenges when assessing the physiological and health effects of these devices. Currently, there are numerous chances to rethink how we assess and communicate the health effects of CEWs and of use-of-force interventions more broadly. Opportunities exist for redesigning and improving research methodologies, standardizing the collection of information, and developing partnerships across disciplines, jurisdictions, and professional practices.

The Panel's report is intended to provide an in-depth and authoritative assessment of the state of knowledge regarding the relationship between CEW use and a range of health effects. In addition, the Panel acknowledges that there are a number of factors that go into decision-making related to CEWs that lie beyond the assessment of health effects; these factors must also be considered in any large-scale assessment of CEW use. This report must therefore complement other work on testing and approval procedures, motivations and protocols for appropriate use, safety and effectiveness standards, appropriateness of the devices compared to other use-of-force interventions, and other socio-political considerations that make up the broader package of information needed to make sound decisions about public health, policing, and CEW use in Canada.

This assessment presents an opportunity to inform municipal, provincial, territorial, federal, and international law enforcement practices, and provides a platform to encourage improved communication among these jurisdictions. Ultimately, public perception and emotion, although important considerations, should not lead the debate — a range of scientific inquiry, risk assessment, and evidence must guide policy surrounding the use of CEWs in Canada.

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1 Introduction and Charge to the Panel

1.1 BACKGROUND

Conducted energy weapons (CEWs) have been in use by law enforcement in Canada since the late 1990s and represent at once a new policing tool, a new bioelectrical device worthy of medical and scientific study, and a new point of discussion for the broader media and public discourse on Canadian public safety and law enforcement. The devices use electrical energy to induce pain or incapacitate a person. They are also generically referred to as *TASER*s — a brand name specific to devices manufactured and produced by TASER® International. Other commonly used names for the devices are listed in Box 1.1.

> ***Box 1.1***
> **Common Synonyms for *Conducted Energy Weapons***
>
> - Conducted Energy Devices
> - Conductive Electrical Devices
> - Electronic Control Devices
> - Electronic Discharge Devices
> - Electro Stimulation Devices
> - Electro-muscular Disruption Weapons
> - Neuromuscular Incapacitating Devices
> - Electronic Immobilization Guns
> - Stun Guns

CEWs are one option on the broad use-of-force continuum employed by law enforcement and public safety personnel. The continuum spans the physical presence of an officer through to use of deadly force. CEWs fit into this dynamic continuum in the category of less-lethal weapons, along with other tools such as pepper spray, batons, and rubber bullets, which are intended to control violent situations and contain subjects, but not to kill. Despite common comparisons between CEWs and firearms, CEWs are not replacements for firearms. Instead, the devices are typically used to facilitate the arrests of uncooperative individuals who are resisting arrest. The induced loss of voluntary muscle control is intended to cause individuals to fall to the ground, where they may be subdued and taken into custody. The subjects are not meant to experience any lasting effects after application of the device.

Decision-making about deploying CEWs resides not only at the institutional and management levels, but also in the field and in the moment. In any policing scenario, the officer on the scene decides whether and how to use force by following protocol, weighing options and outcomes, and estimating risk within the limitations of information available in real time. Use-of-force decisions are not linear and do not follow a steady upward progression through all force options until a conflict is over. Rather, the situation unfolds dynamically, and communication and tactical repositioning occur throughout each event. CEW use is one small part of this ongoing decision-making and intervention process.

Although CEWs are intended to be injury-reducing, less-lethal weapons (compared to alternative interventions), their use is not without risk. Many discussions have focused on the potential harm associated with the use of these devices and their appropriateness as a use-of-force option, yet the potential and actual physiological and health effects associated with CEW use are not well defined. A scientific consensus on what is known and not known about the effects associated with CEW use is essential.

1.2 CHARGE TO THE PANEL AND SCOPING DECISIONS

In 2010, the Centre for Security Science at Defence Research and Development Canada (DRDC) began implementing its Conducted Energy Weapons Strategic Initiative (CEWSI) in partnership with the Director General for Policing Policy at Public Safety Canada. The CEWSI has three main objectives:

- recommend a CEW test procedure and develop comprehensive performance measures for possible inclusion in pan-Canadian guidelines on the use of CEWs;
- convene a panel of medical experts to conduct an independent evaluation of existing research aimed at examining the medical and physiological impact of CEWs; and
- develop a less-lethal-weapons approval process that could be applied to emerging less-lethal technologies.

To fulfill the second objective, DRDC (the Sponsor) asked the Canadian Academy of Health Sciences (CAHS) to conduct an independent, evidence-based assessment of the state of knowledge on the physiological and health effects of CEWs. To undertake the assessment, CAHS established a partnership with the Council of Canadian Academies (the Council). Working collaboratively with CAHS, the Council acted as the secretariat for the science-based exploration of the evidence.

The Council and CAHS were asked to focus on the following three questions:

1. What is the current state of scientific knowledge about the medical and physiological impacts of conducted energy weapons?
2. What gaps exist in the current knowledge about these impacts?
3. What research is required to close these gaps?

To address the charge and develop the final assessment report, the Council and CAHS assembled a 14-member multidisciplinary panel of experts from Canada and abroad (the Panel). The Panel's composition reflects a range of expertise, experience, and demonstrated leadership in academia, industry, and medical science fields. Specifically, Panel members possess expertise from medical, social science, and engineering related disciplines including pathology, electrophysiology, cardiology, epidemiology, psychiatry, pharmacology, neurology, medical ethics, experimental design, criminology, emergency medicine, and biomedical engineering.

To ensure a comprehensive understanding of the charge, the Panel met with the Sponsor at the start of the assessment process to discuss the main scope of interest. Based on the meeting with the Sponsor, the Panel decided the assessment would aim to:

- include evidence-gathering on the potential short-, medium-, and long-term physiological and health effects of CEW exposure including, but not limited to, fatalities;
- identify differential risks and health effects associated with CEW use across varying human populations based on demographic, age, and gender breakdowns, as well as physical and mental health profiles;
- attempt to explore the effects of a range of CEW devices;[1]
- review characteristics of other types of electrical interventions (e.g., defibrillation devices) for comparative purposes;
- identify gaps in the current literature, including evidence related to exposing individuals with specific health conditions and specific sub-populations to CEWs; and
- review ethical and valid ways to fill research gaps and build understanding of differential risks across populations.

In contrast, the assessment would not:

- provide definitive positions on the safety of CEWs (or any particular device) or the appropriateness of their use;
- review why and how CEWs were approved for use in Canada or elsewhere;
- focus on use-of-force by law enforcement agencies, motivations for CEW use, or labelling of CEWs as non-lethal weapons in policing intervention models;
- review police and military training, operational policies and procedures, and protocols;
- compare the effectiveness of less-than-lethal weapons to other use-of-force interventions;
- examine the parameters of proper functioning, technical specifications, or testing thresholds related to approving devices for use and ensuring safe and efficient functioning; or
- review injuries to law enforcement or to bystanders caused or prevented by the devices during a use-of-force scenario.

The Panel's report is intended to provide an in-depth and authoritative assessment of the state of knowledge on the relationship between CEWs and a range of health complications. It complements, and must be considered along with, other work related to testing and approval procedures, motivations and protocols for appropriate use, safety and effectiveness standards, other use-of-force interventions, and other considerations constituting the broader package of information needed to make informed decisions about public health, policing, and CEW use in Canada. The Panel hopes its assessment will not only inform decision-makers, health professionals, and law enforcement about the health effects of CEWs, but also provide a platform for dialogue among various stakeholders on a question of public health importance.

1.3 THE PANEL'S APPROACH

Over the course of 12 months, the Panel met face-to-face four times. There were also numerous teleconferences and other communications involving the Panel as a whole, with select sub-groups assigned to specific subject areas. The Panel's first task was to define key concepts and terms used in the report (see Box 1.2).

1 It should be noted the Panel identified very little evidence related to CEW devices other than certain TASER® models.

> ***Box 1.2***
> **Defining Key Terms and Concepts**
>
> **Use-of-Force Continuum** – Most law enforcement agencies are guided by an incident management and intervention model often referred to as the use-of-force continuum. The continuum involves a continuous assessment process during which the officer takes into consideration situational factors, subject behaviours, officer perceptions, and tactical factors to select the most reasonable option to resolve a situation. Models vary by jurisdiction, agency, and policing strategies but the continuum usually involves a series of possible actions to be taken. Actions can include officer presence, communication and verbal commands, physical control (ranging from soft to hard techniques), intermediary weapons (e.g., CEWs), and lethal force (RCMP, 2009).
>
> **Less-Lethal Weapon** – The U.S. National Institute of Justice (NIJ) defines this term as "[a]ny apprehension or restraint device that, when used as designed and intended, has less potential for causing death or serious injury than conventional police lethal weapons" (e.g., a handgun) (NIJ, 2011). Examples may include impact munitions (e.g., rubber bullets); acoustic devices; laser devices; chemical devices (e.g., pepper spray); electrical devices (i.e., CEWs); and distraction devices (e.g., flash grenade).
>
> **Conducted Energy Weapon (CEW)** – A CEW has been defined as an electrical device designed to immobilize or incapacitate an individual through induction of pain or disruption of the nervous system by delivering enough electrical energy to trigger uncontrollable muscle contractions and to interfere with voluntary motor responses (Hancock & Grant, 2008; NIJ, 2011). The Panel chose to use the broader term *CEW*, rather than refer to a specific make or model because it allows for an investigation of a range of devices.
>
> **Medical and Physiological Impacts** – The Panel interpreted impacts broadly to include any health effect arising from changes or damage to the normal structure and function of the respiratory, cardiovascular, nervous, endocrine, or musculo-skeletal systems in the human body. The Panel included both physical health and mental illness in the review — that is, conditions resulting from impaired structure or functioning of some bodily systems and conditions characterized by alterations in thinking, mood, or behaviour associated with distress or impaired functioning (WHO, 2001).

The two key evidence-gathering activities (see Box 1.3) that informed the Panel's deliberations were reviews of:
- major evidence syntheses, reviews, and books on the physiological and health effects of CEWs; and
- peer-reviewed, primary research exploring the relationship between CEWs and physiological and health effects.

Other activities included the following:
- reviewing technical documents outlining testing results established by the Sponsor;
- attending a hands-on demonstration of CEW deployment during a site visit to the Quality Engineering Test Establishment (QETE) research facilities of the Department of National Defence Canada and the Canadian Forces, which included QETE research staff/scientists and members of the Ottawa Police Service; and
- reviewing literature relating to broad topics of relevance to the context of the report, including research ethics, electrophysiology, and electrical engineering.

To identify the key physiological and health effects associated with CEW use, the Panel first reviewed several major evidence reviews and syntheses. These reviews, undertaken over the last decade in Canada, the United Kingdom, and the United States, explore CEW safety and health effects from medical, law enforcement, and legal perspectives. They include:
- statements produced from 2005 to 2012 by the U.K.'s Defence Scientific Advisory Council Sub-Committee on the Medical Implications of Less-Lethal Weapons, based on a review of literature, government testing and research, and police data (DOMILL, 2005, 2011);
- a report to the Canadian House of Commons Standing Committee on Public Safety and National Security, based on a review of literature and expert witness testimony (House of Commons of Canada, 2008);
- independent reviews of CEWs commissioned by the Royal Canadian Mounted Police (RCMP) (Kiedrowski *et al.*, 2008), the Canadian Police Research Centre (Manojlovic *et al.*, 2005), and the Canadian Association of Police Boards (Synyshyn, 2008);
- an extensive review of medical/scientific literature, coroner and police reports, and expert testimony undertaken by the U.S. National Institute of Justice (NIJ, 2011); and
- a review of CEWs undertaken by the Nova Scotia Department of Justice (NSDOJ, 2008b).

> ***Box 1.3***
> **Evidence Syntheses and Primary Research**
>
> To identify major evidence syntheses, the Panel reviewed the research database created as part of the Conducted Energy Weapons Strategic Initiative (CEWSI) and maintained by the Sponsor, searched the internet, reviewed popular media articles, and hand-searched reference lists. The Panel also searched the following academic databases: *Web of Knowledge, PubMed, Health-Evidence.ca, Cochrane* and *Campbell Libraries, Centre for Reviews and Dissemination*, and *Evidence for Policy and Practice Information and Co-ordinating Centre (EPPI-Centre)*. Search terms included identified synonyms for CEWs (e.g., conducted electrical device, stun gun, TASER®) and electro-muscular stimulation (e.g., electro-muscular disruption, neuromuscular incapacitation).
>
> The Panel used additional comprehensive searching activities to identify and examine primary research studies published between 1989 and April 2013. The Panel identified articles from the *Electronic Control Device Research Index* (ECDRI) maintained by TASER® International, the CEWSI research database, and a Panel-led search of the following databases: *PubMed, Web of Knowledge, Embase, Science Direct, JSTOR, Inspec*, and *Microsoft Academic*. Search terms included synonyms for health complications (e.g., mortality, pathophysiology), as well as terms similar to those used in the search for evidence syntheses. Additional articles were identified through hand searching of reference lists.
>
> Of the approximately 400 peer-reviewed articles identified and reviewed, 171 articles were retained based on pre-determined criteria related to study design, outcome and study variables, and study location. Many of the retained articles then underwent a critical appraisal process, based on an assessment of quality criteria defined by the Panel and adapted from standard quality assurance tools (Kmet *et al.*, 2004; Terracciano *et al.*, 2010). Retained articles also underwent a data extraction process to identify key information related to device characteristics, subject characteristics, physiological and health effects of interest, industry affiliation, and main conclusions. This process did not result in the elimination of any of the retained studies; Panel members used it to further develop the analyses, identify key references to include in the report discussion, and inform deliberations on research context, gaps, and potential strategies for future research.

From its review of the main findings and conclusions of these activities (see Appendix A for a summary of the findings from each review), the Panel determined the key physiological and health effects most discussed in the review literature:

- potentially fatal cardiac arrest caused by abnormal heart rhythm;
- sudden in-custody death;
- physical/musculo-skeletal injuries sustained from direct effects of probe penetration, burns from electrical current, or a fall resulting from incapacitation;
- excited delirium syndrome (i.e., worsening of a state of extreme agitation, which can be potentially fatal);
- respiratory distress or impairment, and related changes in blood chemistry; and
- other effects of extreme pain and emotional trauma such as seizures.

To explore the main health effects identified above in more detail and to narrow the focus of the assessment, the Panel turned its attention to key primary studies (see Box 1.3). Several population-based and single case studies suggest that superficial physical injuries are often associated with CEW deployment — mainly caused by the weapon's probes but also by severe muscle contractions and related falls. While the occurrence of superficial physical injury is high, these types of injuries rarely pose significant risk for morbidity and mortality. There are several case studies that indicate the potential for more severe injuries including lung perforation, head injury, bone (and skull) perforation and fractures, ocular injury, and musculo-skeletal damage. Although these more serious injuries mainly result from falls, there is some evidence that certain CEW probes are long enough to penetrate vital organs when applied at a close distance (see Appendix B for a summary of key population-based and case studies). The risk for experiencing a seizure (similar to a grand mal seizure induced during electroconvulsive therapy) after receiving a CEW head shot, although speculated in the literature as being relatively high (Reilly & Diamant, 2011), has only been documented in a single case study that involved a CEW shot to the upper back and head (Bui *et al.*, 2009).

Keeping in mind that all law enforcement interventions come with a certain risk of physical injury to the suspect involved (Smith *et al.*, 2010; Paoline III *et al.*, 2012), the Panel felt that in the case of CEWs, the risk for significant morbidity and mortality from CEW-induced physical injuries was minimal. As such, the Panel chose not to focus on physical injuries caused by the weapon's probes, or on falls resulting from severe muscle contractions, in great detail.

Instead (given the dearth of available information on long-term health consequences associated with CEWs), the Panel concentrated specifically on acute, short-term physiological and health effects resulting from the electrical characteristics of CEW devices — effects having the most potential for sudden unexpected death. Because sudden unexpected death is likely the end result of a variety of intersecting factors involving the neuroendocrine, respiratory, and cardiovascular systems, the Panel focused on physiological changes in these systems resulting from electrical current and CEW discharge, including neuroendocrine effects and elevated stress hormones, disruption in breathing and related changes to blood chemistry, and changes to heart rhythm and rate and the potential for arrhythmias. The Panel also felt that uncertainties surrounding sudden in-custody death, mental illness, and excited delirium syndrome should be explored more generally.

Within the evidence there was speculation that several sub-groups are at higher risk of injury or death, compared to the general population:

- younger and older populations (children, adolescents, the elderly);
- individuals in vulnerable physical states (frail or low body weight, pregnancy, acute illness, and cardiac weakness or disease); and
- individuals in vulnerable mental states (mental illness, alcohol or drug intoxication, stress, psychosis).

Exploring the interplay between CEWs and these groups, along with other common factors involved in use-of-force events, was integral to the Panel's review of, and deliberations on, the evidence. The Panel sought to determine to what degree these co-factors could increase the likelihood or severity of each of the physiological and health effects identified above. Potential co-factors were divided into two categories: (1) internal co-factors, related to states intrinsic to the individual such as pre-existing medical conditions or drug or alcohol impairment, and (2) external co-factors, related to the situational factors or characteristics extrinsic to the individual.

Following the completion of evidence-gathering activities and decisions, the Panel's penultimate draft report underwent a rigorous and anonymous peer-review process involving 13 experts with multidisciplinary expertise similar to that found in the Panel. All reviewer comments were carefully considered and addressed by the Panel.

1.4 ORGANIZATION OF THE REPORT

The final report captures the collective wisdom of the Panel and is based on the consensus reached by all Panel members. The findings are based on the best available scientific knowledge and the professional experience and expertise of the Panel. It is the Panel's hope that the report will provide a platform for dialogue and will be considered alongside other important policy discussions related to appropriate testing and approval procedures, protocols for use, and risks of CEWs relative to other use-of-force interventions.

The report is organized as follows:

Chapter 2 provides a brief history of CEW use by law enforcement in Canada, along with the legal and regulatory environment in Canada and other relevant international jurisdictions. It also presents the available statistics on CEW use as well as injuries and deaths related to CEW use in Canada.

Chapter 3 examines the state of the evidence on the intended effects of CEWs. It begins by comparing the electrical characteristics of CEW devices to other electrical interventions, followed by an overview of electrophysiology to help understand the intended effects of the devices on the body. It also describes the design and basic operating principles of CEWs and their electrical outputs.

Chapter 4 discusses in detail the advantages and disadvantages of various research models used to study the physiological and health effects of CEWs beyond the intended effects outlined in Chapter 3. These include experimental models (such as computer models, animal studies, and human-based laboratory research) and population-based epidemiological field studies.

Chapter 5 examines the state of the evidence related to the three physiological effects most often associated with CEW exposure and most relevant in the context of understanding sudden unexpected death and severe health effects: neuroendocrine effects and the human stress response, respiratory function and blood chemistry, and changes to cardiac rhythm and rate. Basic physiology, current knowledge of CEW impacts, and co-factors with the potential to increase the likelihood or severity of a health complication following CEW exposure are explored, for each effect.

Chapter 6 looks at the state of the evidence related to the potential role of CEWs in sudden in-custody death. It also focuses on two key co-factors: mental illness and excited delirium syndrome.

Chapter 7 identifies and explores five broad gaps in the state of knowledge about the relationship between CEW use and physiological and health effects. It also discusses the related challenges in funding, conducting, and interpreting CEW research.

Chapter 8 outlines the Panel's potential strategies for an integrated response to address the gaps in CEW evidence. It presents a number of activities that would help improve the knowledge base, enable further research, and support future surveillance and reporting activities.

Chapter 9 summarizes the Panel's overall findings, grouped by the three main questions comprising the charge. It also presents the Panel's final reflections.

2

Use of Conducted Energy Weapons in Canada

- A Brief History of CEW Use in Canada
- Legal and Regulatory Environment
- Statistics on CEW Use and Related Injuries and Deaths in Canada
- Summary

2 Use of Conducted Energy Weapons in Canada

Key Findings

- Decision-making about the protocols for selecting, acquiring, and using CEWs is undertaken by local law enforcement and public safety agencies, and varies across Canada and internationally.
- There is no ongoing systematic and consistent documentation of CEW use in Canada and no standardized way to capture injuries or deaths related to the devices.
- Ad hoc reporting indicates CEW use in Canada is generally declining, the device is largely used as a deterrent (displayed rather than fired), and injuries resulting from CEWs are largely superficial physical injuries; it is challenging, however, to draw any definitive conclusions related to the physiological and health effects of CEW use from current monitoring and reporting practices.
- Since 1998, at least 33 deaths in Canada have followed the deployment of a CEW, but were not necessarily direct results of CEW deployment.

Conducted energy weapons (CEWs) were introduced as one of several less-lethal use-of-force options for Canadian law enforcement in 1998. This chapter briefly outlines the history and use of CEWs in Canada, along with the legal and regulatory environment in which they are deployed. It then goes on to present the available statistics on trends in CEW use, and what can be said about related injuries and deaths based on current monitoring and reporting practices.

2.1 A BRIEF HISTORY OF CEW USE IN CANADA

In 1999 and following operational reviews and field trials carried out by police agencies in the cities of Edmonton and Victoria, the province of British Columbia became the first Canadian jurisdiction to approve CEWs for use by law enforcement (Braidwood Commission, 2009). Following an assessment of the devices and similar field trials, the RCMP approved the TASER® M26™ device for use by its officers across Canada in 2001; select provinces and municipalities later followed suit (Kiedrowski *et al.*, 2008). Figure 2.1 shows a timeline of key CEW-related developments over 15 years.

As of May 2013, there were approximately 9,174 CEWs in use in Canada, including those in service as well as those used for training or in storage (PSC, 2013).[2] This number includes all RCMP inventory as well as inventories of all police services under provincial and municipal jurisdictions. The number of devices currently in use varies greatly based on jurisdiction, as noted in Figure 2.2. In some jurisdictions all police agencies are equipped with CEWs (e.g., British Columbia), while in others only certain agencies use the devices (e.g., 9 of a total of 31 police agencies use CEWs in Quebec); however all federal, provincial, and territorial jurisdictions use CEWs in some capacity across Canada.

2.2 LEGAL AND REGULATORY ENVIRONMENT

CEWs are prohibited firearms under the *Criminal Code* in Canada and may only be handled by law enforcement and public safety personnel (Kiedrowski *et al.*, 2008). In 2010 federal, provincial, and territorial ministers of justice agreed on a set of guidelines for CEW use that involved certain restrictions on use, and recommendations related to training policies, device testing procedures, monitoring and supervision guidance, and maintenance of a usage reporting system (PSC, 2010). Even with these guidelines in place, the use of CEWs by law enforcement in Canada is not governed by a single entity. Decision-making related to their use occurs at federal, provincial, and municipal levels, depending on the police force. Although adoption of CEWs by municipal law enforcement agencies has typically followed federal or provincial approval of the devices, individual agencies make local decisions on whether and how to incorporate CEWs into their practices.

CEWs are also used by law enforcement agencies around the world. To help law enforcement agencies and communities select, acquire, and use CEWs, the International Association of Chiefs of Police has released guidelines for effective deployment of the devices (IACP, 2007). Based on research and lessons learned from agencies deploying the devices, the nine-step strategy involves building a leadership team, placing CEWs within an intervention model or on a use-of-force continuum, assessing the costs and benefits of use, identifying roles and responsibilities, engaging communities, developing policies and procedures, creating a comprehensive training program, using a phased deployment approach, and continually assessing CEW use (IACP, 2007). Similar guidelines have been released by the Police Executive Research Forum and the United States Department of Justice.

2 This information was provided to the Panel by Public Safety Canada after consultations with the RCMP as well as policing policy officials from all provinces and territories, and does not include Aboriginal policing services. Information has not been subjected to any additional validation beyond these consultations, has been collected at varying times through varying methodologies, and is subject to change. Despite these inconsistencies, these numbers are based on the latest information available and provide the best estimate for the number of CEWs in use across Canada.

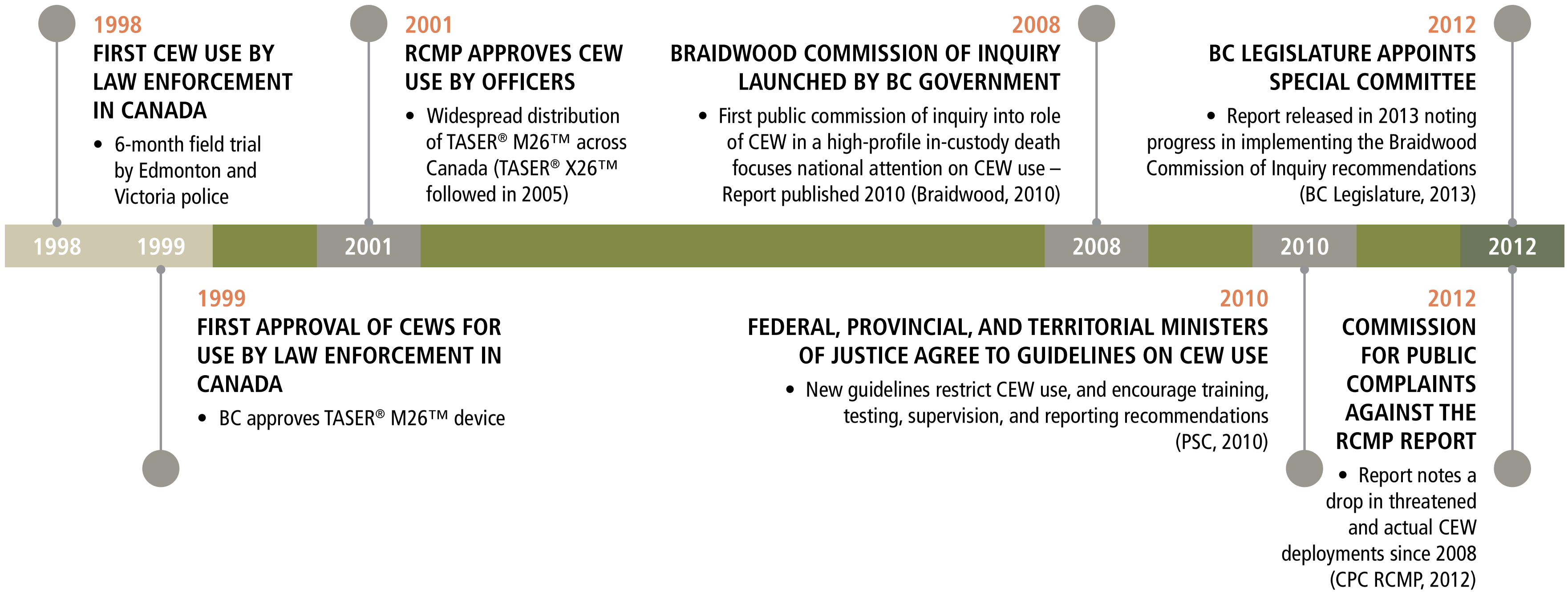
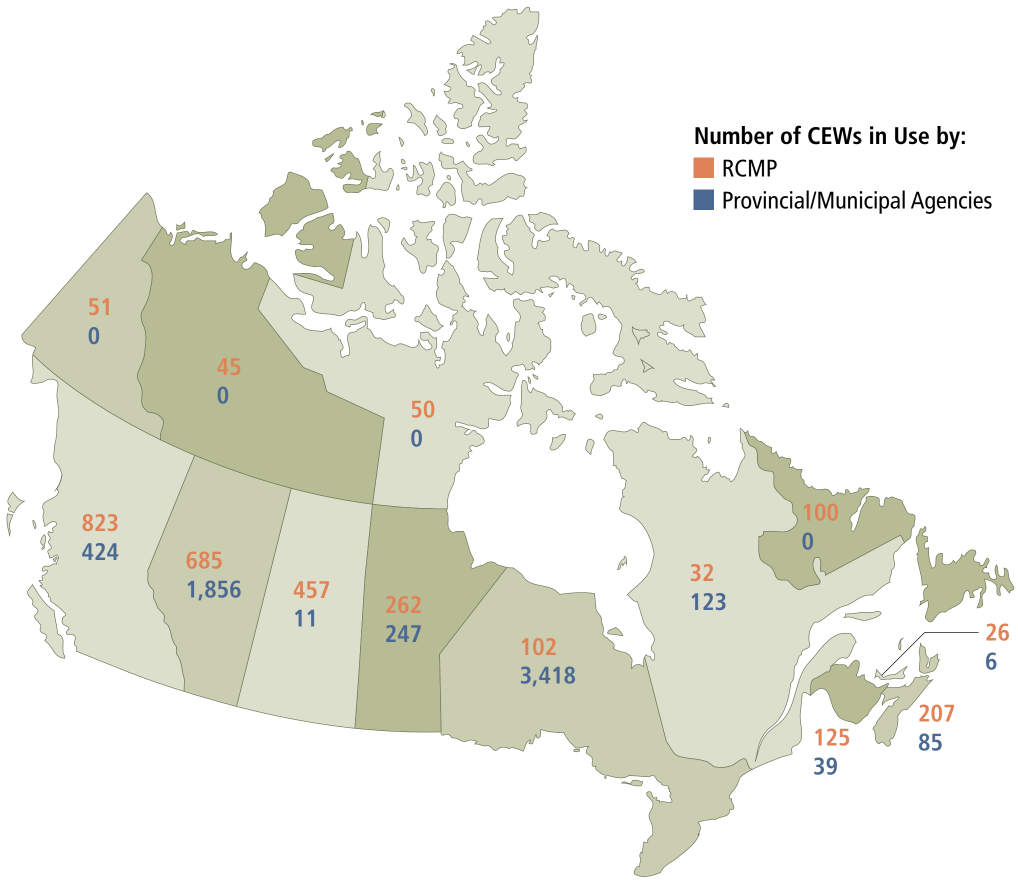


Figure 2.1

Milestones in the Use of CEWs in Canada

The United States was the first jurisdiction to deploy the modern form of CEWs, and the devices have been in use in that country since the early 1990s. In Canada, field trials began in the late 1990s and, subsequently, CEW use became widespread across the country in the early 2000s. After a high-profile death and commission of inquiry in the late 2000s, the use of CEWs elicited much more scrutiny and public debate. This figure depicts key milestones in the use of CEWs since their introduction in Canada.



Data source: PSC, 2013

Figure 2.2

Estimated Number of CEWs in Use in Canada by RCMP and Provincial and Municipal Police Agencies

There were approximately 9,174 CEWs in use in Canada as of May 2013. This includes those in service and those used for training or in storage. The numbers include the RCMP inventory as well as inventories of police services under provincial or municipal jurisdictions. The number of devices currently in use varies greatly based on jurisdiction as noted in this figure. This information was provided to the Panel by Public Safety Canada (PSC) after consultations with the RCMP as well as policing policy officials from all provinces and territories, and does not include Aboriginal policing services. Information has not been subjected to any additional validation beyond these consultations, has been collected at varying times through varying methodologies, and is subject to change. Despite these inconsistencies, these numbers are based on the latest information available and provide the best estimate for number of CEWs in use across Canada.

Updated in 2011, these guidelines provide recommendations about agency policies, reporting and accountability, training and use of CEWs, medical considerations, and public information and community relations (PERF, 2011).

The legal landscape for CEW use in the United Kingdom, United States, and Australia is similar to Canada's, but with a few exceptions:

United Kingdom: Initially (in 2003) only police who were permitted to use firearms were also permitted to use CEWs. In 2007 this was extended to other specially trained police officers (DOMILL, 2005). Training and guidance on the use of less-lethal weapons (including CEWs) by police across the United Kingdom is provided by the Association of Chief Police Officers of England, Wales and Northern Ireland (ACPO) and by its equivalent body in Scotland (ACPOS). Oversight of the medical effects of CEWs on the public is provided by an independent body known as the Scientific Advisory Committee on the Medical Implications of Less-Lethal Weapons (formerly the Defence Scientific Advisory Council Sub-Committee on the Medical Implications of Less-Lethal Weapons). The independent committee provides advice to ministers and operates at arm's length from government. The Home Office of England and Wales maintains a database of CEW use, which includes the circumstances of each use, the mode of use, and officer-reported injuries (Home Office, 2010).

United States: The modern form of CEWs has been in use in the United States since the early 1990s. Adoption of the devices varies greatly across jurisdictions. As of spring 2010, approximately 260,000 CEWs had been distributed to law enforcement officers in 12,000 agencies in the United States (NIJ, 2011). A number of CEW devices are also available for civilian use in certain jurisdictions. Decisions and guidelines related to the adoption and use of CEWs by law enforcement are left up to individual agencies, and there is no centralized body that regulates, authorizes, or captures information on their use nation-wide.

Australia: CEWs are considered prohibited weapons and are not available to the public. They were introduced in the early 2000s for use by tactical and specialist response groups. Starting in 2007, the devices became more widespread and are now used by a range of general patrol officers and specialist and emergency response groups, depending on jurisdiction (Hancock & Grant, 2008; NSWO, 2008). Each jurisdiction within the country has its own set of oversight mechanisms and guidelines governing the use of CEWs and the recording of that use. All officers must undergo training and accreditation to carry and use a CEW, and a recording device is attached to all CEWs used by general duty officers, to capture details related to deployment events (NSWO, 2012).

2.3 STATISTICS ON CEW USE AND RELATED INJURIES AND DEATHS IN CANADA

Similar to all other forms of use-of-force interventions, the use and number of deployments of CEWs in Canada are not documented on an ongoing and systematic basis. Individual agencies do collect use-of-force and CEW information in their own practices, but this information is not captured or reported in a uniform, consistent way across law enforcement, correctional, and other public safety agencies working under municipal, provincial, and federal jurisdictions. Although attempts have been made at the international level to create a less-lethal-weapons database that provides independent and structured data on weapon use worldwide (U.K. Steering Group, 2006), at the time of this report's publication, the funding and overall status of the database were unclear. Constraints such as these have led to ad hoc point-in-time reporting of CEW use statistics and changes over time, as demonstrated by the variable reporting from Nova Scotia and British Columbia.

In 2008 and as part of a larger, provincial review of CEWs, Nova Scotia released CEW use statistics for municipal police departments, RCMP divisions, and Department of Justice services (NSDOJ, 2008b). In 2007, 0.05 per cent of the total calls for service to police involved CEW use. Despite infrequent overall use, CEW use rose steadily from 2005 to 2007 by about 80 per cent, with deployments mostly involving presentation of the device (47 per cent), and with probe (29 per cent) and drive stun (26 per cent) deployment used less frequently (differences between probe and drive stun deployment types are described in greater detail in Chapter 3) (NSDOJ, 2008b).

Also in 2008, British Columbia released CEW use statistics for the 11 independent municipal police agencies working in the province (Ryan, 2008). Per-capita deployment rates between 2001 and 2006 reflect an increase in CEW use across all agencies. In 2001, CEW incidents ranged from 0 to 43.2 per 100,000 persons across different departments; however, in 2006, that range increased to a low of 5.2 and a high of 130.7 incidents per 100,000 persons. Of the total 1,404 incidents reported between 1998 and 2007, a CEW was displayed in 42.7 per cent of the incidents and deployed in drive stun and probe mode in 41.2 per cent and 41.8 per cent of the incidents, respectively (more than one mode may be used in any one incident) (Ryan, 2008).

At the federal level, the Commission for Public Complaints Against the Royal Canadian Mounted Police releases statistics on RCMP use of CEWs on an ongoing basis using the Subject Behaviour/Officer Response (SB/OR) Reporting System, a standardized method for recording use of interventions (CPC RCMP, 2012). Although used only for RCMP forces, this approach provides a clearer and more consistent picture of CEW use over time. According to the most recent report, in 2010 CEWs were used as a deterrent (that is, displayed but not fired) in about 70 per cent of incidents (CPC RCMP, 2012). Of the 30 per cent of incidents where CEWs were actually deployed, 63 per cent of those deployments were in probe mode and 37 per cent were in drive stun mode. Overall, RCMP-related CEW deployments have been consistently dropping since 2004, reflecting a trend of not only using CEWs less, but also of using them more as a means for deterrence and de-escalation (rather than direct incapacitation) (CPC RCMP, 2012). See Figure 2.3 for RCMP-wide trends in CEW use and deployment over time.

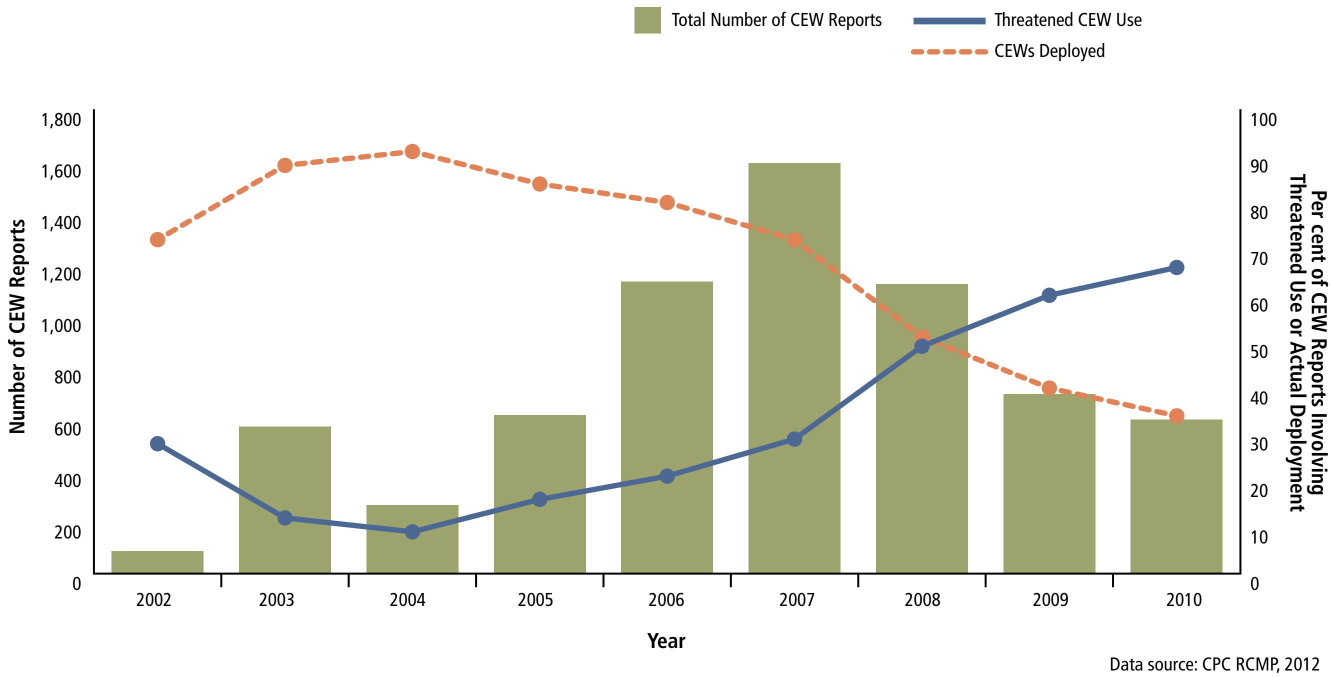


Figure 2.3

RCMP-Wide Trends in CEW Use

It is difficult to obtain accurate numbers related to the use of CEWs across Canada. At the federal level, the RCMP releases statistics on the use of CEWs using a standardized method for recording use-of-force interventions. Although used only for RCMP forces, these numbers provide a consistent picture of CEW use over time. According to the most recent report and noted by the green bars in this figure, overall CEW use has been declining consistently each year since 2007. In 2010, CEWs were used as a deterrent (that is, displayed but not fired) in about 70 per cent of incidents, furthering an annual trend of officers increasingly using CEWs as a means of deterrence (as depicted by the blue line). In contrast, the orange line highlights a drop in the actual deployment of the devices since 2004, further reflecting a trend of not only using CEWs less, but also of using them more as a means for deterrence and de-escalation rather than direct incapacitation.

No standardized method for recording CEW-related injuries in Canada, either by police agencies or by medical practitioners, has been widely adopted across agencies. For example, minor injuries were not recorded in the 2008 report from Nova Scotia (NSDOJ, 2008b). In contrast, all CEW-related injuries were noted in the statistics released for British Columbia, with 24 per cent of the 1,404 incidents noted as CEW-related injuries, of which 98 per cent were superficial wounds and 2 per cent were more serious injuries resulting from falls and dart penetration (Ryan, 2008). Finally, the 2010 RCMP report on CEW use did not note the nature of injuries sustained, if any, even though the report did list when medical attention was required: 10 per cent of probe deployments and 1 per cent of drive stun deployments required medical attention in 2010 (CPC RCMP, 2012). At the time of this report's publication, a population-based study exploring police use-of-force (including CEW use) in seven police agencies in Canada was still in progress; thus, data on injury rates were not available (Hall, In progress).

Canada also does not have a central repository for reports of sudden in-custody death, nor is there a database containing information on CEW-related death. Without a system for tracking these outcomes, it is very difficult to determine the number of sudden in-custody deaths in Canada, and the proportion of deaths that are CEW-related. Based on media reports and documented inquest processes alone, to date at least 33 reported deaths have been proximal to CEW use (Hall, In progress). Across all 33 deaths, reports recording the incidents were not standardized, resulting in highly variable information related to the event characteristics of each death. Although no systematic review of all 33 cases has been published, a scientific review of 32 of the cases was in progress at the time of this report's publication. It is clear from this initial work that several of the cases were clearly not related to the CEW, whereas others were more ambiguous in nature (Hall, In progress). With no synthesized body of evidence documenting the number of deaths related to use-of-force encounters, there is little information to put these numbers into a larger context (this challenge is discussed in greater detail in Section 7.4).

2.4 SUMMARY

Since their introduction in 1998, CEWs have become widespread across Canadian municipal, provincial, territorial, and federal jurisdictions. Even with guidance from various federal, provincial, and territorial governments and international bodies, decision-making about the protocols for selecting, acquiring, and using CEWs is undertaken by local law enforcement and public safety agencies, and varies across Canada and internationally. There is no ongoing systematic and consistent documentation of CEW use in Canada and no standardized way to capture injuries or deaths related to the devices. Since 1998, at least 33 deaths have followed the deployment of a CEW in Canada. It is not clear, however, whether these deaths were results of CEW deployment. Ultimately, with variable documentation about the use of CEWs, and with no standardized way to capture injuries or deaths related to the devices (or to use-of-force more generally), it is challenging to draw any conclusions about physiological and health effects of CEWs based on current monitoring and reporting practices in Canada.

3

The Design, Operation, and Intended Effects of Conducted Energy Weapons

3 The Design, Operation, and Intended Effects of Conducted Energy Weapons

Key Findings

- CEWs describe a range of electronic devices designed to deliver short, repeated pulses of electricity to the skin and subcutaneous tissues through two metal probes. TASER® devices are the most studied and documented devices in the published literature.
- CEW deployment can constitute simply displaying the device, firing a pair of tethered darts into the subject (probe mode), pressing the device directly against the subject (drive stun mode), or a combination of these types. Probe mode, used alone or in combination, has the most potential for causing adverse effects.
- CEWs are manufactured based on the principle that a train of short-duration electrical impulses with a specially designed waveform is powerful enough to effectively stimulate motor and sensory nerves, causing incapacitation and pain, but is too brief to directly stimulate other electrically excitable tissues such as the heart muscle.
- Because the electrical characteristics and outputs of CEW devices are variable and evolving, each CEW device must be tested on its own merit to assess performance as well as the ability to induce neuromuscular incapacitation and adverse physiological and health effects.

Conducted energy weapons (CEWs) are intended to be safe and potentially injury-reducing compared to alternative interventions, but they are not necessarily risk free. CEWs work by discharging electrical currents into a subject, resulting in loss of voluntary muscle control over a large area of the body. This causes the individual to fall to the ground and also induces severe but short-lived pain. To help explain the effects of CEWs, this chapter examines some essential information about the physiology of nerve and muscle cells and how these cells, which themselves use electrical signals, are affected by applied electrical currents. This chapter also compares CEW characteristics to properties of other electrical sources and discusses the variability of these characteristics across devices. It is important to examine the details of the electrical discharge produced by CEWs both to understand how they are intended to function safely, and also to appreciate why there may be a risk of adverse effects from CEW discharge. This chapter provides the information necessary for a detailed discussion of the physiological and health effects of CEW use in subsequent chapters.

3.1 USING ELECTRICITY ON THE HUMAN BODY

Canadians generally enjoy safe and unremarkable interactions with electricity every day. Electricity controls every heartbeat and every movement and sensation in the human body, but it also has the power to injure and even kill. Lightning strikes can be fatal; downed or exposed power lines after a storm can pose a similar risk; and even standard household electrical outlets can deliver a fatal electrocution if not used properly or if the wiring is damaged.

Despite their potential for harm, electrical currents can also be used for therapeutic purposes. Every year nearly one million people worldwide receive implantable pacemakers that electrically stimulate the heart. External cardiac defibrillators are increasingly available in offices and public places, and internal cardiac defibrillators are implanted in patients at risk of sudden cardiac death. These devices use large and carefully shaped pulses of electricity to restore normal heart rhythm. Electricity is also used in other common therapeutic contexts, such as transcutaneous electrical nerve stimulation used in sports medicine to build strength, reduce pain, and promote repair; or electro-convulsive therapy used in psychiatric medicine for the treatment of depression, schizophrenia, catatonia, and mania (Greenhalgh *et al.*, 2002; Khadilkar *et al.*, 2006). More recently, non-invasive transcranial brain stimulation with minute currents has been claimed to have a variety of benefits for a wide range of neurological and mental health problems such as major depression (Berlim *et al.*, 2013).

More than a century of biomedical and biophysical research has helped develop these safe and effective, often life-saving electrotherapies. This research established that the effects of current stimulation on different tissues depends on the characteristics of the electrical current, specifically its strength or power, duration, and waveform, as well as the timing of when the electrical current is applied in relation to the natural electrical activity occurring in the body. The strength or power of an electrical discharge is determined by its current (the quantity of electricity flowing per unit of time) multiplied by its voltage (the force or pressure that causes the flow of electricity). For example, a cardiac defibrillator shock that delivers 20 amps and 1,000 volts consumes 20,000 watts of power. Duration refers to how long the current flows. When the strength and duration are considered together, the energy delivered per pulse of electricity can be determined in joules. To continue the example, if a defibrillator has a pulse duration of 10 milliseconds (0.01 seconds), then it will deliver 200 joules per pulse. Most electrical discharges, including those from CEWs, vary rapidly in time and have the generic shape of an undulating wave when voltage or current is plotted against time. The variation in voltage and current of an electrical discharge over its duration is known as its waveform and will be discussed later in this chapter. The different characteristics of electrical currents are important for understanding why certain electrical sources may be capable of consistently shocking the heart or inducing other physiological effects while others may not. Examples of various sources of electrical discharges are shown in Table 3.1.

The point to remember is that different types of electrical sources deliver electrical currents with different characteristics. These characteristics can be optimized to effectively stimulate a desired tissue or organ, and excessive electrical stimulation (as through a lightning strike or power-line electrocution) can cause permanent damage or death.

3.2 ELECTROPHYSIOLOGY OF NERVES, MUSCLE, AND HEART

The nervous system is a network of nerve cells (neurons) that relay information within the brain and between the brain and all other parts of the body. Two types of neurons are relevant for discussion surrounding CEWs: sensory neurons and motor neurons (Sweeney, 2009a). Sensory neurons carry information from our sensory organs (including pain signals) to the brain. Motor neurons carry commands from the brain and spinal cord to skeletal muscle fibres throughout the body and control the movement of our skeleton by causing muscles to contract and relax. The nervous system uses electricity to communicate, sending small pulses of electricity (about 100 millivolts), known as action potentials, along the nerve cell processes. Skeletal muscle cells also generate action potentials when they are stimulated by a motor neuron, and this causes the muscle cells to contract (Hall, 2011). The cardiac muscle cells of the heart similarly generate action potentials, but these are not initiated by motor neurons. Instead, they are produced by special pacemaker cells in the sinoatrial node that spontaneously and rhythmically generate action potentials, which spread across the heart to cause the coordinated pumping activity of the left and right ventricle (Katz, 2010), as shown in Figure 3.1. This rhythmical electrical activity in the heart can be captured as an electrocardiogram (ECG) through the placement of electrodes on the skin.

Table 3.1

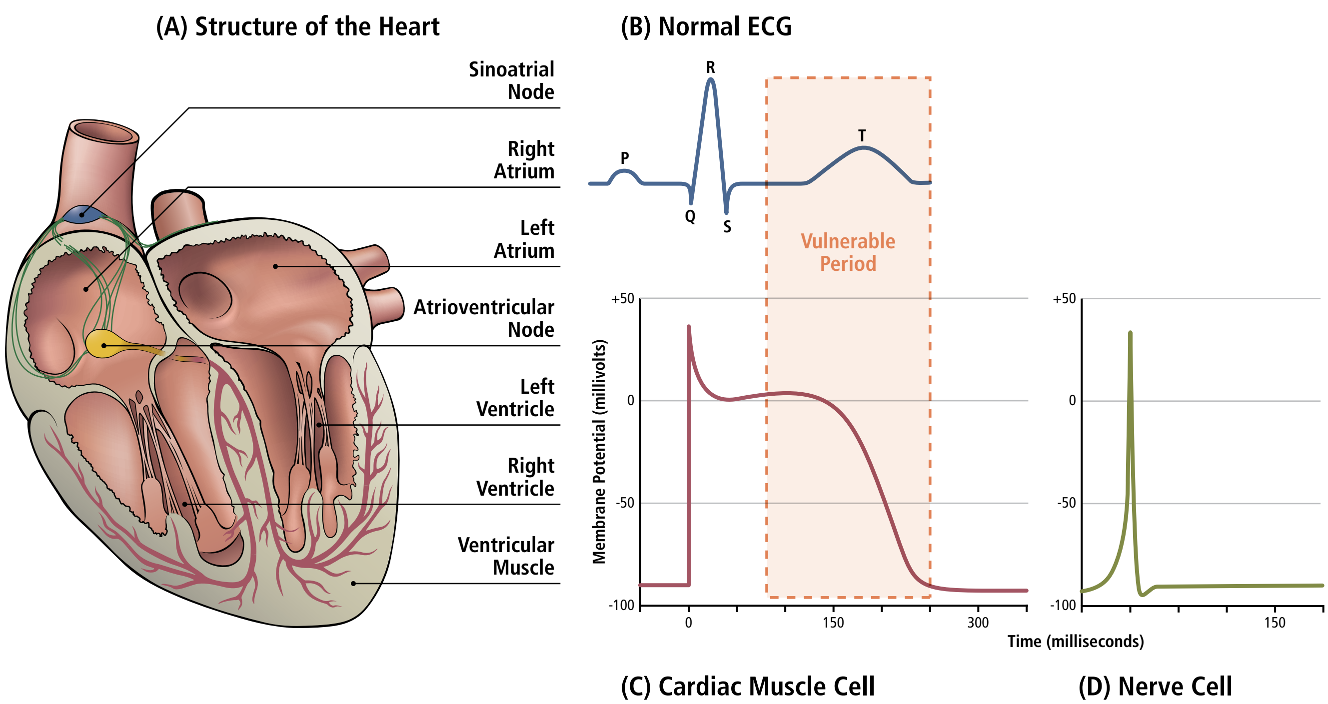
Comparison of Approximate Characteristics of Varying Electrical Sources

Electrical Source	Current (amps; A)	Peak Voltage (volts; V)	Pulse Duration (milliseconds; ms)	Energy Delivered (joules; J)
Lightning Strike	40,000	1 billion	0.12	500 million
Cardiac Defibrillator Shock	10–70	500–2,100	6–17	100–200
North American Household Wall Outlet	15	125	Varies	Varies
CEW (TASER® M26™)	17	50,000 (5,000–7,000 under load)	0.03	0.5
CEW (TASER® X26™)	3	50,000 (1,000–1,500 under load)	0.1	0.08
CEW (Stinger® S200™)	2	800–900 under load	0.3	0.05
Electroconvulsive Therapy (ECT)	0.5–0.9	100–500	0.2–2	10–25 *
Transcutaneous Electrical Nerve Stimulation (TENS)	0.1 maximum (adjustable)	50 maximum (adjustable)	0.05–0.25 (adjustable)	Varies

Data sources: (Weaver & Williams, 1986; Achleitner *et al.*, 2001; CHP, 2007; Nanthakumar *et al.*, 2008; NEMA, 2008; McDaniel *et al.*, 2009; Panescu & Stratbucker, 2009; Peterchev *et al.*, 2010; NIJ, 2011; Reilly & Diamant, 2011; Tens MED, 2011)

All values are approximate per pulse values and vary based on context and impedance load, which is the level of resistance to current flow. During testing, CEWs are fired into a resistive load that mimics the impedance load of the human body (Adler *et al.*, 2013).

* This number represents joules per entire ECT treatment (e.g., four to eight seconds), not joules per pulse (Weaver & Williams, 1986).



(C) Cardiac Muscle Cell and (D) Nerve Cell concepts are adapted and reproduced with permission from CVPhysiology.com

Figure 3.1

Structure of the Heart and Electrical Activity in Cardiac Muscle and Nerve Cells

(A) Diagram of the heart, indicating the location of the atria and ventricles. Action potentials originate in the natural generator (or cardiac pacemaker) tissue called the sinoatrial node (blue), which is located in the right atrium. This action potential excites atrial muscle, followed by the atrioventricular node (yellow) from where it excites the ventricular muscle, the contraction of which pumps blood into circulation. **(B)** Normal ECG, indicating the P wave, the QRS complex, and the T wave of a normal heartbeat that results from this electrical activity. The P wave is formed by the electrical field generated by the atria; the QRS complex is formed by excitation of the ventricular muscle; and the T wave represents the end of action potentials in the ventricular muscle. The QT interval refers to the time between the onset of the Q wave and the completion of the T wave. **(C)** A cardiac muscle cell action potential generated by the ventricular muscle. Note that (B) and (C) are aligned to indicate how the ECG tracing is related to the action potential. The vulnerable period of the action potential and the corresponding period on the ECG are marked with a dashed box. It is during this period that the heart is most susceptible to injury from the application of an electrical current. **(D)** A nerve cell action potential. Notice that the action potential for the nerve is much shorter than that of the cardiac muscle cell. This means that the cardiac cell requires more strength and longer duration from an electrical stimulus in order to be interrupted.

All action potentials are created by the opening and closing of channels in the membrane of the nerve and muscle cells that allow ions such as sodium, potassium, calcium, and chloride to flow across the cell membrane, and the exact waveform of the action potential in a particular cell type will depend on the properties of the ion channels in its membrane (Katz, 2010). Cardiac muscle action potentials from different regions of the heart have different waveforms and durations ranging between 100 and 400 milliseconds (0.10 to 0.40 seconds). Nerve and skeletal muscle action potential waveforms are much shorter than those in the heart, and last for as little as one millisecond (0.001 seconds) (Katz, 2010) (Figure 3.1).

Action potentials can be artificially stimulated in nerve and muscle cells by the application of electrical currents — such as those generated by a household wall outlet, electroconvulsive therapy, or a CEW device. As noted previously, different cell types have different action potential waveforms, and thus require the application of different electrical currents for stimulation. The key determinants of effective artificial stimulation of an action potential are strength and duration (Sweeney, 2009a). Depending on the type of cell being stimulated, the electrical stimulus has to be applied for a certain duration and reach a certain strength to generate an action potential. This is known as reaching a certain threshold. This requirement is due to the specific properties of the ion channels in the cell membrane, as well as other electrical properties. For the purpose of this report, however, it is enough to understand that an electrical stimulus with strength below the threshold value will have no effect on the nervous system; however, once the strength of the stimulus exceeds the threshold value there will be an effect on the system.

The strength and duration of an applied CEW electrical discharge must be tuned to the thresholds of the nerve cells to effectively stimulate them (Sweeney, 2009a; Reilly & Diamant, 2011). Only an electric shock exceeding the nerve threshold will impact nerves and cause incapacitation. The duration of electrical stimulation required to exceed the threshold in a cardiac muscle cell is about 10 to 100 times longer than in a motor or sensory nerve cell. Therefore, the principle guiding the functioning of the CEW is that the short-duration electrical discharges delivered by the device are highly effective in stimulating motor and sensory nerves, causing incapacitation and pain, but are much less effective in stimulating the heart muscle and thereby inducing potentially fatal disruptions to the heart's rhythm and pumping ability. Excitable tissues other than the nerve, skeletal muscle, and cardiac cells (e.g., blood vessels) can also be stimulated or damaged by electrical intervention; however, a discussion of this phenomenon is not included in this report due to lack of evidence and identified connections with CEWs.

Along with strength, duration, and threshold values, the timing of the CEW exposure is also relevant. The susceptibility of cardiac muscle to stimulation by an artificially applied current varies, depending on the point in the rhythmic cycle of the heart. There is a period of vulnerability (shown, approximately, as the dashed box superimposed on the later part of the cardiac muscle action potential in Figure 3.1) toward the end of an action potential or heartbeat when a stimulus that would not reach threshold if applied at the beginning of the action potential may do so. Again, the reason for this has to do with the behaviour of the ion channels in the membrane of the cardiac muscle cells. This phenomenon is important to understand because certain commonly prescribed drugs have the effect of prolonging this period of vulnerability (i.e., they prolong the QT interval of the ECG) (van Noord *et al.*, 2010). There are therefore multiple factors at play when considering the possible physiological and health effects of deploying a CEW. Researchers must take into account the electrical characteristics delivered by the device and the tissues influenced by the currents flowing between the CEW probes and a host of other factors as well — including potential prescription and other drugs consumed by the target individual.

3.3 DESIGN AND OPERATION OF CEWS

Having discussed these fundamental properties of electricity and its effects on nerve and muscle cells, this report turns to examining the workings of CEWs and their effects on the human body. As mentioned in Chapter 1, this report uses the term *conducted energy weapon* to describe the general category of devices, and *TASER* to refer specifically to CEWs manufactured by TASER® International. Other CEW manufacturers and devices include the MPID™ from Karbon Arms®; the Mark 63 Trident™ made by Aegis® Industries; and other dart-firing baton weapons manufactured by Russian, Chinese, and Taiwanese companies (Sprague, 2007).

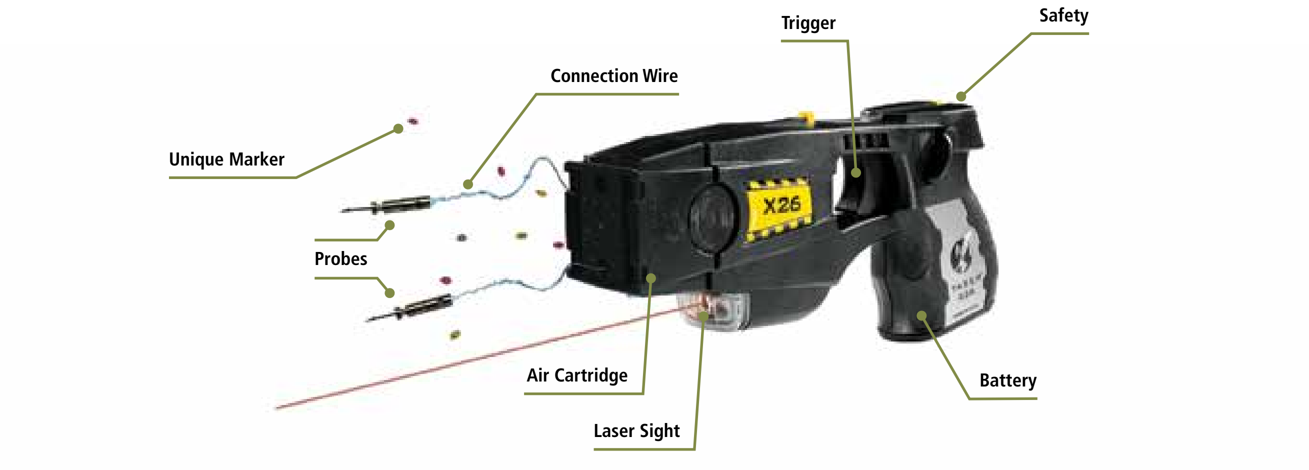
Although traditional stun guns and other modern devices qualify as CEWs, this discussion of CEW operation focuses mostly on TASER® devices, for three reasons:

- TASER® M26™ and X26™ devices[3] are the only CEWs approved for use by Canadian law enforcement, and are the dominant CEWs used by law enforcement agencies worldwide.
- The majority of the published research focuses on TASER® devices.
- TASERs® are representative of the class of CEWs that induce neuromuscular incapacitation by delivering electrical energy to a subject from a distance using probes fired from the device. This is in contrast to traditional stun guns and some other models of CEWs that are primarily pain-compliance devices.

The general principles of operation and design of TASER® devices described in this chapter broadly apply to many other types of CEWs.

CEWs deliver short, repeated pulses of electricity to the skin and subcutaneous tissues through two metal probes. Many CEWs are plastic, hand-held devices equipped with a safety switch and trigger. Additional features may include a laser aim; an internal memory chip that records the time, date, and duration of discharge for each deployment; and a digital readout of battery charge. Trigger action deploys the electrical discharge. For instance, the discharge from the TASER® X26™ (see Figure 3.2) involves a series of brief electrical impulses that last for five seconds, and the device emits this series of impulses for as long as the trigger is held down. Each discharge is accompanied by the release of small confetti-like markers that scatter about

3 Manufacture of the M26™ will soon be discontinued.



Adapted and reproduced with permission from TASER® International, Inc.

Figure 3.2

A Schematic Side-View of the TASER® X26™

The TASER® X26™ is the most commonly used CEW in Canada. When the trigger of the device is pulled, a compressed nitrogen cartridge breaks open, which results in the build-up of pressure. This pressure launches two probes — each with a barbed dart on the end — at 55 metres per second. Thin wires attached to the darts unspool as the darts fly, maintaining an electrical connection to the device. Each discharge is accompanied by the release of small confetti-like markers that bear a printed code unique to the CEW (Kroll, 2007). The darts lodge into a subject's clothing, skin, or soft tissues. If they land far enough apart, the flow of electrical current between them stimulates many nerves, resulting in widespread loss of voluntary muscle control (or incapacitation) and generalized intense pain (Hancock & Grant, 2008; NSDOJ, 2008a). This figure highlights some common features of the device.

the discharge site and bear a printed code unique to the CEW, indicating not only that a device has been fired but also which device, specifically (Kroll, 2007).

Officers most often use CEWs as deterrents (NSDOJ, 2008b; CPC RCMP, 2012), by, for example, activating the laser sight, activating the spark display, drawing and displaying, or pointing the device at a subject. They may also deploy the device for defensive purposes (CPC RCMP, 2012). CEWs can be deployed through one of two basic operating modes: probe mode and drive stun mode. Field use of the devices can also involve a combination of these two modes, termed the three-point deployment option.

Probe mode is most commonly used and most often associated with the need for medical attention (CPC RCMP, 2012) due to loss of voluntary muscle control and increased spread of the current flow across the body. It is also the most researched type of deployment in the literature reviewed by the Panel. In probe mode, a pair of metal darts deploys from the CEW, spreads apart, and penetrates and attaches to a subject's clothing, skin, and soft tissues at a distance of up to a few metres (although some devices are designed for longer ranges, such as the TASER® XREP™). The darts are connected to thin electrical wires that conduct the electrical discharge from the device. If the two darts are spaced widely enough across the body, the flow of electrical current between them stimulates many nerves, resulting in widespread loss of voluntary muscle control (or incapacitation) and generalized intense pain, which typically cease immediately after the discharge ends (Hancock & Grant, 2008; NSDOJ, 2008a).The degree of incapacitation is largely dependent on the spread of the probes, which is thought to be most effective between 9 to 12 inches (Ho *et al.*, 2012).[4] In probe mode, it is more likely the current will flow through tissues in the chest, including the heart, which results in increased risk of unwanted cardiac or other health effects (Sun & Webster, 2007).

4 See Reilly and Diamant (2011) for a detailed description of the three likely mechanisms involved in the loss of voluntary muscle control when a device is fired in probe mode: (1) direct excitation of muscle, (2) stimulation of motor neurons, and (3) activation of reflex activity.

In drive stun (also known as touch stun) mode, the device is pressed directly against the subject like a traditional stun gun. The electrical current is delivered across a more localized area than in a probe mode deployment (NSDOJ, 2008a). As a result, the main effect of drive stun mode is localized pain, and muscle immobilization is likely to be localized, due primarily to direct stimulation of skeletal muscle fibres adjacent to the point of contact with the electrodes.

The combined mode of operation — three-point deployment option — is a hybrid of probe and drive stun modes. If one of the two probes fails to make contact with the subject during a probe mode deployment, or if the probe spread is too small, the CEW deployment will not achieve complete incapacitation. In this case, after the probe deployment and with one or both probes still embedded in the subject, the CEW hand-held unit can be brought in contact with the subject. This increases the total area covered by the combination discharge current and can increase the likelihood of incapacitation and potential health complications.

3.4 CEW WAVEFORMS

As mentioned previously, the strength and duration of CEWs are effective in stimulating the nervous system and inducing incapacitation and pain, but are less effective in stimulating cardiac muscle. The variation in the strength of an electrical discharge over its duration is known as its *waveform*. The CEW waveform is intended to influence the peripheral nervous system in a way that causes temporary, involuntary, and uncoordinated skeletal muscle contraction (Kunz *et al.*, 2012). This phenomenon is also known as neuromuscular incapacitation. The next few paragraphs describe some examples of actual CEW devices and how characteristics and waveforms differ among them.

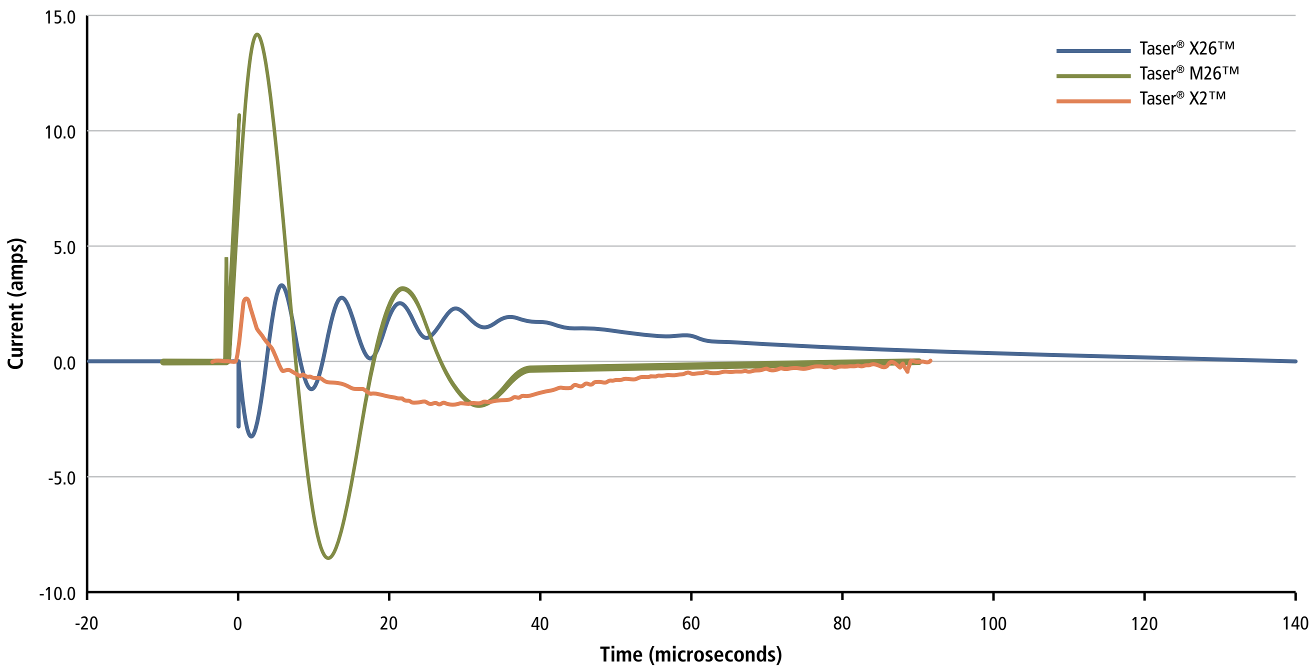
The TASER® X26™ delivers 19 pulses per second over a period of five seconds, with each individual pulse lasting on the order of 100 microseconds (0.0001 seconds) (Sweeney, 2009a; Reilly & Diamant, 2011). The X26™ is capable of generating up to 50,000 volts (peak open circuit voltage); however, the actual voltage delivered to a human subject when the device is applied to the resistance of skin and other tissues has been measured to be between 1,000 volts and 2,000 volts. Peak electric currents have been measured at between three and four amperes (Sweeney, 2009a; Reilly & Diamant, 2011; Kunz *et al.*, 2012). The precise value of current and voltage actually delivered to the subject depends strongly on the nature of the contact between the probe darts and the subject's skin and clothing (Reilly & Diamant, 2011).

In addition to duration, number, and peak voltage and current of pulses, the detailed shapes of CEW waveforms are also relevant for understanding physiological and health effects on the human body. For example, the X26™ waveform is composed of two phases: an initial 100 kilohertz oscillating burst lasting 30 microseconds (0.00003 seconds); and a longer, slowly oscillating tail lasting 70 microseconds (0.00007 seconds) (Sweeney, 2009a). Laboratory measurements and computer simulations of electrical flow in the body suggest that the initial 100 kilohertz burst is meant to reduce contact resistance with clothing or skin, while the tail of this waveform drives the ensuing neuromuscular incapacitation (Sweeney, 2009a).

The older TASER® M26™ device delivers a different waveform. The M26™ waveform oscillates at a frequency of 50 kilohertz, while the intensity of the waveform decreases over a period of 40 to 50 microseconds (0.00004 to 0.00005 seconds). Similar computer simulations suggest that the strong first 10-microsecond cycle of the M26™ waveform (before the intensity decays) is responsible for stimulating the uncontrolled muscle contractions that lead to incapacitation (Sweeney, 2009b).

Figure 3.3 depicts various CEW waveforms to illustrate the variability across devices.[5] The performance of CEW devices varies and their electrical outputs can change with use and under different conditions, for example, under variable temperatures or humidity (Adler *et al.*, 2013; NDC, 2013). Because these variations are common and constantly evolving, each CEW device must be tested on its own merit to assess performance and ability to induce neuromuscular incapacitation while avoiding adverse physiological and health effects. This constant evolution and variation also mean that knowledge based on any particular model does not necessarily translate to other devices and that the characteristics of newer devices are unknown. Further complicating the issue is that much of the literature on the electrical characteristics of CEWs is produced by CEW manufacturers or those affiliated with the industry and not independent testing facilities.

5 See McDaniel *et al.* (2009) and Reilly and Diamant (2011) for depictions of waveforms from additional devices including the Stinger® S200™, Tasertron®, and Sticky Shocker®. For a more detailed discussion of variation in CEW waveforms and effectiveness in causing incapacitation, see Comeaux *et al.* (2011) and Reilly *et al.* (2009).



Data source: Quality Engineering Test Establishment (QETE), Department of National Defence Canada, 2013

Figure 3.3

Waveform Comparison of TASER® Models

The variation in the strength (vertical axis) of an electrical discharge over its duration (horizontal axis) is known as its *waveform*. The CEW waveform is intended to influence the peripheral nervous system in a way that causes temporary, involuntary, and uncoordinated skeletal muscle contraction. The current waveforms of three CEW devices depicted in this figure were generated in the QETE laboratory by firing into a resistive load of 500-ohms (M26™) and 600-ohms (X26™ and X2™). Notice that the waveforms for each device differ substantially from one another. Each waveform depicts a single pulse of the given device, which will be repeated many times during a discharge. For example, the TASER® X26™ delivers approximately 95 pulses over five seconds, which corresponds to a rate of 19 pulses per second (Adler *et al*., 2013).

One prominent question in cardiac CEW research is whether CEW discharges can, in fact, cause abnormal or dangerous heart rhythms, even though they stimulate nerves and skeletal muscle more effectively than heart muscle. That question is addressed more fully in Chapter 5. Here, the Panel only notes that CEWs are more effectively at preferentially targeting the skeletal muscle nerves, by using a lower strength and shorter electrical pulse duration than what is required to induce a potentially fatal heart arrhythmia.[6] In short, available information on the strength, duration, and waveform of CEW devices certainly supports the contention that they effectively target the skeletal muscle nerves with resultant neuromuscular incapacitation and disabling pain (Reilly *et al.*, 2009; Reilly & Diamant, 2011). The possibility that CEWs can have unintended consequences on heart rhythm and other physiological systems, however, is still vigorously debated and may depend on when the CEW is applied during the timing of the heart's natural electrical activity. In addition to artificial electrical stimulation, heart rhythm can be affected by mechanical force. Box 3.1 describes the effects of mechanical force on the interruption of heart rhythm.

6 For more detailed and technical information, see Panescu and Stratbucker (2009); Reilly *et al.* (2009); Sweeney (2009b); Reilly and Diamant (2011).

Box 3.1
Mechanical Force and the Interruption of Heart Rhythm

Mechanical force may be applied to the chest area during a CEW deployment and it is well known that a rapidly applied mechanical force to the area of the chest over the heart (precordium) can result in the development of a potentially fatal cardiac arrhythmia (Kohl *et al.*, 2001; Nesbitt *et al.*, 2001). Arrhythmia typically occurs without any other measurable injury to the heart and organs in the chest cavity. The phenomenon, known as *commotio cordis*, is most often associated with a very rapid and disorganized heart rhythm called ventricular fibrillation (Link *et al.*, 1998). The development of ventricular fibrillation in this setting is influenced by (i) the location of the impact on the chest, (ii) the stiffness of the impact object (harder objects are more likely to induce ventricular fibrillation), (iii) the velocity of the impact object (the minimum velocity ranges from 48-64 km/h), and (iv) the timing of the impact relative to the cardiac cycle (the vulnerable period represents approximately two per cent of the duration of the cycle) (Link *et al.*, 1998; Link, 2012). Thus, it is a relatively rare event that requires a confluence of factors for ventricular fibrillation to be induced by direct physical force on the chest.

The kinetic energy of a standard CEW probe is 1.5 to 2.2 joules (Dawes & Ho, 2012), and an extended-range CEW (designed to be fired from a 12-gauge shotgun) fired from a closer range than recommended has a maximum recorded projectile energy of 50 joules (Kunz *et al.*, 2011). It has been suggested that this amount of impact energy is not sufficient to cause internal organ damage. This assumption is based on the fact that commotio cordis is typically associated with high impact energy in sports such as baseball (150 joules) and hockey (170 joules) (Kunz *et al.*, 2011). Studies have not explicitly identified, however, the minimum energy level required to induce the condition, and no clear understanding exists of whether factors such as pre-existing heart conditions could lower the threshold required to induce this phenomenon. In any event, adolescents are more susceptible to the condition due to their body's greater flexibility and ability to absorb more force, which facilitate transmission of energy to the heart (Deady & Innes, 1999). Adolescents may be at greater risk of experiencing commotio cordis if exposed to projectiles, but more research is needed. Overall, based on the available technical specifications of the devices and the low momentum of one or both probes striking the chest, it is very unlikely that a CEW impact would result in ventricular fibrillation due to commotio cordis.

3.5 SUMMARY

CEWs deliver short, repeated pulses of electricity to the skin and subcutaneous tissues through two metal probes. They can be used in two operating modes; probe mode carries the most risk of unwanted cardiac or other health effects, given the greater likelihood of current running through the tissues of the chest. In addition to causing pain, CEWs influence the peripheral nervous system in a way that causes temporary, involuntary, and uncoordinated skeletal muscle contractions. The response to a CEW depends on the strength, duration, and waveform of the electrical discharge as well as the timing of when the electrical current is applied in relation to the natural electrical activity occurring in the body. The principle guiding the functioning of the CEW is that the short-duration electrical discharges it delivers are highly effective in stimulating nerves, causing incapacitation and pain, but these discharges are much less effective in stimulating the heart muscle and thereby inducing potentially fatal disruptions to the heart's rhythm. Specifications between CEW devices are variable, however, and may change with use and under different conditions. CEW devices and the variations between them are also constantly evolving, so knowledge based on any particular model does not necessarily translate to other devices, and the characteristics of newer devices are unknown. Evaluating the intended and unintended effects of CEWs requires testing each device on its own merit and understanding the context and conditions under which it is to be used.

4

Approaches to Conducted Energy Weapon Research

- Laboratory-Based Experimental Research
- Population-Based Epidemiological Field Research
- Summary

4 Approaches to Conducted Energy Weapon Research

Key Findings

- Computer models are able to simulate different physical characteristics of subjects and various CEW deployment scenarios. Animal models allow for more intensive experimental interventions, which can clarify the intensity of various parameters that are required to consistently achieve physiological and health-related effects following CEW exposure.
- Despite the potential advantages, the applicability of computer and animal models to human physiology and real-world CEW exposures is unclear.
- Human laboratory-based studies allow for greater applicability, but ethical constraints limit experimental intervention. Field research can account for real-world variables that cannot be simulated in the laboratory, but if there are low injury rates and lack of standardization it is difficult to establish meaningful associations.
- Given the advantages and disadvantages of current research approaches, to reach any conclusions about the physiological and health effects of CEWs it is beneficial to consider the results of a range of varying study designs.

Biomedical and other research is performed to test a predetermined set of hypotheses about the nature of the relationship between a set of variables and a particular outcome. Hypotheses may be tested through experimental studies attempting to control or manipulate a set of variables using computer models, animals, or humans, or through field-based epidemiological studies, which study populations in real-world circumstances. Each type of research comes with its own set of challenges that may influence the findings. Therefore, if a relationship is observed during these studies, researchers may be able to establish an association between a particular variable and an outcome; however, because of the effects of chance, error, bias, or confounding factors, a number of possible explanations may exist to establish that relationship. An observed association does not necessarily mean one variable causes the other, and the apparent lack of an association does not necessarily mean a causal relationship is absent. Judgment on whether an observed association is causal is therefore a difficult task that involves the review of multiple studies of varying designs and the consideration of a range of criteria related to the magnitude, consistency, and plausibility of the relationship across all related studies (Rothman & Greenland, 2005).

The hypothesis that conducted energy weapons (CEWs) might cause undesirable physiological or health effects has been explored using a range of study types:

- laboratory-based experimental studies, including:
  - computer modelling;
  - animal model studies; and
  - human studies; and
- field-based epidemiological study of real-world incidents involving CEWs used on varying human populations.

To provide the necessary context for understanding and assessing the available evidence on the physiological and health effects of CEW deployment presented in Chapters 5 and 6, and the challenges involved in establishing associations or cause-and-effect relationships (later discussed in Chapter 7), this chapter discusses the advantages and disadvantages of each approach to CEW research.

4.1 LABORATORY-BASED EXPERIMENTAL RESEARCH

4.1.1 Computer Modelling

Computer modelling is a preliminary line of inquiry in the field of bioelectricity, one which allows investigation without subjecting humans or animals to electrical stimulation. Mathematical and computer models have allowed researchers to predict the probability of responses of excitable cells and tissues, such as those that comprise the cardiovascular and nervous systems, to internal and external electrical stimulation. A typical model consists of two parts: (i) a system of nonlinear differential equations that describe cellular excitability; and (ii) a three-dimensional mathematical description of human or animal anatomy in terms of electromagnetic properties, such as a finite element model. Such models are widely used for computer simulations of cardiac therapeutic stimulation and defibrillation (Efimov *et al.*, 2009). Experts in the field generally agree that while anatomy can be faithfully reproduced with simpler mathematical models, electrical stimulation of the heart should be simulated using more complex and physiologically based versions, an example of which is bi-domain models (Efimov *et al.*, 2009).

Key Advantages

Simulating varying scenarios: By adjusting the variables of a computer model and running additional simulations, different scenarios can be investigated (e.g., different probe locations, penetration depths, separation distances) without having to use human subjects.

Accounting for body size variability: Researchers can account for select tissue characteristics by using different models. For example, the NORMAN model depicts the average European man and the Visible Human model depicts a larger man (Leitgeb *et al.*, 2012b); and researchers have used finite element models to mimic a very thin person (Panescu & Stratbucker, 2009).

Accounting for known co-factors: Certain co-factors, such as the presence of an implantable pacemaker or a metallic stent, can be studied using computer modelling (Leitgeb *et al.*, 2012b). In addition, cellular excitability models can be adjusted to account for various sympathetic nervous system or metabolic states or for genetic predisposition to sudden cardiac death.

Key Disadvantages

Applying relevant models: To date, an advanced bi-domain model of CEW application has not been developed to model electrical stimulation of the heart.

Accounting for unknown co-factors: Although computer models can be modified to account for different physical characteristics, it is difficult to model some mental or physiological states (e.g., extreme agitation, drug intoxication) that are commonly encountered in individuals exposed to CEWs in the field. The unknown effects of some unusually encountered or novel drugs on cellular ionic channels, and therefore on cellular excitability, further complicate the ability to establish appropriate models.

4.1.2 Animal Model Studies

Biomedical research uses animal models in researching health effects and therapies to avoid unnecessary harm to human subjects until more knowledge can be obtained. Each study has to be properly and ethically[7] conceived, designed, carried out, and independently replicated, with clear recognition of the differences inherent in any animal model versus a human subject. In the context of CEW research, the Panel found most literature relies on animal models using pigs, the use of sheep in one study being the exception (Dawes *et al.*, 2010a). While the genetic endowment of pigs and humans is remarkably similar, and while pigs share many of the mutations associated with disease in humans (Lunney, 2007), the genetic variations translate into obvious differences in anatomy, and less obvious differences in physiology, which makes it challenging to extend some animal model findings to humans.

Key Advantages

Anatomical relevance and variability: Data dating back to the 1930s show pigs to be sensitive to electrical induction of ventricular fibrillation, especially in settings of ischemia (restriction of blood flow to the heart) — a condition that is particularly relevant for CEW research (Chan & Vilke, 2009). Similar to humans, the weights of pigs are highly variable; this variation can be used to explore how different physical parameters may relate to health complications, such as the connection between weight and ventricular fibrillation (McDaniel *et al.*, 2005; Chan & Vilke, 2009).

Intensive techniques and co-factors: Fully anesthetized animals provide enormous potential for various experimental interventions and monitoring techniques (e.g., multiple exposures, different probe placements, increases in CEW charge or duration) that cannot be done with humans (Chan & Vilke, 2009). It is also possible to replicate certain field conditions by introducing illicit substances, such as cocaine, to mimic drug intoxication (Lakkireddy *et al.*, 2006), or adrenaline to mimic sympathetic (adrenergic) stress (Nanthakumar *et al.*, 2006).

Key Disadvantages

Comparability of anatomy: Although pigs and humans have similar cardiac muscle and coronary anatomy (Heusch *et al.*, 2011), the differences in the anatomy of pigs' specialized cardiac electrical conduction system (known as the Purkinje network) may mean they respond differently to CEW exposure. There are also differences in skin, connective tissue, muscle mass, and body geometry between humans and pigs that may affect comparability of research findings (Chan & Vilke, 2009).

Comparability of context: Unstressed, resting, anesthetized healthy animals are often studied. CEWs are used in the field, however, to help restrain individuals who are agitated, physically exerted, or possibly intoxicated (Walter *et al.*, 2008). Swine studies use anesthesia, assisted ventilation techniques, and/or muscle relaxants that have their own effects on cardiovascular function, muscle contraction, and pulmonary ventilation (Walter *et al.*, 2008); the applicability of this data for understanding humans involves many unverified and unverifiable assumptions.

7 Each study must conform to ethical constraints on animal research, such as those outlined in the Canadian Council on Animal Care's standards and guidelines, and equivalent regulatory frameworks in other countries.

Multiple exposures: Because sample sizes are generally small (5 to 20 animals), to establish enough measurements for comprehensive statistical analyses, each animal is often exposed multiple times to make the total number of discharges for the study several-fold higher. If the presence of a health complication is observed (e.g., arrhythmia), it can be difficult to ascertain if that complication is a tissue response to the CEW or a result of changes in the animal's physiology due to multiple exposure events over the course of the study.

4.1.3 Human Studies

Experimental human studies have often involved a single CEW exposure of 5 to 15 seconds to healthy, young, and physically fit volunteers, followed by measurement of various parameters such as cardiac rhythm or blood chemistry to check for markers that indicate muscle damage, stress, impaired respiration, or impaired cardiac function. Investigators have begun attempting to replicate field conditions by exposing subjects to CEWs following physical exertion (Ho *et al.*, 2007c, 2009a, 2009b) or alcohol consumption (Moscati *et al.*, 2010); deployment into the chest to deliver a current across the heart has also been done (Ho *et al.*, 2008). While none of these interventions can completely simulate field conditions, they lead the way for more applicable CEW research.

Key Advantages

Sample sizes: In contrast to animal studies, human CEW studies generally use larger samples of healthy volunteers, made possible because thousands of officers undergo training that includes discharge of the CEW in supervised conditions where data can be collected.

General applicability: Concerns about differences between animal study subjects and humans, and relevance of computer models, are no longer issues.

Key Disadvantages

Study recruitment: Human volunteers that are not healthy police officers may be reluctant to participate in CEW studies, and research ethics committees may be hesitant to approve studies (Chan & Vilke, 2009).

Physical characteristics of study subjects: Subjects are usually law enforcement trainees with above average weights and heights (Ho *et al.*, 2007a, 2008), which may not reflect the characteristics of those who are exposed in the field. Subjects are also usually individuals without health complications and who are not overly physically or mentally stressed nor under the influence of illicit substances.

Limitations in experimental design: Probes are often deployed into the backs of subjects or taped into conductive gel on the skin, which does not mimic actual deployment characteristics. Single, short-duration discharges are usually used; however, in the field, multiple discharges may be present. Procedures cannot involve invasive monitoring or an endpoint of an intended adverse event, for ethical reasons. Control groups (i.e., no exposure) and different treatment groups (e.g., different exposure times or dart placements) are often not present, due to limitations in sample size and difficulties in creating fake deployments. Blinded studies (where the subject does not know whether he is receiving the intervention) are unlikely since the pain of deployment is unmistakable. An additional technical challenge occurs when attempting to record the heart's electrical wave pattern during (as opposed to before or after) CEW exposure, because discharge of the device interferes with this recording.

Cost: A comprehensive and detailed randomized controlled trial is costly because of the equipment, infrastructure, and human resources required to ethically and accurately carry out such a study.

4.2 POPULATION-BASED EPIDEMIOLOGICAL FIELD RESEARCH

Large-scale epidemiological research that draws on information captured from databases and records of real-world CEW deployments can capture a range of conditions and circumstances. To date, however, published studies that examine real-world CEW deployments have usually been retrospective, relying on a range of data such as police incident reports, medical exams, and autopsy reports to create more complete pictures of events. Some authors have also used information from media sources to evaluate cases where CEWs are proximal to health effects. To date, most of the CEW field research has focused on collecting data on the types of injuries that occur, how often these injuries happen, the characteristics of those who are most often exposed to CEWs, and the rationale for CEW use. Some attempt has also been made to reconstruct the details surrounding CEW usage events, such as the number of discharges and the anatomical location of the probes.

Key Advantages

Collection of real-world data: Collecting and analyzing data from the types of subjects and events in which CEW deployments actually occur allows researchers to assess and evaluate CEW deployment outcomes across a wide spectrum of variables that would not be captured using healthy subjects in the laboratory.

Range of populations: Through the collection, analysis, and reporting of statistical information across populations exposed to CEWs, a common body of knowledge on CEW use and its risks will become available. It is impossible to acquire this through individual case evaluations or single outcome experimental designs.

Key Disadvantages

Incomplete reporting and diagnosis: Retrospective studies rely on reports prepared by police and other non-medical personnel, physicians, or coroners, which can be incomplete. Data describing the details of a chaotic use-of-force incident may be subject to recall bias and recording errors, especially when information is requested long after the event or if an adverse event has occurred with disciplinary implications for the officer involved. In some cases, determination of the presence of mental illness or its features is made by police officers without the benefit of accurate medical history, known diagnosis, or qualified medical opinion (White & Ready, 2009). Even if medical personnel are involved in preparing or evaluating case reports, impressions from police officers at the scene may be needed to make proper judgments and diagnoses (Bozeman *et al.*, 2012).

Lack of comparability across settings: Various independent police agencies capture varying information for CEW incidents, which prevents collation of large amounts of police data and comparison between sites (unless an agency is specifically participating in a research study). Even if a well-designed field study is in place, real-world use-of-force events occur in chaotic settings where measurements cannot always be taken at ideal moments.

Need for certain prevalence of injury: Some studies attempt to link the characteristics of a subject, or the details of a CEW incident, with physiological and health effects (e.g., exploring associations between number of discharges and certain injuries) (Bozeman *et al.*, 2009b). It is often difficult, however, to perform these types of analyses because injuries more serious than superficial puncture wounds (caused by probe penetration) are rare, even in studies involving over a thousand subjects (Bozeman *et al.*, 2009b; Strote *et al.*, 2010b).

Lack of adequate control groups: To properly examine co-factors that may lead to physiological or health effects following exposure to CEWs or other uses of force, investigators must examine the same factors (e.g., presence of drugs, restraint tactics) in CEW incidents that do not result in death and in similar use-of-force incidents that do not involve CEWs. Although these comparisons may be adequately performed in some cases (White & Ready, 2009), other studies do not have controls, focusing solely on analyses of a few fatal CEW incidents (Strote & Hutson, 2006; Swerdlow *et al.*, 2009; Vilke *et al.*, 2009a; Zipes, 2012). Selection bias can be introduced by including only fatalities or health complications in the evaluation, resulting in over-representation of the condition being studied.

4.3 SUMMARY

Research on the physiological and health effects of CEW exposure includes a range of study types, each with its own advantages and disadvantages. Computer and animal models allow researchers to simulate or physically test parameters such as deeply embedded probes and more intense discharges, which is not possible in human subjects. By testing scenarios that are more severe than those that will likely be encountered in real-world situations, these experiments can help define the upper safety limits for certain CEW parameters. The uncertainty surrounding the applicability of these models to human physiology and to real-world CEW exposures, however, creates several challenges. Human laboratory experiments address some of these challenges, but ethical constraints limit experimental intervention in human subjects. Population-based epidemiological field research can account for real-world variables that cannot be simulated in the laboratory, but low injury rates and lack of complete and consistent data sets make meaningful associations difficult to establish. Nonetheless, the combination of this range of study types will continue to further our knowledge surrounding the overall health effects of CEW exposure.

5

Physiological and Health Effects Associated with Conducted Energy Weapons

- Neuroendocrine Effects and Activation of the Human Stress Response
- Disruption of Breathing and Impact on Blood Chemistry
- Disruption in Heart Rhythm and Rate

5 Physiological and Health Effects Associated with Conducted Energy Weapons

Key Findings

- The absence of evidence on neuroendocrine, respiratory, and cardiac effects of CEW electrical discharge suggests that ongoing and more comprehensive investigations are required.
- CEWs can induce the release of catecholamines (e.g., adrenaline), with undetermined health effects.
- Animal studies indicate an association between respiratory complications and prolonged or repeated CEW discharge; although published experimental data identify respiratory changes in healthy human subjects typical of vigorous physical exertion, studies involving more heterogeneous groups, and humans subjected to prolonged or repeated exposure, have not been conducted.
- Some animal studies suggest CEWs can induce fatal cardiac arrhythmias when a number of discharge characteristics, alone or in combination, are in place: probe placement on opposite sides of the heart (i.e., current delivered across heart); probes embedded deeply near the heart; increased charge; prolonged discharges; or repeated discharges. These studies indicate biological plausibility of adverse health outcomes following CEW exposure.
- A small number of human cases have found a temporal relationship between CEWs and fatal cardiac arrhythmias, but available evidence does not allow for confirmation or exclusion of a causal link. If a causal link does exist, the likelihood of a fatal cardiac arrhythmia occurring would be low, but further evidence is required to confirm the presence and magnitude of any risk.
- The roles of co-factors that may increase susceptibility to adverse effects, such as drug or alcohol use, body type, and health status, have not been adequately tested to properly establish an understanding of vulnerability in humans.

This chapter reviews and assesses the available primary evidence — the literature and results of population-based epidemiological studies and experimental research (discussed in Chapter 4) — on the three adverse physiological and health effects most often associated with conducted energy weapon (CEW) exposure and discussed as potential mechanisms for sudden unexpected death:

- neuroendocrine system: activation of the human stress response and build-up of related levels of stress hormones such as catecholamines;
- respiratory system: mechanical impairment of breathing, changes in blood chemistry, and resulting acidosis; and
- cardiovascular system: changes to heart rhythm and rate and potential for arrhythmias (abnormal heart rhythm).

The chapter also examines a range of potential co-factors that, individually or in combination, could increase the risk or severity of these effects and increase the risk of sudden unexpected death. In this report, the Panel characterizes co-factors as internal, related to states intrinsic to the individual; or external, acute situational factors related to the event itself. Internal co-factors include alcohol or drug intoxication, pre-existing health complications, implantable medical devices like pacemakers, and body type. External co-factors include physical restraint, physical exertion, and a variety of CEW deployment characteristics such as strength of charge, length and number of discharges, and probe location and depth. The majority of the research identified by the Panel and reviewed in this chapter evaluates potential cardiac responses to electrical discharges from CEWs in the presence of various co-factors.

5.1 NEUROENDOCRINE EFFECTS AND ACTIVATION OF THE HUMAN STRESS RESPONSE

5.1.1 Basic Physiology

The neuroendocrine system is made up of the nervous and endocrine systems. The brain responds to stress by activating a structure known as the hypothalamus that, in turn, activates the pituitary gland at the base of the skull, which is the master gland of the endocrine system. The release of the adrenocorticotropic hormone (ACTH) from the pituitary gland stimulates the release of stress hormones (also known as catecholamines), such as adrenaline and noradrenaline. Together, these hormones mediate many of the physiological reactions of the body to stress and are largely the focus in research assessing the health implications of CEW use.

Because CEWs are largely deployed in situations where law enforcement officers are attempting to subdue or restrain an individual, a wide range of stimuli may be involved in activating the stress response, including physical threat, struggle, injury, or pain (NIJ, 2011). In response to these stimuli, the body elicits a fight-or-flight reaction that produces endorphins to help modulate pain, and hormones to increase heart rate, metabolism, and other functions that help prepare the body to deal with the stressor. Because the levels of hormones (e.g., adrenaline) increase in the blood in a stressed individual, they can serve as biomarkers indicating the activation of the human stress response (Dawes & Kroll, 2009). There is some disagreement, however, regarding exactly which markers are reliable and accepted for identifying and measuring catecholamine levels in the blood and for determining when those levels are dangerous (NIJ, 2011).

The fight-or-flight response to an acute physical or psychological stress is unlikely to pose a risk to a normal, healthy individual; after all, this response would not have evolved if it were frequently likely to cause injury. The release of these hormones can induce several adaptive responses including stronger cardiac muscle contractions and heart rate, increased blood pressure, increased metabolism, and increased production of heat. If these hormones are present over a long enough period of time or interact with other health risks, they may induce several maladaptive responses including reduction in blood flow to the heart, irregular heart rhythms, decreased heart rate, abnormal build-up of fluid in the air sacs of the lungs, metabolic acidosis, hyperthermia, or sudden death (Laposata, 2006; Dawes & Kroll, 2009). Elements of the stress reaction such as rapid heart rate, elevated blood pressure, and increased tendency of the blood to clot are also additional risk factors for those already at risk of cardiac arrhythmias, coronary artery blockage, or strokes.

Psychological factors such as fear, anger, apprehension, and confusion can by themselves elicit or heighten a person's stress level and the stress response (NIJ, 2011). The pain induced by a CEW could be enough to stimulate the stress response and likely enhance the effects of these stressors. Psychological stressors can also be exacerbated in situations where individuals feel that the circumstances are out of their control. The severity of the stress response may increase with the presence of other co-factors such as pre-existing medical or psychiatric conditions, or stimulants and drugs (Dawes & Kroll, 2009). An important question is whether a CEW discharge applied to an individual already under stress can further heighten the stress response sufficiently to harm the individual either through increased psychological stress (e.g., fear of pain or dying) or physical stress (e.g., the intense pain induced by a CEW).

5.1.2 Impact of CEWs on the Stress Response

There is speculation that CEW discharge may induce the stress response, increasing the risk of adverse health complications and death (Dawes & Kroll, 2009). The Panel, however, found few studies that specifically examined the relationship between CEW deployment and the stress response. In the limited studies available, researchers used animal and human models to explore the associations between various forms of restraint, including CEWs, and biomarkers of the stress response such as the presence of stress-related hormones. Results indicate that although CEWs can induce the stress response, the increased hormone levels seen as a result of CEW exposure are lower than levels activated by other forms of restraint and stress, and decrease over time. Key studies include the following:

- Werner *et al.* (2012) explored the effects of stress and other physiological processes in swine by exposing pigs to a one-minute CEW discharge, followed by a one-hour rest and a second discharge of three minutes. Overall, catecholamines increased during and immediately after each CEW application, followed by a gradual decline over time.
- Dawes *et al.*, (2009), in a study involving law enforcement agents, examined the capacity of different types of restraint mechanisms (and other interventions) to elicit the human stress response, including pepper spray (oleoresin capsicum spray), a five-second CEW exposure, cold water tank immersion, and physical exertion. The authors concluded that although the CEW did elicit an increase in stress hormones, physical exertion and pepper spray activated the stress response more than exposure to a CEW or a cold water tank.

5.1.3 Impact of Co-Factors

The situations in which CEWs are deployed are complex and dynamic and a number of factors may influence the relationship between CEW exposure and the stress response. Many of these (such as physical exertion, stimulant use or withdrawal, and restraint) can activate the stress response, making it hard to determine the direct effects of CEWs or any other factor. Further complicating our understanding is the combined or multiplicative influence of these various factors. For instance, animal studies (using rats) have shown that catecholamine levels increase when subjects are exposed to a combination of stimulants (such as cocaine) and physical exertion, which is greater than the effects of either of those stimuli alone (Han *et al.*, 1996).

The Panel identified little research that directly explored the relationships between CEWs, the stress response, and co-factors that could increase the likelihood or severity of the stress response. One experimental study, however, used a limited number of subjects (n=66), consisting of a mix of law enforcement officers, public safety personnel, and academic researchers, to explore the impact of arrest-related situations on catecholamine levels and other biomarkers of stress (Ho *et al.*, 2010). Researchers evaluated the impacts of external stimuli including a simulated sprint, physical resistance, a 10-second CEW discharge, a dog chase, and exposure to pepper spray (oleoresin capsicum spray). Results indicated that although prolonged or multiple exposures to a CEW increased hormone levels, the total catecholamine level induced by CEW exposure was approximately one-half or one-quarter the observed levels induced by fleeing or physical resistance, respectively (Ho *et al.*, 2010). Despite these results, it is unlikely that such tests carried out in controlled situations can mimic exactly the stresses experienced in real-world situations. In particular, the key psychological elements of unpredictability and powerlessness are largely missing, which reduces the ability to draw any definitive conclusions.

5.1.4 Summary of the Evidence

Based on the limited research available, CEW exposure can induce the stress response and increase hormone levels, and the risk of resulting stress-related adverse health complications appears similar to vigorous physical exertion. This conclusion, however, is limited by small sample sizes and a lack of epidemiological studies and explorations of real-world scenarios that capture the physical and psychological aspects of stress seen in typical CEW deployments. Finally, the disagreement over reliable and accepted markers for identifying and measuring catecholamine levels in the blood, and for determining when those levels are dangerous, greatly affects the ability to draw any definitive conclusions from the research to date (NIJ, 2011).

The most reasonable conclusion to draw is that we do not know to what extent the discharge of a CEW adds to the high levels of stress already being experienced by an individual in an arrest scenario. Addressing this issue with field research would be challenging because it would require knowing the levels of stress biomarkers in individuals both before and after CEW discharge — a practical impossibility. Additional carefully controlled studies with healthy volunteers are needed. These studies would be strengthened by superimposing CEW discharge upon other stressors such as exertion or psychological stressors, and by measuring the possible additive effect of CEW discharge on the stress response caused by other stressors at the time of discharge. Studies that ethically and safely incorporate the highly stressful elements of unpredictability would also be beneficial.

5.2 DISRUPTION OF BREATHING AND IMPACT ON BLOOD CHEMISTRY

5.2.1 Basic Physiology

The primary function of the respiratory system is continuous gas exchange, involving inhalation, which supplies the body with oxygen, and exhalation, which removes carbon dioxide from the body. To maintain the acid-base balance in the blood, the body increases or decreases its respiration rate and tidal volume and resulting gas exchange, based on the demands of a given situation. For instance, when exercising, muscles and organs demand more oxygen, and intense muscle activity can create a build-up of lactic acid in the blood that can lead to increased blood acidity (acidosis). This acidity is mitigated through stimulation of respiration, resulting in more oxygen entering the blood and more carbon dioxide being removed (Roberts, 2000; Dawes, 2009; NIJ, 2011). Processes such as hyperventilation, or over-breathing, remove carbon dioxide at a faster rate than it is being produced by the tissues, thereby causing the blood to become slightly alkaline (respiratory alkalosis); conversely, processes such as hypoventilation, which can be caused by some opiate drugs, result in decreased removal of carbon dioxide, causing respiratory acidosis (Dawes, 2009).

The respiratory system is composed of a number of key muscles that help carry out this function. The diaphragm is the primary muscle involved in normal breathing, helping to pull air into the lungs when it contracts and subsequently eliminating carbon dioxide on exhalation when it relaxes. The intercostal, scalene, and accessory muscles raise and stretch the rib cage during inhalation to increase the volume of the thoracic cavity during increased activity (Roberts, 2000; Dawes, 2009).

In exploring the relationship between electrical discharge and respiratory function, CEW studies measure changes in respiration, impact upon muscles involved in respiration, impairment of breathing (both inhalation and exhalation), and changes in blood chemistry and acidity.

5.2.2 Impact of CEWs on Respiratory Function

Because breathing depends on the contractions of various respiratory muscles, one could speculate that involuntary muscle contractions caused by CEWs could impair proper muscle functioning and the respiration process during exposure to a CEW discharge (Dawes, 2009; Reilly & Diamant, 2011). The intense muscle contractions involved in the incapacitation of an individual during a CEW discharge could also lead to increased production of lactic acid and blood acidity (Dawes, 2009). Impairment of the breathing process could lead to:

- diminished ability to remove carbon dioxide from the blood (hypercarbia), which results in the retention of carbon dioxide and subsequent production of excess hydrogen ions leading to respiratory acidosis; or
- a lower ability to obtain oxygen (hypoxemia), which could cause the body to resort to anaerobic metabolism, resulting in metabolic acidosis or the accumulation of acid in the blood and tissues.

The presence of severe metabolic and respiratory acidosis has been shown to cause a wide range of dysfunction in various organs in the body including impairment in cardiac function, sensitization to disruption in heart rhythm and rate, decreased respiratory muscle function and hypoventilation, elevated blood potassium levels, protein degradation, coma, and death (Adrogue & Madias, 1998). To explore whether these adverse physiological changes occur during exposure to a CEW discharge, studies have examined changes to the following:

- **tidal volume:** the volume of each breath, which is usually 7 to 8 millilitres per kilogram of body weight per inspiration (ARDS Network, 2000);
- **respiratory rate:** the number of breaths taken within a minute, which is usually 12 to 18 (Sherwood, 2006);
- **blood acidity:** a measure of the balance between acidity and alkalinity, with normal pH being very close to 7.4 on a scale of 1 to 14;
- **lactate levels:** the blood lactate concentration, which is usually 0.5 to 1 mmol/L in unstressed individuals; and
- **carbon dioxide partial pressure (PCO_2):** the partial pressure of carbon dioxide in the blood. Arterial PCO_2 is preferred but venous PCO_2 is commonly used as a replacement. Normal values are between 35 and 45 millimetre Hg (Lemoel *et al.*, 2013).

Each of these standard or normal rates varies based on the characteristics of an individual and formulas used to calculate them. When combined, however, these measures allow for proper understanding of changes to respiration, muscle functioning, and blood chemistry, which may indicate the presence of acidosis and subsequent risk of adverse outcomes.

Observations from Animal Studies

Some animal studies have demonstrated a relationship between respiratory complications (including cessation of breathing and changes in blood chemistry) and CEW exposure (for a summary of these studies, see Appendix C). Studies involving swine indicate the presence of breathing impairment, decreased pH levels, increased lactate levels, and higher PCO_2 levels:

- **Breathing impairment:** Multiple studies note inhibition of spontaneous respiratory effort during CEW exposure (based on visual inspection or tidal volume) and decrease in respiration rate post-exposure (based on breaths per minute) (Dennis *et al.*, 2007; Jauchem *et al.*, 2009b; Jenkins *et al.*, 2013).
- **pH:** Clinically meaningful reductions in blood pH were measured in several studies, with baseline values of ~7.4 and post-exposure values ranging from 6.8 to 7 (Jauchem *et al.*, 2006; Dennis *et al.*, 2007; Jauchem *et al.*, 2009b; Jenkins *et al.*, 2013).
- **Lactate:** Several studies reported post-exposure lactate values 9 to 14 times higher than pre-exposure values, increasing from ~1-1.5 mmol/L to 14-22 mmol/L (Jauchem *et al.*, 2006; Dennis *et al.*, 2007; Jauchem *et al.*, 2009b; Jenkins *et al.*, 2013).
- **PCO_2:** Following exposure, PCO_2 levels doubled from ~40-60 millimetre Hg to ~100 millimetre Hg (Jauchem *et al.*, 2006; Dennis *et al.*, 2007; Jauchem *et al.*, 2009b; Jenkins *et al.*, 2013).

The exposure time in the above experiments ranged from 30 to 80 seconds (or involved repeated five-second exposures). Thus, it is not possible from the available data to identify a precise duration that would elicit significant changes in acid-base blood chemistry (Reilly & Diamant, 2011). Furthermore, animal studies are commonly complicated by sedation, and the animals' breathing can be compromised by the combination of CEW exposure, sedation, intubation, and other sometimes unclear factors from the experimental design, including relatively long duration and repeated CEW exposures (NIJ, 2011; VanMeenan *et al.*, 2011).

Observations from Human Studies

Despite some epidemiological evidence that the probes of a CEW can puncture a subject's lungs (Ryan, 2008; Hinchey & Subramaniam, 2009), most research in humans has demonstrated few respiratory-related health effects resulting from the electrical effects of CEW exposure, although the duration of the CEW discharge is much less than that used in animal studies. Although some research indicates impairment in inhalation during exposure to a CEW, most studies show that tidal volume, respiratory rates, and lactate levels typically increase in a manner consistent with pain or intense physical exertion, and remain within acceptable ranges. Regardless of the changes observed in respiratory functioning during CEW exposure, subjects appear to regain normal breathing ability following that exposure. Key studies all involved five-second exposures to the backs of law enforcement personnel using either probe mode or alligator clips, so they do not provide any information on the effect of probe placement or duration of exposure. The following are some key examples:

- In a study by Vilke *et al.* (2007) ventilation, tidal volume, and respiratory rate increased in all 32 subjects and values returned to baseline after 10 minutes; there was no evidence of hypoxemia or hypercarbia.

- A study of 23 subjects demonstrated both anecdotal and measured reports suggesting that respiration, particularly inspiration, was severely impaired; normal breathing resumed once CEW exposure ceased (VanMeenen *et al.*, 2013).
- In a study involving 66 subjects, lactate levels immediately increased, then decreased at 16 and 24 hours post-discharge (Ho *et al.*, 2006).

5.2.3 Impact of Co-Factors

The many factors involved in a CEW deployment scenario may influence the relationship between CEW exposure and respiratory function. Some attempts have been made to evaluate internal co-factors such as alcohol intoxication, as well as external co-factors such as prolonged exposures to CEW discharges and physical exertion. Although limited, these initial studies point to co-factors that could potentially increase the likelihood or severity of the physiological effects noted above.

Internal Co-Factors — Alcohol Intoxication

Alcohol intoxication appears to contribute to production of lactate and acidosis in studies exploring prolonged exposure. In a study of human subjects intoxicated with alcohol and exposed to a 15-second CEW discharge, researchers observed increases in lactate levels (to as much as 4.19 mmol/L) and a drop in blood pH (to as low as 7.31 from the 7.4 baseline measure). Researchers concluded these transient changes were consistent with what occurs with intoxication or moderate exertion and not significant enough to result in lasting injury or death (Moscati *et al.*, 2010).

External Co-Factors — Prolonged Exposure

There is little research on the role of CEW discharge characteristics, such as dart placement and depth, in respiratory function (NIJ, 2011). There is speculation, however, that long-duration or repeated CEW exposure may be more likely than shorter single exposures to lead to metabolic or respiratory acidosis, particularly in cases where suspects exhibit severe non-compliance and aggression. Of the few studies examining these factors, some have indicated increased lactate levels similar to those experienced during vigorous physical exertion when participants are exposed to a 10-second discharge, while others have demonstrated no significant changes in tidal volume, respiratory rate, hypoxemia, or hypercarbia after exposures of up to 15 seconds. For instance, one study of human subjects observed that exposure to prolonged discharges of 10 seconds can lead to elevated levels of lactate, to as high as 5.52 mmol/L (Ho *et al.*, 2010). Another study comparing respiratory parameters pre-, during, and post-CEW exposure revealed that adult law enforcement personnel demonstrated normal tidal volume and no observed hypoxemia, hypercarbia, or disruption of breathing rate (Ho *et al.*, 2007a).

External Co-Factors — Physical Exertion

Strenuous physical exertion can produce increased lactate and metabolic acidosis. Box 5.1 describes the relationship between CEWs and rhabdomyolysis — a health complication arising from excessive physical exertion or stress and often associated with acidosis. It stands to reason that exposure to a CEW discharge may worsen these physiological changes, increasing the risk of acidosis and related health complications. Although few studies have examined this relationship, it appears that although CEW exposure can increase lactate levels, it does not increase them any more than vigorous physical exertion, which, in severe situations, could increase to as much as approximately 20 mmol/L (Hargreaves *et al.*, 1998). For example, in a study involving CEW discharge on physically exhausted subjects, physical exertion alone led to a reduction in baseline pH from 7.38 to 7.23, and, following a 15-second CEW exposure, pH was 7.22. Concurrently, lactate levels went from a baseline of 1.65 mmol/L to 8.39 mmol/L during the exercise protocol and 9.85 mmol/L after electrical discharge (returning to baseline after 24 hours) (Ho *et al.*, 2009a). In a related study involving healthy law enforcement personnel, a five-second CEW exposure following vigorous exercise demonstrated no clinically significant changes in respiratory rate, ability to breathe, or blood chemistry (Vilke *et al.*, 2009b). Neither study indicated the presence of severe or lasting acidosis, nor were the additive effects of CEW exposures clinically significant.

Experimental studies of CEW exposure in the context of physical exertion are highly relevant to real-world CEW incidents that often occur with extremely agitated subjects who are possibly exerting themselves far beyond a resting state (for example, during pursuit or restraint). Hick *et al.* (1999) presented a case series of five individuals with severe metabolic acidosis (pH ranging from 6.81 to 6.25) who all struggled violently during restraint by law enforcement. Four of these cases were fatal. Although CEWs were not involved in these incidents, the events emphasize the occurrence of acidosis within use-of-force events more generally and with extreme exertion alone, which may complicate the ability to draw any conclusions about the specific effects of CEWs.

> ***Box 5.1***
> **Rhabdomyolysis and Changes in Blood Chemistry**
>
> Rhabdomyolysis is a clinical condition that develops when skeletal muscle is broken down and its contents are released into the bloodstream. It is caused by overuse of muscle fibres or muscle injury associated with events such as excessive physical exertion, or electrical injury involving a strong current conducted through the body (Moscati & Cloud, 2009). Diagnosis of the condition is characterized through measurements of serum markers of muscle injury such as creatine phosphokinase (CPK) and myoglobin, both released from ruptured muscle fibres. Complications arising from rhabdomyolysis include metabolic acidosis, excessive potassium ion concentration, and increased blood clotting, all of which can lead to cardiac arrhythmias (Moscati & Cloud, 2009). The most often noted complication associated with the condition is acute renal (kidney) failure. A diagnosis of rhabdomyolysis following a CEW exposure could be indicative of skeletal muscle injury and increased risk for cardiac or renal complications (Moscati & Cloud, 2009; Reilly & Diamant, 2011).
>
> Research studies (Bozeman *et al.*, 2009b) and case reports (Schwarz *et al.*, 2009; Sanford *et al.*, 2011) suggest mild rhabdomyolysis is observed in very few cases of CEW exposure, and when it is identified there are a number of co-factors present (e.g., stimulant use and physical exertion) that have been implicated in the development of the condition in the absence of CEW application. Although associations between CEW application and the development of rhabdomyolysis are limited, the health effects of prolonged or multiple discharges remain untested in humans (Reilly & Diamant, 2011).

5.2.4 Summary of the Evidence

Studies of animals subjected to prolonged or repeated CEW exposure indicate the potential for respiratory complications (e.g., pronounced acidosis). Published experimental studies identify few complications in healthy human subjects, but to date, this has not been fully investigated in other populations. One possible reason for this conflict could be that animal studies are commonly complicated by sedation, which depresses respiration; and the animals' breathing can be compromised by the combination of CEW exposure, sedation, intubation, and other, sometimes unclear, factors from the experimental design (NIJ, 2011; VanMeenan *et al.*, 2011).

When considering the effects of co-factors that may worsen health complications, such as alcohol intoxication, prolonged exposure, or physical exertion, research suggests CEW discharge does not impact breathing and blood chemistry beyond the typical changes seen during vigorous physical exertion. The effects on subjects with lung disease, however, are unknown. There are limited data on the impact of probe positioning on respiration (NIJ, 2011) since studies examining the impact of discharge characteristics have focused mostly on cardiac responses (discussed in Section 5.3).

5.3 DISRUPTION IN HEART RHYTHM AND RATE

5.3.1 Basic Physiology

The heart is a specialized muscle that pumps blood throughout the body through a series of coordinated contractions, under the influence of electrical activity. The heart consists of four chambers: the two atria, which pump blood returning from the veins at low pressure into the ventricles; and the two ventricles. The right ventricle pumps deoxygenated blood to the lungs, and the left ventricle pumps oxygenated blood to all the body's organs at relatively high pressure. As previously noted, the beating of the heart results from an electrical impulse generated from the sinoatrial node, at a rate of 60 to 100 beats per minute (Katz, 2010).

5.3.2 Impact of CEWs on Cardiac Function

External electrical stimulation has the potential to disrupt the heart's internal electrical system, which may translate into adverse physiological effects and health complications. Cardiac disturbances considered in research exploring the impacts of CEW exposure include ventricular fibrillation, ventricular tachycardia, cardiac capture, and pulseless electrical activity. Although each of these has the potential to cause fatal cardiac arrest if the disturbance is not terminated in time (NIJ, 2011), the two most studied are:

- **Ventricular fibrillation:** Irregular, rapid, and uncoordinated contraction of the ventricular muscle due to rapid repetitive excitation of the muscle fibres with inadequate ventricular contraction. These disorganized contractions of the ventricles lead to ineffective ejection of blood from the heart, which may cause cardiac arrest. (O'Toole, 2003; Rubart & Zipes, 2005).
- **Cardiac capture:** The induction of at least one extra heartbeat by electrical stimulation. This results in a change to the heart's rhythm and requires far less charge than does the induction of ventricular fibrillation (Kroll *et al.*, 2009).

Experiments performed in computer, animal, and human study models seek to determine whether electric stimulation from CEWs can directly disrupt cardiac rhythm and rate, causing cardiac disturbances. Generally speaking, animal model studies suggest that ventricular fibrillation is a possible, although highly unlikely, event that is dependent on the location and depth of the CEW probes and the length of the CEW discharge. Even if the location and depth are set for maximal probability of ventricular fibrillation induction, it is still unlikely to occur in real-world CEW applications given the charge strength of a standard CEW (see Section 5.3.3 for a thorough review of these factors). No cardiac arrhythmias have been observed in experimental human studies using commercially available CEWs; however, an episode of cardiac capture was observed in a study by Ho *et al.* (2011c) during experimental testing of an unreleased CEW. The device was discharged for 10 seconds, with one probe in the centre of the subject's chest and one near the right hip. The CEW was then redesigned and testing of the new version proceeded without incident (Ho *et al.*, 2011c). This episode supports the idea that certain waveforms may capture the heart.

In the field, there has not been a conclusive case of fatal ventricular fibrillation caused solely by the electrical effects of a CEW (NIJ, 2011). A small number of human cases have found a temporal relationship between CEWs and fatal cardiac arrhythmias (Swerdlow *et al.*, 2009; Zipes, 2012) but they do not allow for confirmation or exclusion of a clear causal link. The study by Zipes (2012) is particularly questionable since the author had a potential conflict of interest and used eight isolated and controversial cases as part of the analysis (Myerburg & Junttila, 2012). In addition, both studies examined individual cases of CEW-proximal deaths without any corresponding data from control cases where death was not the outcome (Swerdlow *et al.*, 2009; Zipes, 2012). Use-of-force events are complex and chaotic, involving the interaction of many different factors; therefore, it is difficult to consider the electrical effects of CEWs on the heart in isolation. In many cases, it is likely that several factors lead to the onset of arrhythmias. However, without properly controlled, large-scale studies, it is not possible to determine which factors are associated with lethal cardiac effects and how CEWs interact with these predisposing factors.

Nonetheless, as inconclusive as these studies may be, they still provide some of the only available evidence from field scenarios that explore cardiac disruption. Since subjects are not monitored during use-of-force encounters, it would be extremely difficult to document arrhythmias during or immediately following CEW exposure. Furthermore, even in the laboratory it can be difficult to record the heart's electrical wave pattern during exposure, since the CEW discharge interferes with this recording. Thus, technical, situational, and other barriers (discussed in Chapter 7) have limited the collection of population-based data to confirm the speculation raised in these isolated case reports, but the biological plausibility of arrhythmia is evident.

5.3.3 Impact of Co-Factors

External co-factors most researched in the literature on cardiac effects include the characteristics of the actual CEW deployment (e.g., probe location and depth, strength and length of charge, and deployment mode). While the Panel acknowledges that properties of the CEW waveform other than strength of charge (such as current and pulse duration) are also important for determining whether the heart is affected, delivered charge is the electrical parameter that is commonly varied in experimental studies. Most researched internal co-factors include presence of drugs or alcohol, pre-existing cardiac conditions, implantable medical devices, and body type. Many of these co-factors can increase the risk for health complications in general, even in the absence of a CEW. Although not investigated fully, some co-factors point to potential increases in susceptibility to disruption of cardiac function following CEW exposure.

External Co-Factors — Discharge Characteristics

Numerous aspects of the discharge itself undoubtedly impact the likelihood that cardiac effects will ensue. It is difficult to discuss these characteristics in isolation, since studies often examine multiple characteristics without controlling for the effects of each one. The Panel's review of the literature revealed four important features of a discharge: probe location, probe depth, strength of charge, and length and number of discharges.

An important issue in the discussion about probe location is the position of the darts in relation to the heart. Darts placed in various positions on either side of the heart will cause the CEW current to flow across the heart. This results in exposure of cardiac tissue to different current densities,[8] which depends on the precise dart configuration (Leitgeb *et al.*, 2010). Darts in these positions may be referred to as transcardiac vectors. Figure 5.1 depicts the placement of probes across the heart.

8 Current density refers to the current per unit of area (i.e., the amount of current flowing through a given area). For example, it may be reported as amps per metres squared (A/m^2) or milliamps per millimetres squared (mA/mm^2) (Holden *et al.*, 2007; Leitgeb *et al.*, 2010).

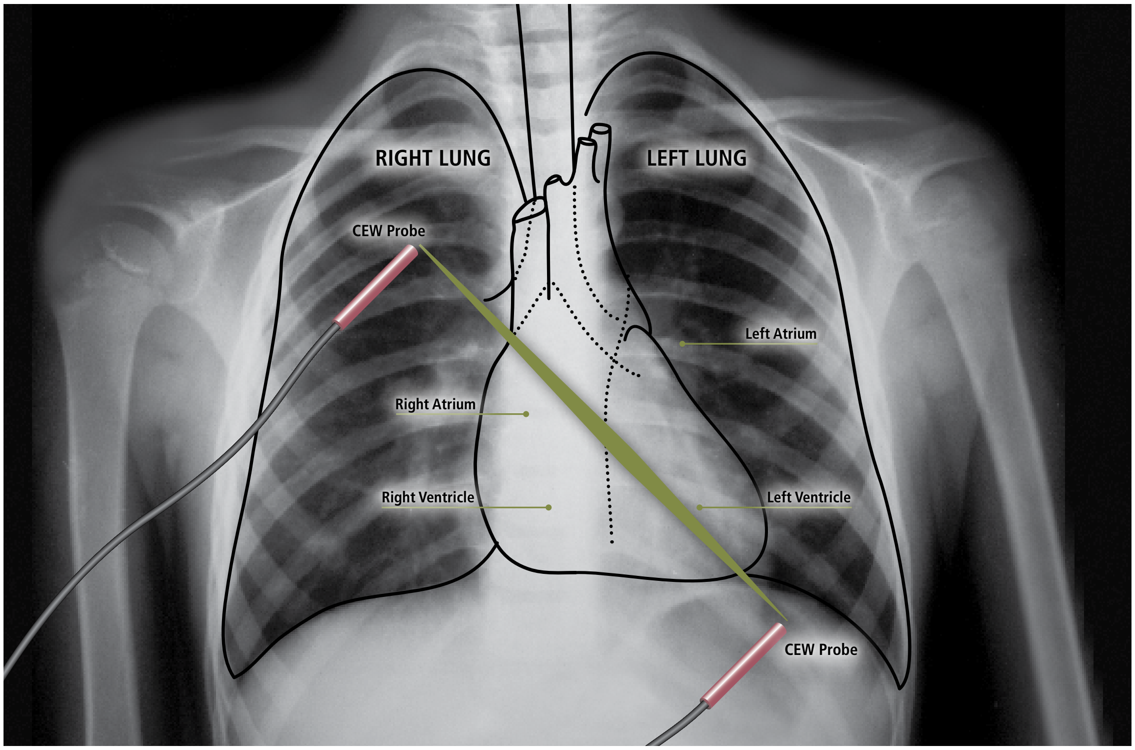


Figure 5.1

Depiction of a CEW Probe Deployment to the Chest

It is generally thought that a CEW deployment to the chest holds potentially more risk for adverse health effects due to the increased likelihood of the current from the device crossing the heart. This figure depicts the heart situated in the chest cavity. The CEW probes are positioned in such a manner that the current from the device will directly cross the subject's heart, thereby potentially increasing the risk of cardiac arrhythmias. For obvious ethical reasons this type of deployment has not been extensively researched in humans, but it is important for understanding the physiological and health effects of CEW use in relation to the heart.

For obvious ethical reasons, the effects of CEW discharge characteristics on disruption of cardiac functioning have been studied much more extensively in animals than in humans. The main findings of these animal studies are as follows (for more information on these studies, see Appendix D):

- Cardiac capture is more common when the CEW probes are located such that a current pathway directly crosses the heart; however, ventricular fibrillation is a rare event (Nanthakumar *et al.*, 2006; Lakkireddy *et al.*, 2008; Valentino *et al.*, 2008a).
- As the distance from the tip of the probe to the heart gets smaller, the likelihood of ventricular fibrillation increases because the amount of current flowing through the heart increases. If a dart were to penetrate fully (at the most sensitive location) in a human with a small skin-to-heart distance, it would be within the range at which pigs experienced ventricular fibrillation. Approximately five per cent of humans have a small enough skin-to-heart distance for this to be possible (Wu *et al.*, 2008).
- The strength of a standard CEW discharge is unlikely to induce ventricular fibrillation. Generally, a charge of between 5 and 15 times greater than standard is required (McDaniel *et al.*, 2005; Lakkireddy *et al.*, 2008; Kroll *et al.*, 2009).
- Prolonged or multiple discharges may increase the risk of ventricular fibrillation. Approximately 80 to 90 seconds of exposure, either delivered continuously or with one short pause, has been shown to induce ventricular fibrillation (Dennis *et al.*, 2007; Walter *et al.*, 2008; Kroll *et al.*, 2010); however, studies that directly compare different charge lengths are lacking. There is also evidence that ventricular fibrillation does not occur during prolonged or multiple discharges, even when the current is delivered across the heart. For example, one study using a 60-second exposure failed to observe any episodes of ventricular fibrillation (Jauchem *et al.*, 2009a). An additional study used a protocol that involved five five-second exposures in a row, repeating this pattern four times with rest in between, for a total of 20 exposures in 31 minutes. Similarly, no episodes

of ventricular fibrillation occurred (Esquivel *et al.*, 2007). In an extreme example, Jenkins *et al.* (2013) subjected animals to up to 30 minutes of continuous CEW exposure; although several animals died, the deaths were attributed to mechanical cardiac muscle failure and not electrically induced ventricular fibrillation.

More limited than animal studies, human studies primarily involve discharges that do not deliver a current across the heart. The CEW current is typically applied by firing the probes into the backs of subjects (Ho *et al.*, 2006; Dawes *et al.*, 2009); taping the CEW probes to the skin within conductive gel (Ho *et al.*, 2009b; Dawes *et al.*, 2010d); or attaching the CEW wires with alligator clips (Vilke *et al.*, 2008; Bozeman *et al.*, 2009a). Many of these methods fail to mimic the actual application of CEW devices in the field. A few studies have tested discharges across the heart in humans; two involved pre-placed probes (Ho *et al.*, 2007c, 2008), and two involved discharges into the chest (Dawes *et al.*, 2010c; Ho *et al.*, 2011c). As discussed in Section 5.3.2, Ho *et al.* (2011c) observed a single episode of cardiac capture during testing of a commercially unavailable CEW, but no other cases of cardiac disruption have been noted in any other study. No additional experimental studies with healthy human volunteers have identified cardiac injury (using direct cardiac monitoring or biomarkers) following CEW exposures of less than 45 seconds (Ho *et al.*, 2007a, 2009a, 2009b, 2011a; Dawes *et al.*, 2010b; Moscati *et al.*, 2010; NIJ, 2011).

Exposures that deliver a current pathway across the heart occur at a rate of approximately 15 per cent in the field (Bozeman *et al.*, 2012), but data relating probe location to cardiac effects are not available. A retrospective study relying on media reports of CEW events showed that fatal incidents were more likely to involve multiple deployments than were non-fatal incidents (White & Ready, 2009); however, these results have been called into question due to the reliability of the information sources used. Available evidence from a few case reports of real-world incidents support a temporal (but not necessarily causal) relationship between CEWs and fatal cardiac arrhythmias (Swerdlow *et al.*, 2009; Zipes, 2012). The study by Zipes (2012) examined eight cases of sudden cardiac arrest where subjects experienced immediate loss of consciousness following CEW exposure with at least one probe near the heart. Autopsy reports indicated that four subjects had structural heart disease. Initial cardiac rhythms, recorded anywhere from 4.5 to 13 minutes after CEW application, were ventricular fibrillation in 6 of 8 subjects. Zipes suggested that electrical stimulation from the CEW in the presence of heart disease could have disrupted cardiac rhythm. Details of the study by Swerdlow *et al.* (2009) are discussed in Section 6.3. Although these case reports are compelling, they can only point to potential hypotheses and not any firm conclusions.

To estimate the probability of inducing ventricular fibrillation without performing human experiments, computer models and calculations based on electro-stimulation laws have been used. The resulting conclusions are:

- **Probe depth and location:** In agreement with animal studies, computer models have indicated the probability of ventricular fibrillation increases as the dart-to-heart distance decreases (Sun *et al.*, 2010; Leitgeb *et al.*, 2011). Based on current densities at various distances from the tip of the CEW probe and typical skin-to-heart distances in humans, ventricular fibrillation remains a possible, though unlikely, event (Panescu *et al.*, 2008). Although computer models predict the overall risk is extremely low, if the CEW probes land in a critical position (referred to as a worst-case dart hit), the ventricular fibrillation probability may increase to a level high enough to explain occasional ventricular fibrillation (Leitgeb *et al.*, 2011).
- **Strength of charge:** Using electro-stimulation standards and existing experimental data, researchers determined that a one-ampere current of a standard CEW pulse is less than half the minimum strength required for cardiac capture. The authors calculated that 0.4 per cent of individuals could experience cardiac capture (but not necessarily ventricular fibrillation) if the CEW probes were placed at the most sensitive position (across the chest) (Ideker & Dosdall, 2007). Using a computer-based model of a human, Holden *et al.* (2007) calculated the peak current density at the ventricles following discharge across the heart. A current density greater than 60 times the value predicted by the model was required to induce cardiac capture in isolated guinea pig hearts, and ventricular fibrillation required an even higher density (Holden *et al.*, 2007).

External Co-Factors — Deployment Mode

Studies have been conducted to determine the increased cardiac risk for probe and drive stun modes (see Section 3.3 for a description of deployment modes). The risk of ventricular fibrillation is extremely low when a CEW is applied to a subject in drive stun mode (NIJ, 2011). First, because the probes on standard CEWs are recessed (i.e., below the surface of the cartridge), they are not expected to make perfect electrical contact with the subject's body when the cartridge is pressed against the subject (Panescu *et al.*, 2009). Second, computer modelling studies have shown that when CEW darts are close together, much of the current travels from one to the other near the surface. Alternatively, when the darts are far apart (as in probe deployment), the current travels deeper into the tissue, potentially causing a higher current density at the location of the heart (Sun & Webster, 2007). In animal studies, discharges in drive stun mode of up to 80 seconds on the hind limb (Valentino *et al.*, 2007a, 2008b) or over the heart (Valentino *et al.*, 2007b) failed to induce any cardiac rhythm changes.

When drive stun and probe modes are used together in a three-point deployment option, the probes are applied to the subject following firing of the darts. The current passes from a single probe to either or both of two drive stun probes that are pressed against the skin. Concerns have been raised about use of this mode, with two drive stun probes on a subject's back and a probe lodged into the subject's chest (Panescu *et al.*, 2009). A computer model comparing current densities in the tissues following three-point deployment and probe mode suggests that three-point mode would be as safe as, or safer than, probe mode. The model predicted that the majority of the current would be shunted between the two drive stun probes instead of penetrating deep into tissues (Panescu *et al.*, 2009).

Internal Co-Factors — Drugs and Alcohol

Drug use is common in individuals exposed to CEWs (NIJ, 2011). A handful of animal and human studies have investigated the possible role of drugs or alcohol in contributing to cardiac effects following CEW exposure. One study examined the effect of cocaine on ventricular fibrillation induction by CEWs in a pig model (Lakkireddy *et al.*, 2006). The authors concluded the drug actually decreased the likelihood of CEW-induced ventricular fibrillation, which is confusing because cocaine is known for its pro-arrhythmic properties. The study, however, was limited by lack of controls and the need for complex manipulation of the animals (NIJ, 2011). In another animal study using methamphetamine, CEW exposure exacerbated atrial and ventricular irritability induced by methamphetamine intoxication in sheep, but only in smaller animals and not in larger, adult-sized ones. Ventricular fibrillation did not occur in any of the animals (Dawes *et al.*, 2010a).

For ethical reasons, this is a difficult area to research in humans. One study examined the effects of a 15-second CEW exposure in alcohol-intoxicated individuals and found no clinically significant effects on markers of cardiac injury; however, direct cardiac monitoring was not performed in this study (Moscati *et al.*, 2010). Based on the Panel's analysis of these and related studies, it is not possible to form any definitive conclusions about potential interactions between drugs, alcohol, and CEW exposure in eliciting cardiac effects.

Internal Co-Factors — Pre-existing Cardiac Conditions

There is no evidence to show that electrical stimulation by CEWs contributes to the development of cardiac conditions such as coronary artery disease (narrowing of the vessels that supply the heart with blood and oxygen) or cardiomyopathy (weakening of the heart muscle) (Dosdall & Ideker, 2009). Correlative studies have, however, shown a high incidence of cardiac disease in subjects who died following CEW exposure (Strote & Hutson, 2006; Swerdlow *et al.*, 2009). Although the deaths were all temporally proximate to a CEW incident, the CEW was not ruled as a potential cause of death in most cases (Strote & Hutson, 2006); therefore, it may be fair to consider pre-existing cardiac conditions as potential triggers for death following a use-of-force incident more generally, rather than a CEW incident specifically (causes and triggers of sudden unexpected death and sudden in-custody death are discussed in more detail in Chapter 6).

Internal Co-Factors — Implantable Medical Devices

Electromagnetic interference is known to affect the functioning of implantable cardiac devices such as pacemakers and implantable defibrillators (Vanga *et al.*, 2009a). In general, pacemakers maintain heart rhythm when it gets too slow, whereas implantable defibrillators detect rapid rhythms and deliver an electric shock to reset the electrical activity of the heart (NIJ, 2011). Although potential interactions between CEWs and implantable cardiac devices has been recognized, it is based on a few case reports, none of which resulted in adverse health outcomes (Haegeli *et al.*, 2006; Calton *et al.*, 2007; Cao *et al.*, 2007).

Animal studies have not found any evidence that CEWs have harmful effects on pacemakers and implantable defibrillators following standard five-second discharges (Vanga *et al.*, 2009b). Although implantable cardiac devices may sense the electrical activity of CEWs, they do not actually deliver an abnormal shock or change native cardiac rhythm following a short discharge (Lakkireddy *et al.*, 2007; Khaja *et al.*, 2011). Upon sensing an abnormal rhythm, an implantable defibrillator begins charging its capacitors, and then reconfirms that the arrhythmia is present before delivering a shock. Extended exposures that persist beyond the charge and re-detection phases of an implantable defibrillator may result in shock delivery (Calton *et al.*, 2007; Vanga *et al.*, 2009a). Computer modelling studies have similarly suggested that although CEWs likely would not cause irreversible change or damage to implantable cardiac devices, they may transiently interfere with the function of these devices (Leitgeb *et al.*, 2012a, 2012b).

Internal Co-Factors — Body Type

Although research has not been conducted on children, the elderly, or subjects with low body weight, these groups have been identified as populations that may be more likely to suffer adverse effects following CEW exposure than adults with larger weights (Panescu & Stratbucker, 2009; NIJ, 2011). To date, the only evidence that subjects of smaller stature have a higher probability of ventricular fibrillation comes from animal studies that have suggested a lower body weight and a shorter distance from the probe to the heart (dart-to-heart distance) correlate with a higher likelihood of ventricular fibrillation (McDaniel *et al.*, 2005; Wu *et al.*, 2008; Sun *et al.*, 2010; Leitgeb *et al.*, 2011). A single case study describing the death of a seven-month-old infant following the application of a CEW by a guardian has been reported. The small size of the infant and the location of CEW discharge (near the heart) suggested the CEW injury was responsible for the infant's death (Turner & Jumbelic, 2003). While a higher body weight may protect a subject from the electrical effects of CEWs, if an individual is overweight or obese this may pose an increased risk for other adverse effects during a use-of-force encounter, such as a greater likelihood of experiencing compression of veins carrying blood to the heart when prone positioning is used (Brodsky *et al.*, 2001; Ho *et al.*, 2011b).

5.3.4 Summary of the Evidence

When considered as a whole, the research literature shows that electrical stimulation of the heart by CEWs is unlikely to disrupt cardiac rhythm and rate. Although the risk is low, however, animal studies clearly support the idea that it is biologically plausible for a CEW to induce a fatal cardiac arrhythmia. These animal studies indicate that the characteristics of a CEW deployment event, such as where the probes land on the subject, how deep they penetrate, and how long the device is discharged, affect the likelihood of ventricular fibrillation. There is a very low probability that, in a single discharge event, each of these variables will be at the right value to cause a fatal cardiac episode; however, an additional aspect of real-world CEW incidents is the multitude of co-factors (e.g., illicit substances and pre-existing cardiac conditions) that impact the probability of adverse health effects. Experimental human studies are performed primarily on healthy, physically fit men and thus fail to capture these co-factors. In addition, human laboratory studies often use discharges into the back or exposure methods that do not involve probe penetration, making these models less useful for studying cardiac effects. Current field data, in the form of a few case studies, support the existence of a temporal link between CEWs and fatal cardiac arrhythmias, but a causal link can neither be confirmed nor excluded at this time. Further epidemiological evidence that provides information on the role of co-factors involved in use-of-force events would help elucidate the potential mechanisms of cardiac disruption associated with CEW deployment.

6

Role of Conducted Energy Weapons in Sudden In-Custody Death

- Potential Causes and Triggers of Sudden Unexpected Death
- Potential Causes of Sudden In-Custody Death
- Relationship Between CEWs and Sudden In-Custody Death
- Impact of Co-Factors
- Summary

6 Role of Conducted Energy Weapons in Sudden In-Custody Death

Key Findings

- Sudden unexpected death is a rare event typically involving various behavioural, environmental, and genetic factors. It may result from numerous interactions of multiple physiological systems, including the cardiovascular, respiratory, and neuroendocrine systems.
- Sudden in-custody deaths resulting from use-of-force events are complicated scenarios that may involve agitation, physical or chemical restraint, disorientation, stress or exertion, pre-existing health conditions, and drugs or alcohol, all of which can potentially contribute to the death. This makes it difficult to isolate the contribution of a single factor.
- Although evidence shows the electrical characteristics of CEWs can potentially contribute to sudden in-custody death, no evidence of a clear causal relationship has been demonstrated by large-scale prospective studies. In a few coroner reports, however, CEWs were ruled as the primary cause of death in the absence of other factors and when excessive exposure was present. Given the limited evidence, a clear causal relationship cannot be confirmed or excluded at this time.
- If a causal relationship does exist, the likelihood that a CEW will be the sole cause of a sudden in-custody death is low. The extent to which the device would play a role in any death is unclear and dependent upon the co-factors involved.

Sudden in-custody death (also known as arrest-related death) refers to "rapid, unexpected death during detention of individuals by law enforcement or public safety personnel" (Stratton, 2009). Sudden in-custody death can occur at the scene of detainment, when the individual is being transported, or at the detention facility (Wetli, 2009). These fatalities typically involve complicated scenarios that include agitation, physical restraint, disorientation, physical and psychological stress, pre-existing health conditions, and/or drugs or alcohol. Scenarios often initiate speculation as to whether law enforcement agents may have precipitated death by using excessive force in the detainment of the subject (Ho *et al.*, 2009c). In contrast to sudden cardiac death and sudden death more broadly, literature discussing sudden in-custody death is scarce (Stratton, 2009) and, even after an autopsy has been performed, the cause of death often remains inconclusive. Research suggests associations between sudden in-custody death and individuals who are:

- in states of acute psychiatric agitation, hyperactivity, or paranoia;
- unusually aggressive, strong, unresponsive to pain, or sometimes acting destructively; and
- not responding appropriately to rational reasoning or commands.

(Robison & Hunt, 2005)

Other features may also be present, and the precise combination of characteristics can vary for each individual and the context and circumstances of their involvement with law enforcement. Figure 6.1 is a representation of the most common factors discussed in the literature on the health effects of conducted energy weapons (CEWs) and the complex relationships among various factors and sudden in-custody death.

This chapter begins with a summary of the evidence on the causes and triggers of sudden unexpected death in general, before focusing more specifically on sudden in-custody death and the potential role of CEWs in those deaths. The Panel's discussion also focuses on two key co-factors often discussed in the relationship between sudden in-custody death and CEWs: mental illness and excited delirium syndrome.

6.1 POTENTIAL CAUSES AND TRIGGERS OF SUDDEN UNEXPECTED DEATH

Sudden unexpected death describes death occurring within a short timeframe after the onset of acute symptoms (Stevenson *et al.*, 1993). The term *sudden cardiac death* is used when "a person dies suddenly and unexpectedly from a suspected [primary] cardiovascular cause" (George, 2013). Each year, up to 40,000 Canadians die of sudden cardiac arrest (Heart and Stroke Foundation, 2012). The annual incidence of sudden cardiac death in North America and Europe ranges from 50 to 100 per 100,000 persons (Fishman *et al.*, 2010). Although often unexpected in otherwise healthy individuals, it is usually related to a structural abnormality of the heart or its blood vessels, which leads to fatal ventricular arrhythmias. In adults of more than 40 years of age, the most common cause of sudden unexpected death is coronary artery disease (Tan *et al.*, 2005). Diseases of the heart muscle (called cardiomyopathy), defects in heart valves or ion channels, and other congenital or genetic disorders may also lead to cases of sudden unexpected death (Huikuri *et al.*, 2001). Because the prevalence of coronary artery disease increases with age, the incidence of sudden cardiac death similarly increases (Zipes & Wellens, 1998). In older individuals, sudden cardiac death may be less sudden than the term suggests, frequently occurring in people with a history of documented heart disease and following symptoms that last for at least two hours (Muller *et al.*, 2006).

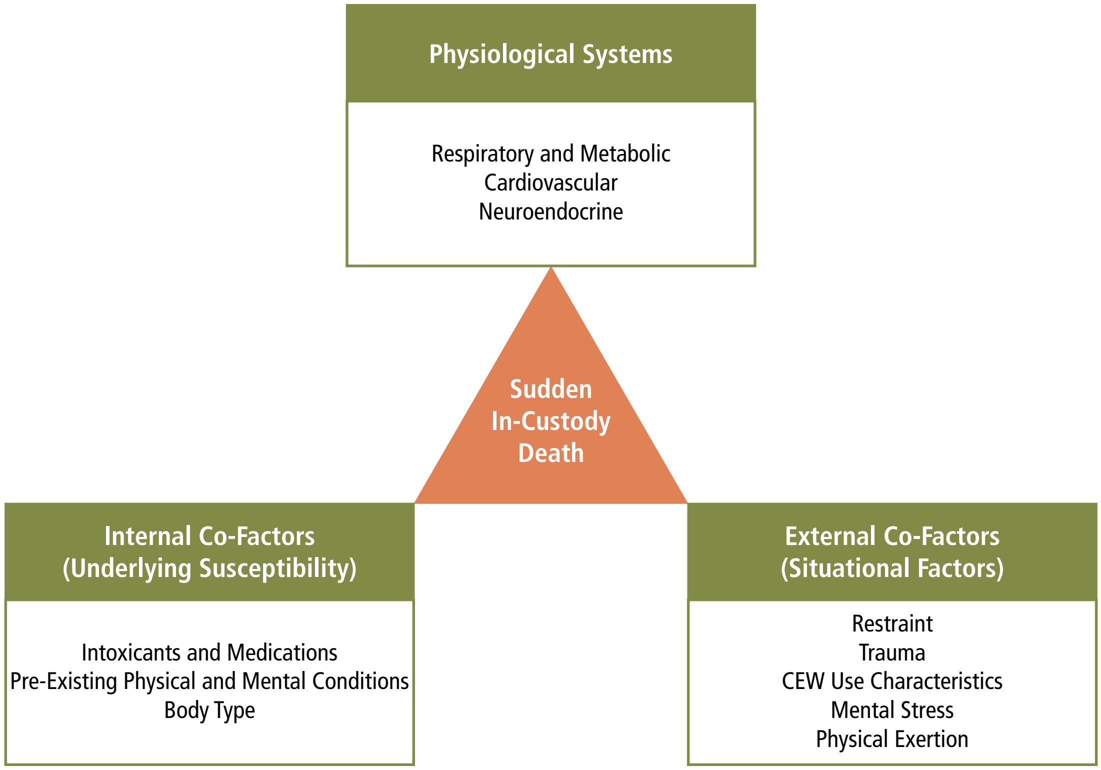


Figure 6.1

Potential Factors Associated with Sudden In-Custody Death

Sudden in-custody death refers to rapid, unexpected death during detention of individuals by law enforcement or public safety personnel. It is a rare event that may result from interactions of multiple physiological systems, including the cardiovascular, respiratory, and neuroendocrine systems. Sudden in-custody deaths resulting from use-of-force events are complicated scenarios that may involve various genetic, behavioural, and environmental factors, all of which can potentially contribute to death. This figure demonstrates some of the most common internal co-factors (intrinsic to individuals) and external co-factors (inherent to the situations in which CEWs are deployed) represented in the literature on the health effects of CEWs; additional factors may also be relevant. The complex relationships among all factors involved in CEW deployment scenarios make it difficult to isolate the contribution of any single factor in a sudden in-custody death; more research will help to resolve this complexity.

In those younger than age 40, although the majority of unexpected deaths are still cardiac related, other causes such as respiratory (e.g., asthma) and neurological (e.g., epilepsy) diseases may be common (Vaartjes *et al.*, 2009). Other conditions associated with sudden unexpected death include hemorrhage in the brain or another internal organ; blood clots in major arteries supplying the brain, heart, or lungs; and side effects or overdoses of drugs (Stratton, 2009). In comparison to adults (age 19 or older), sudden cardiac deaths in children and adolescents (age 2 to 18), although rare occurrences, are more likely to occur during moderate to vigorous exertion (Pilmer *et al.*, 2013). This finding may be relevant for adolescents involved in physically demanding use-of-force encounters with law enforcement. Many sudden unexpected death cases in young individuals, however, remain unexplained because medical history and autopsy results are absent or fail to provide a probable cause (Tan *et al.*, 2005).

Even in cases where an underlying cause of death has been identified (e.g., pre-existing coronary artery disease), it is important to determine the event that precipitates or triggers the cause in an otherwise healthy individual (Rubart & Zipes, 2005). Researchers need to unravel the complex interactions among various environmental, behavioural, functional, structural, and genetic factors affecting both the susceptibility to, and initiation of, sudden cardiac death (Rubart & Zipes, 2005). Restriction of blood flow to the heart is considered the most common triggering factor for fatal arrhythmias. Other triggers can include alterations in metabolism or neurotransmitters, and effects of drugs or toxins (Huikuri *et al.*, 2001). Causes of sudden cardiac death, however, are determined after the fact by autopsy, and factors that are able to predict an increased risk of sudden cardiac death are largely unknown.

The flow of ions (e.g., calcium, sodium, potassium, and hydrogen) across the membranes of heart muscle cells is ultimately responsible for electrical activation of the heart. Therefore, proper ionic balance is essential for coordinated contraction and relaxation of the heart muscle (Rubart & Zipes, 2005). As demonstrated in Chapter 5, the cardiovascular system is closely linked with other physiological systems, such as the respiratory and neuroendocrine systems. Disturbance of any of these systems can trigger ionic imbalance and, eventually, fatal arrhythmias. For example, excessive exertion and elevated temperature, which may occur during prolonged struggle, can both enhance carbon dioxide production and promote the development of respiratory acidosis. Acidosis elevates the incidence of cardiac arrhythmias through various mechanisms such as fluctuations in ions and increased catecholamine (e.g., adrenaline) release (Epstein & Singh, 2001). Physiologic stress (caused by exercise, emotion, arousal, etc.) also activates the neuroendocrine system, leading to release of catecholamines by neurons that innervate the heart (Volders, 2010). Although the mechanisms are not fully known, stress hormones can affect cardiac function by disrupting ion flow and inducing myocardial ischemia. Ischemia can further upset ionic balance and enhance the likelihood of sudden cardiac death (Rubart & Zipes, 2005). All of these factors, combined with genetic predisposition and conditions such as obesity, coronary artery disease, and diabetes, elevate the possibility of sudden cardiac death during a physically or emotionally stressful situation.

Changes within each of the neuroendocrine, respiratory, and cardiovascular systems have the potential to individually, or in combination, act as mechanisms leading to sudden unexpected death. During the investigation of a use-of-force associated fatality, when co-factors such as health status of the individual, presence of drugs or alcohol, occurrence of a prolonged struggle, and use of restraint all need to be considered, it becomes extremely difficult to determine the contribution of each individual element involved in the sudden unexpected death event. Ultimately, the effects of CEW discharge within the complex interplay of physiological changes are challenging to accurately determine.

6.2 POTENTIAL CAUSES OF SUDDEN IN-CUSTODY DEATH

One of the most significant issues preventing a better understanding of sudden in-custody death in Canada is the lack of accurate, uniform, publicly available information, along with any central database (see Section 2.3) to track this phenomenon. Drawing conclusions about the role of any single element in sudden in-custody death is further complicated by two main factors:

- **Low incidence:** The low incidence of sudden in-custody death in the real world of police use-of-force (Hall *et al.*, 2012) makes it difficult to set up prospective studies to examine potential causes.
- **Complexity of use-of-force events:** The complexity and uniqueness of each use-of-force event means it is often impossible to collect enough useful data on arrest scenarios to explore one particular factor consistently (NIJ, 2003). For example, assessing the role of a pre-existing cardiac condition in sudden in-custody death would, ideally, involve a comparison of two groups with similar risk factors and arrest circumstances (e.g., alcohol-intoxicated, obese, highly agitated individuals who undergo one five-second CEW exposure) that can only be differentiated based on the presence or absence of a cardiac abnormality.

Although there is much evidence related to the causes and triggers of sudden unexpected death more generally, large-scale studies need to be carried out to unravel the causes and triggers of sudden in-custody death. Of the limited evidence available, some research points to the potential contributions of various health conditions, behaviours, circumstances, and methods of restraint. These factors, discussed in this section, must be considered to understand the potential role of CEWs in complex sudden in-custody death scenarios. These potential causes/triggers, however, are not exhaustive; natural diseases or physical injuries resulting from use-of-force encounters may also play a role. It is probable that each case of sudden in-custody death is caused by several of these factors acting in combination. The relevant factors, and their levels of involvement, are likely different for each individual and each use-of-force event.

6.2.1 Chemical Restraint

Law enforcement officers use oleoresin capsicum (OC) spray (i.e., pepper spray) to facilitate control of a subject by irritating the skin, eyes, or — if inhaled — the mucous membranes of the airways. Respiratory symptoms can include a burning sensation in the throat, coughing, and wheezing (Smith & Greaves, 2002). Several sudden in-custody deaths have occurred following the use of OC spray. An examination of 63 of these cases by the U.S. NIJ (2003) concluded that although OC spray was not the sole cause of death in any particular case, it has the potential to aggravate underlying airway disease, which can lead to death. Several cases of severe respiratory distress requiring intubation have also been observed in children following accidental exposure to OC spray (Winograd, 1977;

Billmire *et al.*, 1996), but controlled laboratory studies do not support a role for it in compromising the respiratory function of healthy adults (Chan *et al.*, 2002). Although evidence is limited, because there may be instances where OC spray and CEWs are both employed in use-of-force events and because these two methods of restraint have the potential to influence similar physiological systems, it can be complicated to unravel the individual effect of each.

6.2.2 Physical Restraint

The physical restraint of subjects, particularly placement in the prone (i.e., face-down) position or the use of specific forms of neck restraint or compression, may have a role in sudden in-custody death (Robison & Hunt, 2005; Hall *et al.*, 2012). In these instances, the cause of death is believed to be positional asphyxia, where the position of the body does not allow for adequate breathing. Obstruction to the airway can also occur if individuals are unconscious and cannot adjust their heads or necks to facilitate the exchange of air (Stratton, 2009). The literature examining the outcome of prone positioning has usually focused on autopsy studies of small groups of individuals who died suddenly in police custody. Researchers must investigate the different forms of restraint used in fatal and non-fatal outcomes, however, to determine the effects of positioning on sudden in-custody death, and the phenomenon cannot be understood through retrospective examinations of subject deaths alone (Hall *et al.*, 2012).

Statistically significant changes in respiratory parameters have been measured in experimental studies as individuals move from sitting to supine (i.e., face-up), prone, or hog-tie positions, but none are clinically worrisome (Chan *et al.*, 1998), even in heavily exerted subjects with up to 100 kilograms of applied weight force (Chan *et al.*, 2004; Michalewicz *et al.*, 2007). Because CEWs are often used to temporarily incapacitate subjects so that they may be restrained by law enforcement, restraint and CEW exposure commonly occur together, further complicating the ability to discern the role that either might play in contributing to, or increasing the risk of, death.

6.2.3 Pre-Existing Cardiac Disease

Similar to sudden unexpected death in general, cardiac disease is the primary suspected underlying cause of sudden in-custody death in middle-aged or older individuals, although there are several other potentially relevant natural diseases including epilepsy and intra-cranial hemorrhage (Wetli, 2009). Cardiac abnormalities are frequently observed during autopsies of sudden in-custody death cases. In multiple studies, approximately half of the subjects classified as sudden in-custody death victims had cardiac abnormalities, including fibrosis and/or enlargement of the heart (Stratton *et al.*, 2001; Strote & Hutson, 2006; Swerdlow *et al.*, 2009). These conditions may be caused by an underlying disorder such as coronary artery disease (narrowing of the vessels that supply the heart with blood and oxygen) or cardiomyopathy (weakening of the heart muscle) (Zipes & Wellens, 1998). Coronary artery disease and cardiomyopathy are also common abnormalities in cardiac structure or function that can eventually lead to sudden cardiac death (Zipes & Wellens, 1998; Dosdall & Ideker, 2009). In addition, ventricular fibrillation can occur with exposure to stimulants such as cocaine, alcohol, and methamphetamines (Stratton, 2009). Several of these factors acting in combination with other aspects of a use-of-force event, such as stress or CEW exposure, could heighten the risk of sudden in-custody death.

6.2.4 Drugs and Alcohol

The use of illegal drugs, particularly stimulants such as cocaine and amphetamines, is strongly associated with sudden in-custody death (Stratton, 2009) and is common in individuals who are exposed to CEWs (NIJ, 2011). The literature is quite consistent, with both small and larger-scale studies (ranging from fewer than 20 to greater than 150 cases) indicating that 60 to 80 per cent of sudden in-custody deaths involve drugs and/or alcohol; of these cases, approximately 80 per cent or more involve stimulants (Stratton *et al.*, 2001; Strote & Hutson, 2006; Southall *et al.*, 2008; Ho *et al.*, 2009c). Evidence of chronic drug use is also common (White *et al.*, 2013).

Many studies have identified an association between adverse cardiovascular effects and illicit drug abuse. Medical examiners frequently report cocaine as the cause of drug-related deaths (SAMHSA, 2012); it induces restriction of blood flow to the heart by narrowing the coronary arteries and can produce or exacerbate cardiac arrhythmias (Lange & Hillis, 2001). Cocaine toxicity can also reduce the ability of the heart muscle to contract (Morcos *et al.*, 1993) and can cause coronary artery spasms (Stephens *et al.*, 2004). The effects of amphetamines such as MDMA (known as Ecstasy) are similar to those of cocaine. Following amphetamine use, excessive catecholamine activity, vasoconstriction, high blood pressure, and spasms of arteries in the brain can lead to brain hemorrhage, particularly in the presence of pre-existing vascular abnormalities (Pilgrim *et al.*, 2009).

In addition to their individual effects, drugs may act in combination to trigger sudden unexpected death. For example, amphetamines and cocaine can interact with antidepressants to induce serotonin syndrome, a "potentially life-threatening condition caused by excessive serotonergic activity in the central nervous system" (Malik & Kumar, 2012). Alcohol also alters the biotransformation of cocaine, so that the combination of alcohol and cocaine is associated with a greater risk of death than cocaine alone (Harris *et al.*, 2003). Drugs may also alter behaviour such that an individual will continue to resist law enforcement, resulting in extreme physical exertion that likely plays an essential role in a sudden in-custody death incident (White & Ready, 2009). Furthermore, individuals under the influence of drugs may be less likely to comply following CEW exposure due to a decreased ability to feel pain, a situation that could lead to prolonged or multiple discharges (NIJ, 2011).

Withdrawal from drugs and alcohol can also increase the risk of severe health complications and death. Alcohol withdrawal syndrome (AWS) begins with symptoms such as nervousness and increased heart rate and may progress to a stage that is characterized by cardiovascular, respiratory, and metabolic abnormalities, ongoing agitation, and delirium (Carlson *et al.*, 2012). Although the risk of mortality from AWS has declined over the past few decades, a significant risk remains, particularly if other conditions such as liver disease are present (Carlson *et al.*, 2012). It is conceivable that AWS could be a contributing factor when an agitated, disoriented individual dies in custody.

Drugs taken for medicinal purposes may also play causal roles in cases of sudden unexpected death and sudden in-custody death, due to their abilities to alter the electrical properties of the heart. Drugs such as some anti-arrhythmics, anti-psychotics, and anti-infectives have the potential to disturb the repolarization phase of the cardiac cycle, resulting in prolongation of the QT interval (see Figure 3.1), which can eventually lead to increased vulnerability for ventricular fibrillation (van Noord *et al.*, 2010).

6.2.5 Exertion and Intense Physical and Psychological Stress

During law enforcement encounters that end in sudden in-custody death, suspects are typically non-compliant, highly agitated, physically aggressive, and sometimes act in bizarre manners that include delirium and paranoia (Ho *et al.*, 2009c; Vilke *et al.*, 2009a). Their behaviour indicates they are experiencing states of extreme, acute stress far beyond reason and beyond the distressed states that police usually encounter (Robison & Hunt, 2005); as a consequence, their behaviour results in intense physical exertion and thus the psychological and physical stress they experience is likely an important element in the sudden unexpected death equation. As discussed in Section 5.1, stress leads to the release of catecholamines (e.g., adrenaline). These hormones can affect cardiac function by restricting blood flow to the heart, and a sudden decrease in blood flow relative to the need at the moment can upset the ionic balance essential for proper contraction of the heart (Rubart & Zipes, 2005).

While researchers have demonstrated the link between stress and cardiac arrest, the risk is relatively small in individuals with normal cardiac function and no coronary heart disease (Chugh *et al.*, 2000). High levels of catecholamines can trigger a potentially lethal syndrome called stress cardiomyopathy, however, where the left ventricle of the heart contracts abnormally. This syndrome is typically initiated by acute physical or emotional stress in patients with no pre-existing coronary artery disease (Steptoe & Kivimaki, 2012). Although some researchers speculate that sudden in-custody death cases in young men with bizarre or violent behaviour and recent physical exertion could be explained by stress cardiomyopathy (Otahbachi *et al.*, 2010), this hypothesis has yet to be adequately tested.

Another mechanism that may contribute to sudden in-custody deaths involving excessive physical exertion is metabolic acidosis, which can cause depressed myocardial function, arrhythmias, and cardiovascular collapse (Ho *et al.*, 2010). Struggle against restraints used by law enforcement may result in a build-up of lactate and, subsequently, acidosis. Although physical exertion, even in athletes, does not normally lead to fatal acidosis, several other factors may come into play during a use-of-force event. Stimulants such as cocaine can worsen acidosis and alter pain sensation, resulting in exertion far beyond normal physiologic limits (Hick *et al.*, 1999). During metabolic acidosis, the body attempts to compensate with increased respiration, which reduces acidosis by excretion of carbon dioxide from the lungs (Swenson, 2001). Certain restraint positions, however, may prevent this compensation by impeding respiration (Hick *et al.*, 1999). Many of these encounters may also involve less-lethal weapons such as CEWs or OC spray (Ho *et al.*, 2009c). The combination of emotional stress, extreme agitation, physical exertion, drug intoxication, and less-lethal weapons may culminate in a fatal cardiac event.

6.3 RELATIONSHIP BETWEEN CEWS AND SUDDEN IN-CUSTODY DEATH

Since CEWs are deployed to aid in detaining, incapacitating, or physically restraining individuals who are demonstrating resistance, agitation, or violence, they need to be considered as possible factors in the complex etiology of sudden in-custody death. When used as recommended, there have been no studies demonstrating electrical effects of a CEW as the primary cause of death in the absence of other contributing factors. Although there is no universal guideline for proper CEW usage and no definition of prolonged exposure (NIJ, 2011), in the few cases where a CEW has been ruled the primary cause of death, excessive exposure was used (Fox & Payne-James, 2012; White *et al.*, 2013) (see details below). Death due to secondary trauma induced by a CEW, such as fatal head injuries caused by CEW-induced falls or fatal burns caused by CEW-ignited fires, have also been documented in rare cases (Fox & Payne-James, 2012). Despite being infrequently ruled as a primary cause in the absence of other factors, coroners have at times noted a CEW as a contributing factor or as the primary cause of death in the context of several contributing factors. The extent to which a CEW contributes to death across these types of cases is not known.

A recent review did not find any cases where sudden in-custody death was due “directly or primarily to the electrical effects of [CEW] application” (NIJ, 2011); however, the timing of death in some anecdotal cases with no other known risk factors suggests that CEW exposure may have been the cause (NIJ, 2011). For example, one of the only field studies designed to examine the possibility that sudden in-custody death could be caused by immediate disruption of cardiac rhythm by a CEW analyzed a population of 56 subjects who collapsed (and subsequently died) within 15 minutes of CEW exposure. The authors concluded that one death analyzed in the study fit the profile of electrically induced ventricular fibrillation since this rhythm was successfully recorded on an ECG, the CEW current was delivered across the heart, the subject collapsed immediately, and there was no evidence of drug use or cardiac disease (Swerdlow *et al.*, 2009). It is therefore a possibility that CEW exposure was the cause of death in this subject, but this possibility could neither be confirmed nor excluded.

CEW exposure was listed by medical examiners as the primary cause of death in 2 of 213 sudden in-custody death cases investigated by White *et al.* (2013). Methamphetamine intoxication was a contributing factor in one case while, in the other case, no contributing factors were listed but the individual was subjected to more than four minutes of CEW exposure during the incident (White *et al.*, 2013). At the time of this report’s publication there was an ongoing coroner inquest in Ontario, Canada into the death of a suspect exposed to a CEW, where a pathologist attributed the death to cardiac arrhythmia primarily caused by the CEW. Despite this attribution, the coroner’s jury overseeing the inquest ruled the cause of death as a cardiac arrhythmia due to excited delirium syndrome and schizophrenia, with CEW deployment, an enlarged heart, and genetic vulnerability as contributing factors (OCC, 2013). The results of the inquest shed further light on the complicated nature of implicating CEW exposure as a primary cause of death. In a study analyzing characteristics of 26 Canadian fatalities proximal to CEW deployment, researchers noted that certain characteristics were common among CEW-proximal fatalities including history of drug use, poverty status, and male gender (Oriola, 2012).

In most other sudden in-custody death studies, CEW exposure is listed as a contributory (but not a primary) cause in a low frequency of cases (~10 per cent) (Strote & Hutson, 2006) or in no cases at all (Southall *et al.*, 2008). Two of the more common causes of death appear to be illicit drugs and pre-existing cardiac conditions, but, in many cases, the manner of death remains undetermined (Strote & Hutson, 2006; Southall *et al.*, 2008; White *et al.*, 2013). Prolonged, forceful struggle is frequently associated with sudden in-custody deaths but rarely identified as a cause (Stratton *et al.*, 2001; White & Ready, 2009; White *et al.*, 2013).

Despite the challenges apparent in determining cause of death, some researchers have attempted to use sophisticated statistical techniques to determine causality. For example, one study used a modified version of the Naranjo algorithm, which was originally developed to assess putative adverse drug reactions. When this algorithm was adapted to determine cause of death in 175 CEW-associated fatalities occurring in North America and internationally, CEWs were considered a probable or definite cause in 21 (12 per cent) of them (Fox & Payne-James, 2012). Of these 21 fatalities, however, CEW exposure was stated as the official cause of death (as a result of cardiac arrest) in only one case, which involved multiple and prolonged exposure (nine discharges within 14 minutes), whereas CEWs played an indirect role (e.g., by causing falls that resulted in fatal head injuries, influencing pre-existing cardiac conditions, igniting fuel on subject’s clothing) in the others.

During a use-of-force event, numerous subject and situational factors may play roles in enhancing the risk of death (Hall *et al.*, 2012). These factors lead to dysfunction

> **Box 6.1**
> **CEWs and Risk of Fetal Death**
>
> Although most of the published case reports describing fetal death following electric shocks involve exposures to higher amounts of electricity than those delivered by CEWs, risk factors for fetal injury following electrocution include the magnitude of the current, the pathway along which the current travels, the duration of the current in the body, the body weight, and whether or not the mother was proximal to water at the time of exposure. High-voltage currents, and those that pass from hand to foot through the uterus, increase the risk of fetal death (Goldman *et al.*, 2003). In one of the only prospective studies following women who received an electric shock during pregnancy, most received electric shocks of 110 volts or 220 volts while using home appliances. Of the 31 pregnant women, 28 delivered healthy newborns. One spontaneous abortion may have been related to the electric shock injury; however, the study concluded that low-voltage electric shock does not pose a major risk to the fetus (Einarson *et al.*, 1997).
>
> The Panel's review of the literature identified one case report of a pregnant woman who was exposed to a CEW, with the path of the current travelling through the uterus. She began spotting after one day, and received medical attention after seven days, when an incomplete spontaneous abortion was diagnosed. The conclusion was that because the uterus and amniotic fluid are excellent conductors of electric current, the fetus may have been vulnerable, depending on the contact points of the CEW probes (Mehl, 1992). Contact points that facilitate the passage of current through the fetus may, therefore, increase the risk for adverse outcomes. Since no studies have explored this question to date, the risk remains unknown.

of various physiological systems, which likely act in concert to ultimately produce fatal outcomes. The introduction of CEWs into this milieu makes it even more challenging to determine cause of death. For example, it is not known if a CEW discharge against an individual resisting arrest adds to the high levels of stress already being experienced by that individual, or if this combination of stressors elevates catecholamine levels enough to increase the risk of dangerous cardiovascular or cerebrovascular events. Conversely, CEWs can also potentially act as protective factors in terminating situations that may otherwise culminate in sudden in-custody death (Ho *et al.*, 2007b), although no evidence exists to confirm this speculation. Although further research is needed, current studies show that within the complexity of law enforcement encounters, CEWs have the potential to act as contributory factors in sudden in-custody deaths. A few coroner reports have ruled a CEW as the primary cause of death in the absence of other factors when excessive exposure was present. No evidence of a causal relationship has been demonstrated, however, by large-scale prospective studies — and given the limitations of the evidence, such a relationship can neither be confirmed nor excluded. The strength of a CEW's contribution may vary from case to case and be based on other contributory factors.

6.4 IMPACT OF CO-FACTORS

The two co-factors most discussed in the literature related to the role of CEWs in sudden in-custody death are mental illness and excited delirium syndrome (an acute hyperarousal state).

6.4.1 Mental Illness

Most of the published data on the effects of CEWs on subjects with mental illness appear to be usage data suggesting that individuals living with mental illness are more likely to receive a CEW discharge when apprehended by police officers than those with no mental illness. That being said, almost 20 per cent of the Canadian population will experience a mental illness during their lifetime, and there are many types of mental illness (GC, 2006). The proportion of those with a mental illness who actually come into contact with the police and CEWs is very low. Individuals with some types of mental illness (e.g., severe psychoses) may be confronted with CEW discharge when the unique behavioural, emotional, or cognitive states associated with their illness bring them to the attention of law enforcement.

Studies have indicated CEWs are 2.7 times more likely to be discharged during mental health emergencies than during criminal arrests (O'Brien *et al.*, 2011). Some reports have focused on the beneficial effects of CEW use in this population, suggesting CEWs may effectively prevent deadly force or facilitate the prevention of self-harm (Ho *et al.*, 2007b). Others have speculated that people with mental illness will be disproportionately impacted by CEWs, since police may view this population as dangerous and thus be more likely to respond pre-emptively with a CEW in situations involving mentally ill individuals (O'Brien *et al.*, 2011).

One study indicated death was nearly twice as likely to occur following CEW exposure when the subject was emotionally disturbed or mentally ill (White & Ready, 2009). The study's findings are called into question, however, because it compares media reports of fatal and non-fatal CEW incidents and does not differentiate between transient emotional disturbance and underlying mental illness. Although there is evidence that individuals with mental disorders are at greater risk of experiencing the discharge of a CEW when involved in a use-of-force encounter, the vast majority of individuals with mental illness do not exhibit the severe behavioural disturbances that result in contact with first responders and possible CEW discharge. Overall, there is little evidence that individuals with mental disorders are at greater risk of experiencing the discharge of a CEW when involved in a use-of-force encounter, unless other factors, such as the exhibition of agitated or violent behaviours, are present (CPC RCMP, 2012).

There is some speculation that, for the physiological reasons associated with a mental disorder or the pharmacologic treatment of some mental disorders, individuals exhibiting aggressive or violent behaviours in the context of a mental disorder may be at greater risk for sudden in-custody death (Robison & Hunt, 2005). As discussed by O'Brien *et al.* (2007), others have argued people taking anti-psychotic medications are already at an increased risk of sudden cardiac death (Straus *et al.*, 2004), and CEW intervention may increase this risk. There is no evidence to support or refute these speculations.

O'Brien *et al.* (2007) also speculate that CEWs discharged at individuals with a mental illness may reduce the likelihood that they will seek subsequent mental health care, but no relevant data support this claim. People with severe mental illness are more likely to experience post-traumatic stress disorder (PTSD) irrespective of CEW use, but the underlying reasons for this association are unknown (Alvarez *et al.*, 2012). Although it is clear that chronic stress leads to adverse health outcomes, a single, acute trauma exposure may also have negative consequences for physical and mental health (D'Andrea *et al.*, 2011). It is possible that a use-of-force intervention may be more likely to elicit a PTSD-like disorder in a person with severe mental illness and may cause persistent mental health problems in a previously healthy individual; however, these ideas remain speculative.

The limited data available on this topic do not allow any substantial conclusions to be drawn about the impact of CEW use in individuals with a mental disorder, nor do they allow any causal relationship to be identified between the use of CEWs on individuals with a mental disorder and negative mental or physical health (such as sudden in-custody death). Given the speculations discussed above, especially on the potentially greater negative interaction between CEWs and compromised health status of some individuals with mental disorders, this area is a priority for research. The possible use of CEWs by law enforcement called into therapeutic settings to elicit compliance or provide restraint in specific situations also deserves future study.

6.4.2 Excited Delirium Syndrome

Excited delirium (ExD) syndrome is a highly controversial condition often associated with sudden in-custody death and CEW use (Strote & Hutson, 2006; Southall *et al.*, 2008; White *et al.*, 2013). The term *excited delirium* is a syndromal classification used to denote a physical and mental state characterized by a range of signs and symptoms commonly including paranoia, hyperactivity, agitation, restlessness, speech incoherence, numbness to pain, extraordinary strength, profuse sweating, elevated body temperature, disorientation, aggression, and combative behaviour (Di Maio & Di Maio, 2006; ACEP, 2009; NSDOJ, 2009) (See Box 6.2). Not all individuals with ExD syndrome exhibit the full spectrum of signs and symptoms, and varying degrees of the same symptoms can be found in different cases.

Box 6.2
Controversy over Diagnosis of Excited Delirium Syndrome

Recent debates about whether excited delirium (ExD) syndrome is or is not a medical diagnosis may be of little value in bringing better understanding to this phenomenon (NIJ, 2011). For example, organizations such as the American Medical Association and the American Psychiatric Association do not recognize ExD as a diagnosis, whereas groups such as the National Association of Medical Examiners and the American College of Emergency Physicians have both formally endorsed ExD as a medical diagnosis (Vilke *et al.*, 2012b). The World Health Organization (WHO), while not officially recognizing ExD in the International Classification of Disease, did affirm the right of medical examiners to use their own parlance and clinical judgment to make informed pronouncements of causes of death without any constraints from approved lists of conditions (WHO, 2000). In Nova Scotia, a recent provincial task force review of this issue concluded that ExD syndrome and the syndromes identified by numerous other labels or diagnoses were likely similar and suggested that, in the absence of an as-yet-agreed-upon diagnostic classification, the term *autonomic hyperarousal state* be used to describe the syndrome (NSDOJ, 2009).

The phenomenological presentation of ExD syndrome has been described historically in the psychiatric literature beginning in the mid-1800s and has been variably labelled as acute exhaustive mania, acute behavioural disorder, Bell's mania, fatal catatonia, acute lethal excitement, acute exhaustive syndrome, acute delirium, and manic-depressive exhaustive death (Adland, 1947). A 1947 study noted greater incidence in women and individuals aged 18 to 35 than in other populations, and that it resulted in death in about 75 per cent of cases (Adland, 1947). Historically, scientific reports on this state decreased substantially when phenothiazine medications were introduced in the treatment of acute psychiatric illnesses (Cancro, 2000). Reports appeared again in the 1980s where ExD syndrome was described in association with ingestion of illicit substances, especially cocaine (Wetli & Fishbain, 1985), methamphetamines (Vilke *et al.*, 2012a), and phencyclidine (PCP) (Yago *et al.*, 1981). Additionally, a number of other conditions associated with adverse effects arising from side effects of anti-psychotic medications (Neuroleptic Malignant Syndrome) (Caroff & Mann, 1993) and anesthetics (Malignant Hyperthermia) (Ali *et al.*, 2003) present with similar symptoms. Other definitions of similar phenomena known in the psychiatric literature include malignant (fatal) catatonia (Francis, 2010) and acute delirious mania (Lee *et al.*, 2012). The well-documented state of acute alcohol withdrawal, delirium tremens (DT), also includes similar signs and symptoms (Carlson *et al.*, 2012).

While various hypotheses exist about the cause of the above states, no simple explanation of their cause or progression has been conclusively demonstrated. In all of the above states, death as an endpoint is commonly reported. There is no definitive cause attributed to ExD syndrome, although some research suggests it may result from the complex relationships involved when a number of factors are present, including psychiatric illness (such as schizophrenia or mania), intoxication with illicit substances (such as cocaine or PCP), head trauma, and alcohol withdrawal (Samuel *et al.*, 2009). Some research has also suggested chronic abusers of illicit substances may be more predisposed to ExD syndrome (Mash *et al.*, 2009). Autopsy studies of chronic cocaine abusers who died with or without symptoms of ExD have led to the suggestion that ExD victims may represent a special sub-group of cocaine users who have different neurological responses following long-term use of the drug (Mash *et al.*, 2002, 2003). ExD syndrome-related deaths are commonly clinically associated with rhabdomyolysis, hypoxia, agitation-related acidosis, and pre-existing heart conditions (Strote & Hutson, 2006). The condition has also been linked to an overstimulation of the sympathetic nervous system and an abundance of hormones including catecholamines, such as adrenaline and dopamine (Mash *et al.*, 2002; NIJ, 2011). A number of these factors are also found at increased frequency in cases of sudden in-custody death (Stratton *et al.*, 2001). Further complicating the matter is the observation that sudden in-custody death can occur following a struggle with law enforcement officers where the subject is placed in a restraint position that may impair his or her ability to breathe (restraint asphyxia) (Di Maio & Di Maio, 2009). The relationships between restraint asphyxia, ExD syndrome, and sudden in-custody death are currently not well understood.

Because ExD syndrome involves violent, erratic, unpredictable, and combative behaviour, it is often associated with a struggle and physical restraint of an individual applied by law enforcement or medical personnel (Di Maio & Di Maio, 2006; Hall *et al.*, 2013). This restraint is sometimes supported by the use of CEWs. When cases of ExD syndrome coupled with CEW use have culminated in in-custody death, some researchers have argued CEWs could not serve as a sole reason for death but may play contributory roles in concert with a number of other risk factors (Jauchem, 2010). Others have argued that the death of individuals who experienced both ExD syndrome and CEW exposure was a coincidence (Di Maio & Dana, 2007). This argument is founded in the notion that death occurring during an ExD state (or other similarly described states labelled with different diagnostic terms) in the absence of CEW deployment was well recognized for a century or more before the introduction of CEWs (Adland, 1947; NSDOJ, 2009).

Simultaneously, however, concerns have been expressed that CEW deployment may result in undue or additional harm in cases of individuals experiencing ExD syndrome (Miller, 2007). Questions have been raised around the deployment of CEWs on individuals who may be experiencing ExD syndrome, particularly in mental health settings (O'Brien *et al.*, 2007). Some authors have called for guidelines prohibiting the use of CEWs on mentally ill individuals (SCJC, 2006), and others have questioned whether the deployment of CEWs on individuals with psychotic disorders is ethical (Erwin & Philibert, 2006). These concerns have been raised in the absence of substantive data to allow determination of the relationship between ExD syndrome, CEW use, and sudden in-custody death. Additionally, these analyses have not addressed the comparative difference between rates of sudden in-custody death in ExD syndrome with CEW use and rates of sudden in-custody death in ExD syndrome with other forms of restraint. It is also possible that CEWs discharged in the presence of ExD syndrome may have protective effects, since the CEW discharge could result in allowing law enforcement or medical personnel to more rapidly provide needed therapeutic interventions that could actually decrease the risk of death associated with the ExD syndrome.

Given the nature of the available information, it is not possible to determine if, and to what degree, the use of CEWs increases or decreases the probability of sudden in-custody death in the presence of a state of ExD (or an acute hyperarousal state). The literature also does not present any conclusive knowledge on the proportional risk of using CEWs versus other forms of restraint in the context of ExD syndrome.

6.5 SUMMARY

Sudden in-custody death refers to rapid, unexpected death during detention of individuals by law enforcement or public safety personnel. These fatalities typically occur during complicated scenarios that may include agitation, physical or chemical restraint, disorientation, stress or exertion, pre-existing health conditions, and the use of drugs or alcohol, all of which can potentially contribute to the death. This makes it difficult to isolate the contribution of any single factor. Although evidence shows the electrical characteristics of CEWs can potentially contribute to sudden in-custody death, no evidence of a clear causal relationship has been demonstrated by large-scale prospective studies. In a few coroner reports, however, CEWs were ruled as the primary cause of death in the absence of other factors and when excessive exposure was present. Conversely, it has been argued that CEWs could potentially play protective roles in stopping situations that may otherwise culminate in sudden in-custody death. Given the limitations and scarcity of the evidence, a clear causal relationship between CEW use and sudden in-custody death cannot be confirmed or excluded at this time. In addition, there is insufficient evidence to determine whether the use of CEWs increases or decreases the probability of sudden in-custody death in the presence of co-factors such as mental illness or ExD syndrome. If a causal relationship does exist, the likelihood that a CEW will be the sole cause of a sudden in-custody death is low. The extent to which the device would play a role in any death is unclear and dependent upon the co-factors involved. Further research is needed to better define these relationships.

7

Gaps in the Evidence on the Physiological and Health Effects of Conducted Energy Weapons

- Confidence in Establishing Direct Causal Relationships
- Identifying Length of Time Needed to Establish Probability
- Understanding Health Effects on Varying Populations
- Lack of Standardization of Reporting and Record-Keeping Practices
- Insufficient Funding of Independent CEW Research

7 Gaps in the Evidence on the Physiological and Health Effects of Conducted Energy Weapons

Key Findings

- It is difficult to establish the extent to which CEW exposure could act as the primary cause of severe adverse health effects in real-world settings due to the challenge of weighting the contribution of the multiple factors.
- The length of time between discharge and health effect necessary to suggest a probable CEW-related injury or death is unclear, although probability diminishes over time.
- There is a lack of knowledge about the health effects associated with CEWs outside controlled settings and within varying, potentially vulnerable populations. CEW research typically involves healthy, physically fit volunteers.
- Use-of-force record-keeping and reporting practices are currently not standardized across varying agencies. This means detailed and consistent information on the characteristics of the subject and the events surrounding a use-of-force incident are not collected in a comparable manner, if at all, leading to a lack of large-scale population-based field studies and surveillance.
- There is a lack of transparent, independent research on a range of CEW devices and their health implications.

The Panel's review of the evidence in previous chapters has demonstrated that many key issues have not been fully explored across varying populations or in the operational settings in which conducted energy weapons (CEWs) are actually deployed, thus pointing to several priorities for future research:

- To what extent can the electrical characteristics of CEWs cause cardiac arrhythmia `and sudden in-custody death in humans when deployed in real-world operational settings?
- Are certain groups or individuals with particular conditions at increased risk for adverse outcomes related to CEWs, and if so, what are the key co-factors?
- What CEW design and deployment features could minimize the risk of adverse health effects?

The Panel has outlined various suggestions for the specific types of research studies needed to address these questions more fully in the relevant chapters presented thus far. This chapter identifies and explores five overarching gaps in knowledge and evidence concerning the health-related effects of CEW use, along with related challenges in funding, conducting, and interpreting CEW research. The Panel feels the following gaps are of equal importance for understanding the state of the literature and places no emphasis on one over another. In addition, these gaps and other research questions related to appropriate testing, approval, and use of CEWs, and appropriateness of CEWs in relation to other use-of-force interventions, need to be considered to make informed decisions about public health, policing, and CEW policy.

7.1 CONFIDENCE IN ESTABLISHING DIRECT CAUSAL RELATIONSHIPS

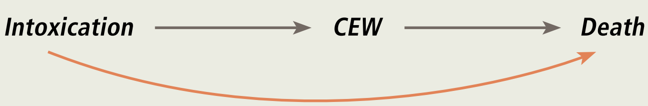
Establishing causality is not a simple task in any situation without an experimental research design, and the concept and definition of causation elicit continuing debate among philosophers, scientists, and medical experts alike. While some evidence demonstrates an association between CEW exposure and certain health effects, and other research does not, the effects of chance, error, bias, or confounding factors may provide a number of possible explanations regarding those relationships (or the lack thereof). An observed association does not necessarily mean one variable causes the other, and the lack of an association does not necessarily mean a causal relationship is absent. Laboratory-based experimental study designs can help establish causation because of their ability to control the context in which the study is taking place. For example, in a randomized controlled trial using study participants who are reasonably healthy and mentally sound, the circumstances surrounding the CEW exposure can be as controlled as possible and the experimental measurements can be made immediately. This kind of study would, however, have questionable real-world relevance.

In the real world, because many factors are usually present, it becomes much more complicated to establish the extent to which one specific cause may contribute to an event. What is identified as a cause will sometimes only operate under conditions where numerous other conditions are in effect. Or, there may be several factors, each of which has the potential to act as a cause for a particular effect when they coincide in time and space (Rothman & Greenland, 2005). It is highly unlikely that a CEW will be the only factor having the potential to lead to adverse outcomes in a use-of-force scenario. There may also be complex interactions between CEW exposure and co-factors such as drugs or restraint characteristics. For example, many investigations have focused on the ability of a CEW to induce a potentially fatal cardiac arrhythmia. Although not fully investigated, it is also possible that, rather than directly causing death, the CEW may interact with an existing co-factor, such as a cardiac condition or intoxication with a stimulant, which could contribute to the arrhythmia. If this is the case, although the cause (CEW exposure) may not be *sufficient* to induce death on its own, removal may result in prevention of death. Similarly, it is also possible that the CEW has no adverse influence, and the subject's death still occurs in a similar situation when the CEW is not present. In that case, removing the CEW from the equation may not prevent death; instead, death may be completely attributable to one or more co-factors, such as drug intoxication. The ability to distinguish between these two cases represents a major challenge for CEW research. Simply put, when so many potentially harmful factors are present during a CEW incident, it is challenging to weight the relative effect of each. Box 7.1 further illustrates the complicated nature of establishing causality and this degree of uncertainty.

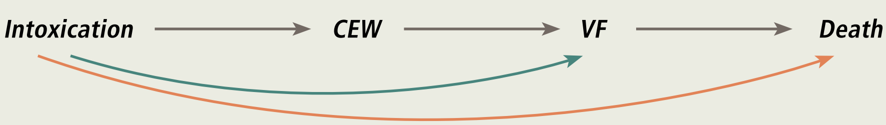
Box 7.1
Establishing Causal Inference for Conducted Energy Weapons

Consider a hypothetical randomized controlled trial, whereby researchers are able to control a range of factors, allowing the researchers to directly assess the relationship between CEW discharge and an outcome, as demonstrated by the following diagram:

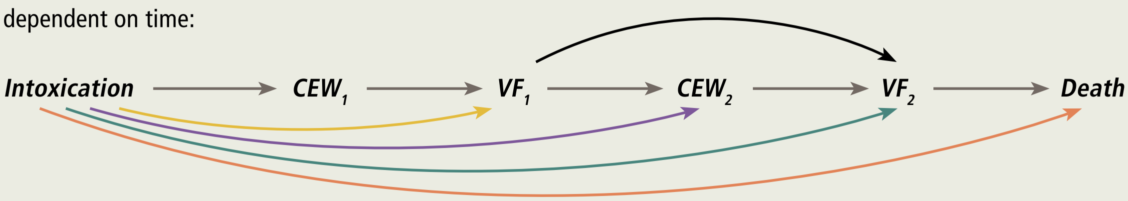
Consider a co-factor that is common to CEW incidents, such as drug intoxication. This co-factor could increase the probability of someone being exposed to a CEW, and is also associated with morbidity and mortality irrespective of CEW exposure. The diagram of the causal pathway would change to the following:



In this relationship, controlling for the effects of the co-factor (intoxication) is relatively straightforward using standard regression techniques to get an estimate of the causal effect of the CEW on death. But, imagine that this same co-factor could change the threshold for induction of ventricular fibrillation, in which case intermediate variables are introduced along the potential causal pathway. The diagram now changes to the following (VF represents ventricular fibrillation):



Imagine adding another potential co-factor, such as receiving multiple CEW exposures, which make the intermediary variables now dependent on time:



In these cases, it is no longer appropriate to apply standard regression techniques. Instead, estimating the causal link of CEW exposure to death, in the context of time-dependent exposures in the presence of time-dependent covariates (that may be simultaneously initial co-factors and intermediate variables), requires marginal structural models, which use inverse probability weighting (Robins *et al.*, 2000), or other sophisticated methods (Petersen *et al.*, 2006). A further complication is that these diagrams are largely incomplete because they do not include the full range of potential co-factors and the time dependencies. With so many factors at play over a given time period, it becomes challenging to weight the relative effect of each factor, including CEW exposure.

7.2 IDENTIFYING LENGTH OF TIME NEEDED TO ESTABLISH PROBABILITY

Currently, no guidelines are in place to specify the length of time needed between CEW discharge and a health effect in order to suggest the CEW was likely responsible for that effect. CEW-induced collapse due to ventricular fibrillation illustrates this ambiguity. The prevailing opinion in the review literature and various studies is that for a temporal relationship to exist, collapse should occur within seconds to several minutes of a CEW discharge in order for the CEW to be a factor in the collapse (Brewer & Kroll, 2009; Swerdlow *et al.*, 2009; NIJ, 2011). The medical reasoning behind the exact cut-off times used in this research is, however, not fully clear. Although several theoretical mechanisms for delayed onset ventricular fibrillation following CEW exposure have been suggested, they are considered unlikely (Dosdall & Ideker, 2009).

Rather than consider the issue of timing in a dichotomous manner (that is, there is a time beyond which ventricular fibrillation and subsequent collapse can no longer be attributed to a CEW), it may be beneficial to consider a probability continuum based on the time of the outcome post-discharge. As time of outcome moves farther away from time of deployment, the probability that a CEW was directly responsible for collapse decreases, but does not suddenly decrease from high to low probability at a certain cut-off point. This probability continuum would also be influenced by the various co-factors involved in the situation, which may themselves have time dependencies (e.g., the effects of drug intoxication may affect the body longer than effects of physical restraint). Although a particular cut-off point may exist, the evidence does not allow for a realistic point to be established at this time.

7.3 UNDERSTANDING HEALTH EFFECTS ON VARYING POPULATIONS

7.3.1 Ethical Considerations

There are many ethical principles and guidelines that have been established for medical research involving human subjects (WMA, 2008; HC, 2009) and research in general (Tri-Council, 2010). However, there is little ethical guidance for research involving weapons deployed on human subjects and little academic discussion of this topic. Ethical challenges and lack of guidance on how to deal with them have created a gap in evidence related to laboratory-based experimental research on the health effects of CEWs across varying populations.

A central ethical challenge in researching the health effects of CEWs is the balancing of risk and potential benefit (Tri-Council, 2010). For research to be ethically sound, the potential benefits must outweigh the potential harms of conducting that research (HC, 2009). For animal studies, experiments must be designed to minimize pain and distress and, if they cannot be minimized, the value of the study must be determined by independent external evaluation (CCAC, 1989). In human studies, although precise policies vary from country to country, the widely held view is that very small or minimal risks can be considered acceptable even if the experimental intervention is not intended to benefit the individual; however, for risks that are considered greater than minimal, the prospect of direct therapeutic benefit to the participant must exist (HC, 2009; Bos *et al.*, 2012).

There are no clear rules for assessing minimal risk, potential benefits, and their relationship to each other in a reliable way. Evaluating the level of risk is a difficult task because identical protocols and related risks can be interpreted differently across review mechanisms and because there is a subjective element in determining risk and benefit that can lead to varying individual experiences of identical protocols (Bos *et al.*, 2012). In addition, both the severity (e.g., ranging from no danger to possible irreversible damage) and the probability (e.g., ranging from cannot be excluded to probable) must be considered in assessing risks and benefits (Helmchen, 2012). From limited CEW research involving healthy individuals, available studies suggest the severity of potential harm would be considered high, but the probability of experiencing an unintentional adverse health outcome would be low (although it should be noted that a painful, unpleasant outcome will always be experienced due to the nature of CEW field research). An individual will likely not directly benefit from CEW exposure in an experimental trial because it is not an intervention aimed at treating a pre-existing condition. The benefit of conducting CEW research where the device is deliberately applied to a subject exists only on the social or community level (i.e., advancement of knowledge regarding the possible adverse health effects of CEWs to prevent injuries or fatalities). Such research (i.e., the intentional application of a CEW for the specific reason of evaluating related health outcomes) in a population with a potentially higher probability of experiencing an adverse health outcome would not be acceptable.

In addition to assessing risk and benefit, the ability to obtain informed consent from research subjects is another important ethical consideration. Informed consent refers to an ongoing indication of agreement by an individual with the capacity to participate in a research project, after the individual has been provided with all of the information necessary for making an informed decision. In addition, research participants must be free from undue influence or manipulation that may arise when subjects are recruited by individuals in a position of authority (Tri-Council, 2010). In the context of CEW research, obtaining informed consent could be challenging when dealing with populations who might not have the capacity to provide consent. Even with populations consisting of healthy law enforcement volunteers, there could be pressure to participate in order to fit in with colleagues.

Considering these ethical challenges in conducting experimental laboratory-based human studies, CEW research has generally focused to date on healthy anesthetized pigs and healthy human volunteers (Adler *et al.*, 2010). This has created a gap in knowledge related to physiological and health effects among varying, and potentially vulnerable, populations often involved in use-of-force encounters. Some population-based epidemiological field studies have attempted to fill this gap and hold promise for identifying health effects across varying populations (Jenkinson *et al.*, 2006; Bozeman *et al.*, 2009b; Strote *et al.*, 2010a). These studies face a range of technical challenges, however (see Section 7.4), and must abide by other ethical considerations such as provincial laws and the federal *Personal Information Protection and Electronic Documents Act* (PIPEDA), which place limits on the collection and use of anyone's personal and medical information. PIPEDA (and most provincial privacy laws) does allow for the collection and use of personal information for the purposes of research without that person's consent if certain conditions are met, such as: it is for research purposes; the research cannot be conducted without that information; the use of the information ensures confidentiality; and it is impractical to obtain consent (DOJ Canada, 2011). Although currently lacking, well-designed population-based studies on the health effects associated with police use-of-force events — a part of which involves CEW deployment — could easily meet all of these criteria and will be discussed in more detail in Chapter 8.

7.3.2 Defining and Ethically Researching Vulnerability

The gap in knowledge related to physiological and health effects of CEWs among vulnerable populations is further exacerbated because defining vulnerability is not a straightforward task. It is difficult to agree on a definition of vulnerable populations that is applicable to any given situation, and many populations may be considered vulnerable based on physical, mental, social, cultural, or economic differences (HC, 2009). In the context of CEWs, vulnerability can be considered across a number of dimensions. Certain groups may be more likely to have interactions with police than others, or may be more likely to experience a CEW discharge during those interactions. Specific groups may also be more susceptible to the occurrence of certain health effects or to more severe health effects than other groups. Depending on which dimension is explored, socio-economic, psychosocial, or physiological aspects may take precedence in determining vulnerability.

The populations that are over-represented in real-world CEW use statistics include young men (average age in the low 30s), those with a history of alcohol use or drug use, and/or those with a mental illness (Bozeman *et al.*, 2009b; Strote *et al.*, 2010b). Almost 50 per cent of individuals who are subjected to CEWs have a psychiatric history, and more than 70 per cent have a history of drug or alcohol abuse (Strote *et al.*, 2010b). There is also speculation that these groups may face an increased risk of harm following CEW exposure, compared to other adults. One study comparing media reports of fatal and non-fatal CEW incidents suggested death was nearly twice as likely to occur following CEW exposure when the subject was emotionally disturbed or mentally ill and four times as likely when drug use was present (White & Ready, 2009). Because the study combined emotional disturbance and mental illness, it is difficult to isolate the effect of each condition. Another retrospective study indicated that CEW-proximate deaths typically occur in subjects who are under the influence of drugs or alcohol (53 per cent), show evidence of chronic drug use (87 per cent), or are described as mentally ill (20 per cent) during the incident (White *et al.*, 2013). A caveat for both of these studies is that source data may be inconsistent because media reports were used to generate many of the statistics. Furthermore, it is not surprising that emotionally disturbed, mentally ill, or intoxicated individuals are over-represented in a sample of people who die following CEW exposure, since it has been demonstrated that these groups are also more likely to be exposed in the first place (O'Brien *et al.*, 2011) and that they have greater risk for sudden unexpected death, even in the absence of any CEW discharge, compared to other groups (White & Ready, 2009).

A common theme in the CEW review literature is the speculation that certain groups — such as pregnant women, the elderly, children, and individuals with implantable cardiac devices — are potentially vulnerable during exposure to electrical impulses (Hancock & Grant, 2008; Adler *et al.*, 2010). Although CEW literature often speculates on potentially vulnerable populations, no risk assessment structure, data, or methods seem to be in place to quantify the nature or magnitude of the putative increased risk faced by these populations. CEW research on vulnerable populations in a laboratory setting is unlikely to be approved by an ethics committee for a number of reasons related to informed consent from certain populations, lack of direct therapeutic benefit to an individual, the presence of pain (which could be considered a harm) and an unacceptable risk-benefit ratio. These types of studies would also not represent the actual circumstances that make up a dynamic police use-of-force encounter. One alternative involves simulating the vulnerable condition, such as alcohol intoxication, in the laboratory on healthy subjects who are able to give informed consent before reaching a vulnerable state.

For populations whose vulnerability cannot be simulated, such as mental illness, it will likely be necessary to perform large-scale population-based field studies that involve detailed and consistent collection of information on the characteristics of the subjects and the events surrounding the CEW incidents. Data collection for population-based studies requires a lot of time and study across a large population of interest to correctly identify risk profiles. However, difficulties in spotting certain characteristics in field settings and privacy restrictions prevent access of data on certain populations (e.g., minors), particularly in cases of police interaction, and this hinders epidemiological studies. In addition, some individuals, particularly those with implantable cardioverter defibrillators (ICDs) and those who are pregnant, represent a small segment of those involved in use-of-force incidents and an even smaller subset of those experiencing CEW deployment; therefore, it will be challenging to collect enough data for population-based analyses. For these reasons, population-based studies capturing real-world CEW scenarios and subject characteristics, including vulnerable populations, are lacking.

7.4 LACK OF STANDARDIZATION OF REPORTING AND RECORD-KEEPING PRACTICES

Since municipal, provincial, and federal agencies in Canada do not use a standard definition of a use-of-force event, it is impossible to compare these events and related health effects among police agencies and challenging to develop population-based studies. There is also little standardization in the characteristics and features recorded after use-of-force interventions and there are few central registries with standardized recording of CEW incidents by law enforcement or medical personnel. Records are therefore inconsistent in how they distinguish an intervention as a use-of-force event, the type and duration of force used, the circumstances leading to the intervention, the outcomes of the intervention, and the characteristics of the subjects involved. These inconsistencies make it difficult to evaluate the characteristics within or surrounding the use-of-force event that may be associated with specific health outcomes.

Inconsistent and non-standardized reporting arises in Canada partly because the governance of law enforcement agencies is split across municipal, provincial, territorial, and federal governments. Within this oversight structure, each individual law enforcement agency has its own use-of-force reporting structure and content, which may be different from agencies in other jurisdictions. For example, in some provinces the definition of a use-of-force event can involve hard physical control (i.e., physical force above a simple joint lock application), and these events are routinely recorded even if no additional use-of-force measures are used or if no injury results from the encounter. In contrast, this same intervention (hard physical control) is only recorded in other provinces if an injury results from the encounter. In addition to country-wide inconsistencies, complications may also arise within a single province. For example, recent efforts by the Solicitor General's Office in Alberta to standardize police use-of-force reporting across the province (GOA, 2011) has been met with varied responses, with some agencies participating and others opting out (C. Hall, personal communication, 2013).

At the federal level, the Royal Canadian Mounted Police (RCMP) collects routine information on use-of-force events on an ongoing basis using the Subject Behaviour/Officer Response (SB/OR) Reporting System — a standardized method for recording subject behaviour and the use of interventions (CPC RCMP, 2012). The information collected includes details on force modalities, the nature of the event, and the characteristics of the subject involved. RCMP data for a province, however, are not comparable with data collected by municipal and provincial agencies in that province. Scientifically robust comparisons are limited by these reporting differences.

This lack of standardization is not unique to Canada. In the United States, some information is available from the U.S. Department of Justice (USDOJ) Bureau of Justice Statistics report on arrest-related deaths; however, reporting of U.S. CEW-related incidents, injuries, or use is not standardized. The reasons for this appear to be many. There is no centralized controlling agency that regulates or authorizes these weapons to be used nation-wide. Decisions about deployment are left up to individual police agencies.

With many thousands of U.S. police agencies, including multiple agencies in the same city often attending the same incident, there is no routine standardization, sharing, or even reporting of use-of-force statistics. Collection of this data requires resources, and there are no predetermined funding mechanisms to support this activity, though the USDOJ has supported this kind of research through the National Institute of Justice, albeit limited in scope and scale (Smith *et al.*, 2010; NIJ, 2011). The perception seems to be that collection and subsequent reporting of data that may suggest an injury is the result of a police agency's CEW use could lead to civil liability.

In the United Kingdom, the Home Office in England and Wales has collated data on the use of CEWs since the original operational trial of the TASER® M26™ in 2003. Limited data are captured after every CEW incident (i.e., the device is drawn, aimed, laser-sight activated, arced, drive stunned, or fired in probe mode) and returned to the Home Office and the Association of Chief Police Officers. These data do not currently include detailed medical data, although calls have been made to establish such a process (Payne-James *et al.*, 2010). A 2011 decision to transfer the collection and collation function between Home Office units, and simultaneously update the database software, resulted in the stoppage of the quarterly publication of these data, with the last figures being published up to March 2010 (Home Office, 2010). More recent data were expected to be published in 2013, and periodic updates were supposed to then re-commence (G. Smith, personal communication, 2013). In addition, comparing U.K. and North American policing is challenging because of the differences in police agency scope and practices, along with definitions of use-of-force.

Across police agencies worldwide, differences also exist in how a CEW deployment is defined and which characteristics of the deployment are recorded. For example, some agencies record a CEW deployment as having occurred as soon as the laser light sighting beam is activated, since that alone may engender subject compliance. Other agencies record it only when a subject receives an actual charge. Most police agencies do not record the actual location of the CEW contact points on the subject's body, which is important information for assessing the potential link between probe placement (e.g., transcardiac deployment) and certain health complications.

The current recording of sudden in-custody deaths in Canada does not enable focused evaluation of the situations in which deaths have occurred, whether a CEW was or was not involved; this limits the ability to interpret these events. The current Statistics Canada method of reporting all custodial deaths does not allow for an evaluation of police use-of-force events that do and do not culminate in sudden unanticipated death of the subject. This is because of the lack of discrimination between natural, suicidal, and unexplained deaths in penal institutions and those that occur unexpectedly on the street during a use-of-force encounter. Instead, reporting focuses solely on providing an annual count of all custodial deaths.

Device testing is also currently not standardized in Canada. Even if the characteristics of use-of-force events are recorded consistently, health outcomes may still not be comparable if researchers are unable to assess whether the CEWs used in these events were functioning in a similar manner and according to the intended specifications. Research indicates the potential for varying operating and performance parameters between devices of the same model, especially pulse repetition rates. Parameters such as the type of battery used in the device and the load resistance that the device is fired into can significantly alter the results obtained during a CEW test (Adler *et al.*, 2013). Weather conditions and temperature can also lead to CEWs misfiring and variable testing results that do not meet industry operational specifications (NDC, 2013). Some research has attempted to define and articulate testing protocols for CEW devices (Adler *et al.*, 2013), yet there is little evidence of regular and standardized testing of CEWs across agencies in Canada and other countries. Although it would likely still be challenging to account for different circumstances surrounding individual use-of-force events, a systematic protocol for testing the electrical output of CEWs would help to ensure that each event involves devices that are performing according to intended standards.

7.5 INSUFFICIENT FUNDING OF INDEPENDENT CEW RESEARCH

In any research study, a potential conflict of interest occurs if a profit-seeking organization with a vested interest in the outcome of a particular study is providing funding for the study. For individual researchers, a conflict of interest may arise when the responsibilities related to research are in conflict with the personal, business, or financial interests of a researcher. When researchers investigate products for which they receive payment or other benefits, their judgment surrounding ethical design and conduct of the research and the interpretation of its results may be distorted (Tri-Council, 2010). It is therefore important for researchers to ensure transparency and disclose the funding source for a study as well as information on their connection to any relevant organizations. Declaration of such a conflict does not nullify study findings, but additional scrutiny on the part of the reader is warranted to evaluate the objectivity of the study and to detect possible biases that affect the interpretation and application of the results.

Much of the CEW research has been performed using two devices manufactured by TASER® International: the X26™ and the M26™. Other devices, such as the TASER® X2™ and X3™, the Karbon MPID™ manufactured by Karbon Arms®, and the Mark 63 Trident™ made by Aegis® Industries, are also used by law enforcement or civilians in jurisdictions around the world, but technical specifications and health effects are not evident for these models. Literature reviews have noted that TASER® International, the manufacturer of the popular TASER® CEW models, has funded a number of the studies on the effectiveness of the devices (Adler *et al.*, 2010). Some researchers have specifically examined the phenomenon, reporting that 23 of the 50 studies (46 per cent) in their literature sample were disclosed as TASER®-funded or TASER®-affiliated, and that these studies had 17.6 times greater odds than independent studies to conclude that a TASER® is safe (Azadani *et al.*, 2011). While this does not necessarily indicate that the results of any given TASER®-affiliated study are biased, it could reflect selective publishing of research supporting the safety of the devices by TASER® International. Similarly, research indicating possible harmful effects of CEWs may be preferentially authored by those who stand to benefit from criticizing manufacturers (financial gain through legal consultancy, building academic careers, speaking engagements, etc.), although there is no scientific evidence available to confirm such allegations. Furthermore, any bias could be the result of the framing or shaping of the actual research questions, which may be more likely to lead to certain conclusions even if the integrity of the research is sound.

Regardless of whether bias is present, an author who has any relationship or perceived relationship, including an adversarial one, with manufacturers does have a potential conflict of interest that should be disclosed to improve transparency and allow readers to interpret the results of the work. In the Panel's review of the literature it was often difficult to ascertain whether a conflict was present, and this lack of transparency made interpretation of study findings challenging.

Declaration of funding is also beneficial when industry funds are donated to agencies that support research initiatives, a less likely but still indirect source of possible conflict. For example, the International Association of Chiefs of Police has supported and released a number of reports involving the appropriate selection, procurement, and use of CEWs, but has also received large donations from CEW manufacturers (Johnson, 2012). These sources of funding must be declared to allow interpretation of studies completed with agency support. While industry-funded studies are important and can still be accepted when scientifically robust, there is a gap in the CEW evidence related to independent CEW research from organizations without financial or other ties to the CEW industry, as well as from researchers who do not profit from criticism of the CEW industry. Transparency and independence in the creation of questions and the exploration of those questions will be important to build a strong body of knowledge related to CEWs in the future.

8

Integrated Strategies to Address Gaps in the State of Evidence on Conducted Energy Weapons

- Standardizing and Centralizing the Recording of CEW Incidents
- Enabling Comprehensive Medical Assessment Following CEW Exposure
- Improving Access to, and Sharing and Integration of, Knowledge Across Fields
- Supporting Large-Scale, Multi-Site, Population-Based Studies
- Improving Understanding of CEW Risk Relative to Other Use-of-Force Interventions
- Understanding Specifications of CEWs Manufactured by a Range of Companies
- Furthering Ethical Laboratory-Based Experimental CEW Research

8 Integrated Strategies to Address Gaps in the State of Evidence on Conducted Energy Weapons

Key Findings

- CEW research gaps can be addressed through a series of integrated strategies that support increased surveillance and large-scale, prospective population-based epidemiological study, as well as continued ethically conducted laboratory-based experimental research.
- Standardized and centralized recording of CEW incidents, underpinned by comprehensive and innovative medical testing immediately following an incident, would improve the quality of future research on the health implications of CEW exposure.
- CEW evidence would be strengthened by ethically and responsibly improving access to, and sharing and comparability of, information related to CEWs and other use-of-force interventions. Emphasis on better understanding of the risk of CEWs in relation to other interventions would also help.
- More robust and objective research on varying device specifications and performance standards of CEWs would improve understanding of their health effects.

The Panel was challenged to identify research that would address the knowledge gaps related to the physiological and health effects of conducted energy weapon (CEW) use. As demonstrated in previous chapters, although current research indicates an association between CEWs and various physiological and health effects, a number of possible explanations may exist to explain these relationships due to the limitations of the research and the effects of confounding factors. Subsequently, the Panel identified specific research questions and overarching gaps in Chapter 7. The Panel feels that answering these questions can be achieved through a series of integrated strategies underpinned by improved surveillance, monitoring, and reporting as well as population-based epidemiological study. This chapter proposes a number of considerations that could form the basis of this integrated response.

8.1 STANDARDIZING AND CENTRALIZING THE RECORDING OF CEW INCIDENTS

Standardizing Reporting

The first step in understanding and comparing use-of-force events generally, and CEW use more specifically, would be to establish a common definition of a use-of-force event. Then, implementation of a standard method of reporting, to enable police and medical personnel to record a minimum level of information, would ensure the same details were recorded for each event and make it possible to compare various parameters at the population level. In Canada this process would need to engage law enforcement, public safety, and medical personnel working at federal, provincial, territorial, and municipal levels, and could only be achieved through collaboration and cooperation. Standard forms for both law enforcement and medical personnel to complete, and a method of linking the information about the CEW incident and the health status of the subject, would enable investigators and improve the quality of information produced. Standardization of reporting would also help improve the knowledge base of other jurisdictions outside of Canada.

Creating a Central Repository of Use-of-Force Events in Canada

Understanding the prevalence of, and the specific factors that predict, health complications requires the capability to evaluate police use-of-force events that do and do not culminate in adverse health conditions such as sudden in-custody death. This capability would be supported by a Canada-wide registry of use-of-force events, which would quantify the number of health complications. This would enable focused evaluation of the situations in which adverse health effects occur whether or not a CEW was involved, and limit the effects of reporting and recording bias in the interpretation of use-of-force events. A data sample across a large cohort of consecutive and consistently recorded events would capture adverse events and be adequately powered to evaluate scientific connections by co-factor or event characteristics (e.g., number of discharges, subject characteristics) and outcome (e.g., sudden in-custody death, major injury) if those connections consistently existed.

8.2 ENABLING COMPREHENSIVE MEDICAL ASSESSMENT FOLLOWING CEW EXPOSURE

Engaging Medical Personnel in Assessing Effects

Not all individuals exposed to a CEW or other use-of-force intervention require medical care or treatment following the event. Nonetheless, when subjects are brought to the hospital for evaluation, health care professionals most likely to engage with these subjects (e.g., emergency room physicians) would benefit from guidance on the effects of CEW deployment characteristics and the specific physiological changes and injuries most relevant to assess as part of providing patient care (e.g., the presence of metabolic acidosis, rhabdomyolysis, cardiac arrhythmia, spinal injury, musculo-skeletal punctures). With knowledge of the relevant co-factors and potential complications of

CEW exposure, health care professionals could more routinely perform detailed medical examinations relevant for evaluating physiological effects of CEW exposure, such as tests that capture medication or drug use, medical history, imaging of musculo-skeletal injury, or electrocardiography. Beyond potentially improving the quality and responsiveness of patient care, more consistent medical testing would have the added benefit of improving surveillance efforts involving the effects of CEWs more broadly.

Using New Technologies to Aid in Testing Procedures

If a CEW is responsible for inducing certain health outcomes such as cardiac arrhythmias, the prevailing opinion in the literature is that these conditions should occur within seconds to a few minutes of discharge. In the field, cardiac monitoring usually occurs several minutes after the last CEW discharge (Swerdlow *et al.*, 2009). A technology that allows for instant, automatic recording of heart rhythm following CEW exposure would help establish whether the CEW was responsible for any rhythm disturbances. For example, it would be useful if the CEW darts themselves were able to record electrocardiography data once they had been deployed and lodged into a person's body. In addition, video recording technology could be built into the device to capture circumstances involved in the CEW deployment (such video attachments are already in use in certain devices (NSWO, 2008)).

8.3 IMPROVING ACCESS TO, AND SHARING AND INTEGRATION OF, KNOWLEDGE ACROSS FIELDS

Improving Access to Records

Access to medical and law enforcement records is guided by privacy regulations. Exploring the relationship between CEWs and health outcomes requires examination of law enforcement records and pre-hospital, emergency room, and other medical records. Research protocols and review processes that are respectful of the need for privacy, yet still enable research of use-of-force events and health effects, would be helpful for the research community. For example, current restrictions do not allow researchers to access the records of minors, an important sub-population. To establish associations or cause-and-effect relationships between CEWs and health outcomes, and to lend support to further population-based studies that would advance understanding, researchers would benefit from access to as much information as is ethically and reasonably possible. Data should be presented in aggregate form to respect the privacy of individuals.

Sharing of Information

Currently, there is little to no linking of data between law enforcement agencies and hospitals, and often the data collected can be of little medical use. No formal linkage procedure exists for the tracking of police calls that progress to hospital visits following incidents involving CEWs or other uses of force. Data are also not linked between law enforcement agencies or between health care practitioners (although provincial health card numbers can be used to confirm health records). A lack of sharing of information between law enforcement and health provider agencies limits the examination of physiological and health effects of CEWs in Canada. Law enforcement agencies in Canada do not have jurisdictional authority to access medical records of subjects, and cannot follow up on the specific outcomes of police use-of-force events or CEW deployments unless the subject specifically allows such follow-up and provides the information. Similarly, general duty medical practitioners do not have access to law enforcement records or information beyond what is transferred during initial presentation to a health care facility. Except under the auspices of a research protocol, the physiological and health effects experienced by a subject exposed to a CEW cannot therefore be followed comprehensively by either group.

In other jurisdictions, such as the United States, law enforcement agencies have medical advisors who participate in the investigation of subject injuries or complaints and can gain access to the medical records to facilitate more integrated record-keeping. Canada could benefit from these types of initiatives. Linking information about different use-of-force modalities, and how they affect the health of individuals, could encourage investigation of a range of relevant phenomena and increase the number of high-quality publications.

Improving and Sharing Knowledge Across Disciplines

Some of the physiological and health effects experienced by individuals who are exposed to CEWs are not well studied themselves; therefore, it is difficult to hypothesize why or how they might play a role in a use-of-force incident. For example, excited delirium syndrome remains controversial, and challenges related to diagnosis can also make it challenging to study its relation to CEW exposure. Research also demonstrates that individuals with mental disorders are more likely to experience cardiac complications than individuals without these disorders, yet the reasons for this increased risk are unclear (Bensenor *et al.*, 2012; Chauvet-Gelinier *et al.*, 2013). Acquiring additional information on these relationships, along with the sharing of this knowledge across medical fields, would help illuminate the possible connection between mental illness and CEW-proximal fatalities. Ultimately, a greater understanding of the causes of relevant health conditions in the context of CEW use, as well as risk factors related to these conditions, would lead to better knowledge of how CEWs could influence potential physiological and health effects.

8.4 SUPPORTING LARGE-SCALE, MULTI-SITE, POPULATION-BASED STUDIES

Ensuring Multi-National, Multi-Site Study

The challenges related to CEW deployment and assessing physiological and health effects are not isolated to one particular jurisdiction. Our body of knowledge would benefit from robust, multi-national, prospective population-based studies, in which a broad range of health care professionals are trained in the nature and breadth of CEW injury, and conduct consistent, comprehensive, and detailed medical examinations of individuals exposed to CEWs. These collaborative studies would undertake detailed assessments of the various factors involved in CEW deployment, and use appropriate statistical methodologies to evaluate direct and indirect factors and their relative strength. The inclusion of sites where CEWs are not in use would also make for useful comparisons in these studies (for an example see PERF, 2009). Similarly, assessment of outcomes before and after the introduction of CEWs within a particular site could prove useful (for an example, see Smith *et al.*, 2010).

Improving Knowledge on Varying, Potentially Vulnerable, Populations

Conducting more population-based studies could help build knowledge of the health effects of CEWs on vulnerable populations such as the mentally ill, but without the ethical constraints faced by laboratory-based experimental studies. It is usually impractical to obtain voluntary, informed consent for these studies from certain populations, the risk-benefit ratio is unacceptable, and there is a struggle between the natural duty to protect the rights of people who are deemed vulnerable and the need to advance scientific information.

Population-based studies with appropriately designed protocols that ensure privacy and confidentiality could also pose minimal risk to the vulnerable individuals involved. Because the information would already be part of existing record-keeping (e.g., law enforcement or emergency room records), it could be standardized and analyzed for study purposes without posing any additional burden or legal risk for the participants. Studies investigating mortality risk in use-of-force events could rely on information from coroner records, the acquisition of which would pose little further risk. The anonymity and privacy of the individuals involved would be further protected by presentation of the data in aggregate form.

Encouraging Adaptive and Inclusive Surveillance Research

Well-constructed, multi-centred, population-based studies often have research protocols that evaluate physiological and health effects across several communities. If a CEW event occurs outside of that research protocol (e.g., an incident occurring in a neighbouring community that may not record events in a way that is comparable with the study), information is often not captured in a manner that would allow the event to be used in a research study. To enable scientific analysis and reliable comparisons across events, research protocols would benefit from dynamic evidence-gathering methods that allow for the capturing of unforeseen events (and their characteristics) in neighbouring communities during data collection. Standardized record-keeping across agencies would also help improve comparability and inclusion in these instances.

8.5 IMPROVING UNDERSTANDING OF CEW RISK RELATIVE TO OTHER USE-OF-FORCE INTERVENTIONS

Comparing Sudden In-Custody Deaths Related and Unrelated to CEW Incidents

To shed light on the issue of whether CEWs are contributing to sudden in-custody deaths, it would be useful to compare sudden in-custody death rates in use-of-force events that involve CEWs with those that do not. Currently, this information is unavailable. Since these data do not require unethical experimentation, but rather diligent collection of the details surrounding use-of-force incidents, this task should be achievable. If death rates were similar among similar populations, whether a CEW was involved or not, this finding would suggest that CEWs do not present a greater risk than any other factor in a use-of-force event.

Exploring the Risk of Not Using a CEW

The Panel's charge was to review the physiological and health effects of CEWs alone; however, as previous expert panels have highlighted (NSDOJ, 2008b; NIJ, 2011), CEWs exist alongside many other devices and possible interventions used by law enforcement and public safety personnel. Thus, the "risk associated with [CEW] deployment must be viewed in relationship to the risks of other alternatives, and not viewed in a vacuum" (NIJ, 2011). Any law enforcement intervention comes with a certain risk of injury, to both the officer and the suspect. Some studies have indicated that, in comparison to other less-lethal uses of force, such as chemical spray, baton strikes, and police dogs, the potential for suspect injury is lower with CEWs (Jenkinson *et al.*, 2006). Other studies have noted consistent decreases in suspect injuries when CEWs are used as well as evidence of reductions in officer-related injuries following adoption of the devices (PERF, 2009; Smith *et al.*, 2010). In contrast, researchers have also found that suspects are more likely to experience injuries following CEW deployment when compared to the use of soft- or hard-hand force, and chemical spray. Injuries are also more likely when CEWs are used in conjunction with other uses of forces (Paoline III *et al.*, 2012). Given these contrasting findings, some important questions remain:

- How does the risk of using a CEW in a given situation compare to the risk of not using a CEW in that same situation, in terms of injuries for the officer, suspect, and other bystanders who may be involved?
- When comparing CEWs to other use-of-force interventions, how do the potential for injury and the possible severity of these injuries differ?
- Is it preferable to promote an intervention that comes with a higher risk of death but a lower injury rate, or an option that has a lower risk of death but a higher injury rate?

The answers to these questions are unclear and far beyond the scope of the Panel, but they are important considerations nonetheless. To properly assess the risk of CEWs in relation to other interventions, future studies should account for jurisdiction and context, the use-of-force techniques and protocols in place, and the related adverse health effects that include morbidity, its severity, and mortality. Assessments might also benefit from capturing morbidity, its severity, and mortality information on the responding officer and bystanders.

8.6 UNDERSTANDING SPECIFICATIONS OF CEWS MANUFACTURED BY A RANGE OF COMPANIES

Improving Understanding of Varying Device Specifications

Much of the CEW research has been performed using two devices manufactured by TASER® International: the X26™ and the M26™. Other devices, such as the TASER® X2™ and X3™, the Karbon MPID™ manufactured by Karbon Arms®, and the Mark 63 Trident™ made by Aegis® Industries, are also used by law enforcement or civilians in jurisdictions around the world. Although technical specifications are not always evident for each of these models, the waveforms delivered by, and weapon characteristics of, all of these devices are different, and may elicit different physiological and health effects. When the specifications among devices are variable and continually evolving, it is possible that differences in device characteristics could be significant enough that safety data for one weapon might not directly reflect the safety profile of a new or different device. By studying and comparing these devices, researchers could better understand how CEWs with distinct outputs are associated with physiological effects that vary in type and severity. A useful scenario would consist of a study with a large sample size, which includes groups that are evaluated following exposure to various types of CEW devices and to variable device performance standards.

Establishing Performance Testing and Approval Protocols

CEWs are designed to provide certain outputs each time they are used; however, performance parameters may vary based on factors such as the environment in which the CEW is used (e.g., in cold weather), the type of power source used (e.g., NiMH versus alkaline battery cells), and the device's ability to stand up over time (NDC, 2013). Some research has attempted to define and articulate testing protocols for CEW devices to ensure there are standard means for assessing device performance over time (Adler *et al.*, 2013). With protocols such as these in place and appropriate testing procedures continually undertaken, law enforcement agencies could ensure devices were working as intended, and re-test devices involved in any CEW incident resulting in adverse health effects to assess whether the device could have inadvertently malfunctioned. In addition, with appropriate standards in place to ensure proper functioning, the ability to compare CEW incidents resulting in adverse health effects within and across agencies would be improved because researchers could be assured that devices were performing in a similar manner in different contexts (Adler *et al.*, 2013). To properly assess the relationships between CEWs and physiological and health effects, researchers and law enforcement personnel would benefit from ensuring the devices are functioning as intended, and in a similar manner across various incidents, exposures, and contexts.

8.7 FURTHERING ETHICAL LABORATORY-BASED EXPERIMENTAL CEW RESEARCH

Although there may be more promise and increased relevance of knowledge gleaned through improved surveillance, monitoring, and reporting, as well as through population-based epidemiological study, supplementing these activities with continued support of ethically conducted experimental research studies using animal and human models could provide some value.

Supporting Further Research Using Animal Models

Many of the challenges in applying CEW animal research to our understanding of how the devices influence human populations are common to most phenomena studied using other species. Differences in genetics, anatomy, and physiology between humans and animals cannot be remedied, so the applicability of findings will always be questionable and the current research in this area adds little to the state of evidence related to CEW devices. Despite these shortcomings, animal studies can increase understanding of how certain conditions common to CEW incidents influence the relationship between CEWs and health effects. Research involving simulating use of illicit substances (Lakkireddy *et al.*, 2006) and mimicking the stress response (Nanthakumar *et al.*, 2006) are examples of such studies. Any future studies that explore the relationships between CEWs, health effects, and co-factors would need to ensure large sample sizes and carefully designed experiments with proper comparison groups to improve the quality of the study. They would also need to be designed to minimize pain and distress in animals, and, if these cannot be minimized, the value of the study would need to be determined by independent external evaluation (CCAC, 1989).

Supporting Further Research with Human Populations

Studies that imitate field conditions by exposing human subjects to CEWs following physical exertion (Ho *et al.*, 2011a) or alcohol consumption (Moscati *et al.*, 2010) have been conducted. While taking into account ethical constraints on laboratory-based research and the value of what can be learned from population-based study, further development of human research studies that consider less homogenous study subjects (e.g., varying physiological states), larger sample sizes, and use of comparison groups could be beneficial. Furthermore, improved guidance around the ethics of weapons-related research and testing with all populations could be useful for researchers engaging in any sort of future CEW study. In the absence of large human data sets, alternative techniques that use smaller sample sizes coupled with effective and robust prediction models of potential injuries could also be developed. Human research studies would be complemented by future computer modelling that applies novel approaches in assessing potential co-factors (e.g., bi-domain computer models).

9

Summary and Conclusions

- What Is the Current State of Scientific Knowledge About the Medical and Physiological Impacts of Conducted Energy Weapons?
- What Gaps Exist in the Current Knowledge About These Impacts?
- What Research Is Required to Close These Gaps?
- Final Reflections

9 Summary and Conclusions

This chapter synthesizes the main findings that emerged from the Panel's review, deliberations, and assessment of the evidence on the physiological and health effects of conducted energy weapons (CEWs). It organizes the findings by answering each of the three questions comprising the charge and concludes with the Panel's final reflections on moving forward in this field. The answers provided are based on the Panel's collective judgment of the evidence, and represent the most accurate responses the current state of knowledge permits.

9.1 WHAT IS THE CURRENT STATE OF SCIENTIFIC KNOWLEDGE ABOUT THE MEDICAL AND PHYSIOLOGICAL IMPACTS OF CONDUCTED ENERGY WEAPONS?

Since their introduction in the late 1990s, CEWs have become one of the many use-of-force options available to law enforcement and public safety personnel across Canada. Currently, there are approximately 9,174 CEWs in use in Canada and although the number varies based on jurisdiction, all federal, provincial, and territorial jurisdictions use the device in some capacity. In addition to causing pain, CEWs influence the peripheral nervous system in a way that causes temporary, involuntary, and uncoordinated skeletal muscle contractions. This incapacitation is achieved through the delivery of short, repeated pulses of electricity to the skin and subcutaneous tissues through two metal probes. The principle guiding the functioning of the CEW is that the short-duration electrical discharges it delivers are highly effective in stimulating motor and sensory nerves, causing incapacitation and pain, but are much less effective in stimulating the heart muscle and thereby inducing potentially fatal disruptions to the heart's rhythm and pumping ability.

The available information on the electrical design and output characteristics of a limited number of CEW devices shows that they are sufficient to cause the intended pain and incapacitation through stimulation of the peripheral nervous system. Specifications among CEW devices are variable, however, and may change with use and under different conditions. CEW devices and the variations among them are also constantly evolving, so knowledge based on any particular model does not necessarily translate to other devices and the characteristics of newer devices are unknown. Evaluating the intended and unintended effects of CEWs requires testing each device on its own merit and understanding the context and conditions under which it is used.

Decision-making about selecting, acquiring, and using CEWs, and record-keeping related to the outcomes of using the devices, are largely undertaken by local law enforcement agencies and officers and vary across municipal, provincial/state, and federal/national jurisdictions in Canada and internationally. This has resulted in little ongoing systematic and standardized documentation capturing comparable information on the use of CEWs and related injuries, health complications, or deaths.

Despite the lack of surveillance activity, there has been a range of scientific inquiry focused on the potential unintended physiological and health effects associated with CEWs. Several population-based and single case studies suggest superficial physical injuries are often associated with CEW deployment, which are mainly caused by the weapon's probes, but also from severe muscle contractions and related falls. Although the occurrence of superficial physical injury is high, these types of injuries rarely pose significant risk for morbidity and mortality, and case studies indicating more severe physical injuries are rare. Keeping in mind that all law enforcement interventions come with a certain risk of physical injury to the suspect involved, the Panel chose not to focus on physical injury in great detail.

Other health effects associated with CEW electrical discharges are not as well documented or studied. In its assessment of the limited evidence available, the Panel agreed the physiological and health effects of most concern in the context of CEW deployment were those effects that could be considered potential mechanisms for sudden unexpected death. These include activation of the human stress response and build-up of related stress hormones such as catecholamines, disruptions in breathing and the potential for metabolic and respiratory acidosis, and the risk of disruption to the heart's natural functioning and the potential for arrhythmias.

From the Panel's review of the limited available literature on each of these potential effects, the majority of which focus on cardiac effects, several findings emerged:

- Although limited studies suggest CEW exposure can induce the stress response and increase hormone levels, these increases are of uncertain clinical relevance. It is also unclear to what extent the discharge of a CEW adds to the high levels of stress already being experienced by an individual in an arrest scenario.
- Studies of animals subjected to prolonged or repeated CEW exposure indicate the potential for respiratory complications (e.g., pronounced acidosis). Although published experimental data identify respiratory changes in healthy human subjects typical of vigorous physical

exertion, studies involving more heterogeneous groups or humans subjected to prolonged or repeated exposure have not been conducted.

- Some animal studies suggest CEWs can induce fatal cardiac arrhythmias when a number of discharge characteristics, either alone or in combination, are in place: probe placement on opposite sides of the heart (i.e., current is delivered across the heart), probes embedded deeply near the heart, increased charge, prolonged discharges, or repeated discharges. These studies indicate the biological plausibility of adverse health outcomes following CEW exposure.
- A small number of human cases have found a temporal relationship between CEWs and fatal cardiac arrhythmias, but available evidence does not allow for confirmation or exclusion of a causal link. If a causal link does exist, the likelihood of a fatal cardiac arrhythmia occurring would be low, but further evidence is required to confirm the presence and magnitude of any risk.
- The roles of co-factors common to real-world CEW incidents (e.g., intoxication, exertion, struggle, restraint) and other co-factors (e.g., body type, existing health complications) that may increase susceptibility to adverse effects have not been adequately tested to properly establish an understanding of vulnerability in humans.

Sudden in-custody death resulting from a use-of-force event typically involves a complicated scenario that includes agitation, physical or chemical restraint, disorientation, stress or exertion, pre-existing health conditions, and the use of drugs or alcohol, all of which can potentially contribute to a death. This makes it difficult to isolate the contribution of any single factor. Although evidence shows the electrical characteristics of CEWs can potentially contribute to sudden in-custody death, no evidence of a clear causal relationship has been demonstrated by large-scale prospective studies. In a few coroner reports, however, CEWs were ruled as the primary cause of death in the absence of other factors and when excessive exposure was present. Conversely, it has been argued that CEWs could potentially play protective roles in terminating situations that may otherwise culminate in sudden in-custody death. Given the limitations and scarcity of the evidence, a clear causal relationship between CEW use and sudden in-custody death cannot be confirmed or excluded at this time. In addition, there is insufficient evidence to determine whether the use of CEWs increases or decreases the probability of sudden in-custody death in the presence of co-factors such as mental illness or excited delirium syndrome. If a causal relationship does exist, the likelihood that a CEW will be the sole cause of a sudden in-custody death is low. The extent to which the device would play a role in any death is unclear and dependent upon the co-factors involved. Further research is needed to better define these relationships.

These conclusions are limited by a number of challenges presented by the available laboratory-based experimental research studies, including translation of findings from computer and animal model studies to humans, human studies with mainly healthy subjects that do not represent the varying populations involved in CEW events, the absence of adequate control groups, lack of diverse and robust experimental designs and monitoring (e.g., biased samples), and small sample sizes. Large-scale population-based studies that better capture the complexity of real-world CEW deployment scenarios, along with a range of potential co-factors, are lacking.

9.2 WHAT GAPS EXIST IN THE CURRENT KNOWLEDGE ABOUT THESE IMPACTS?

The Panel's review of the evidence demonstrated that many key issues have not been fully explored across varying populations or in the operational settings in which CEWs are actually deployed, thus pointing to several priorities for future research:

- To what extent can the electrical characteristics of CEWs cause cardiac arrhythmia and sudden in-custody death in humans when deployed in real-world operational settings?
- Are certain groups or individuals with particular conditions at increased risk for adverse outcomes related to CEWs, and if so, what are the key co-factors?
- What CEW design and deployment features could minimize the risk of adverse health effects?

The Panel further identified and explored five overarching gaps in health-related CEW research and knowledge:

Confidence in Establishing Direct Causal Relationships

It is highly unlikely that a CEW will be the only factor having the potential to lead to adverse physiological and health effects in a use-of-force event involving many factors. It is, therefore, difficult to establish the extent to which CEWs could act as a primary cause of adverse health effects in real-world settings given the available study designs and the complexity of assessing the multi-factorial situations in which CEWs are deployed. When so many potentially harmful factors are present during a CEW incident, it is challenging to weight the relative effect of each. This greatly reduces the ability to reach definitive causal conclusions.

Identifying Length of Time Needed to Establish Probability

Presently, the length of time between a discharge and a health effect necessary to suggest a probable CEW-related injury or death is unclear. Rather than consider the issue of timing in a dichotomous manner, it would be beneficial to consider a probability continuum based on the time of the outcome post-discharge. That is, as time of outcome moves farther away from time of deployment, the probability that a CEW was directly responsible for that event decreases, but does not suddenly decrease from high to low probability at a certain cut-off point.

Understanding Health Effects on Varying Populations

Ethical constraints are associated with CEW laboratory studies, including unacceptable risk-benefit ratios, lack of direct therapeutic benefit to an individual and the presence of pain, and obtaining voluntary informed consent. These concerns are exacerbated for potentially vulnerable individuals. In this context, vulnerability is challenging to determine and no risk assessment structure, data, or methods seem to be in place to quantify the nature or magnitude of the putative increased risk of adverse health effects faced by these populations.

To date, experimental laboratory-based CEW research has generally focused on healthy anesthetized pigs and healthy human volunteers. These types of studies do not represent the actual circumstances that make up a dynamic police use-of-force encounter, thus limiting their generalizability. Large-scale population-based field studies involving detailed and consistent collection of information on the characteristics of the subject and the events surrounding the CEW incident hold promise for addressing ethical constraints, but currently these studies are lacking. This has led to a gap in knowledge related to physiological and health effects among varying, and potentially vulnerable, populations often involved in use-of-force encounters.

Lack of Standardization of Reporting and Record-Keeping Practices

The ability to carry out adequate surveillance and population-based study is hindered by a lack of standardization and consistent reporting and record-keeping practices related to use-of-force events. There are few central registries with standardized recording of CEW incidents by both law enforcement and medical personnel. The gap in surveillance efforts and population-based study severely hinders the ability to form evidence-based conclusions about the relationship between CEW use and adverse health effects.

Insufficient Funding of Independent CEW Research

Many of the available studies appear to be affiliated with, or receive support from, CEW manufacturers or individuals with perceived conflicts of interest, and funding sources are not always transparent. Although these studies may be scientifically robust, there is a perceived conflict of interest that limits their widespread acceptance. There is insufficient funding, creating, and conducting of independent research by organizations without financial or other ties to CEW manufacturers or with other perceived conflicts of interest.

9.3 WHAT RESEARCH IS REQUIRED TO CLOSE THESE GAPS?

The Panel was challenged to identify research activities and mechanisms that would address the knowledge gaps related to the physiological and health effects of CEW use. The Panel determined the need for a series of integrated strategies underpinned by surveillance, monitoring, reporting, and population-based epidemiological study. The following considerations could form the basis of this integrated response:

Standardizing and Centralizing the Recording of CEW Incidents

Establishing common definitions of use-of-force and CEW use would ensure that record-keeping efforts in Canada and internationally could support population-based monitoring and study. Implementation of a standard method of reporting to enable police and medical personnel to record a minimum level of information would then ensure the same details were recorded for each event, making it possible to compare various parameters at the population level. Further study would also be supported by the creation of a central repository of use-of-force events in Canada.

Enabling Comprehensive Medical Assessment Following CEW Exposure

When subjects are brought to the hospital for evaluation, health care professionals most likely to engage with these subjects would benefit from guidance on the co-factors and specific physiological changes and injuries most relevant to assess for patient care. With this knowledge, health care professionals could more routinely perform detailed medical examinations relevant for evaluating physiological effects of CEW exposure. Beyond the treatment of individuals, these more routine practices could aide in surveillance efforts more broadly. Innovative technologies could also be integrated into CEW devices to allow for the instant and automatic recording of health and circumstantial information.

Improving Access to, and Sharing and Integration of, Knowledge Across Fields

Researchers would benefit from improved access to law enforcement and medical records, based on what is ethically and reasonably possible. Respecting privacy concerns, a process could be established to anonymously share and link this information across disciplines, institutions, and jurisdictions. Linking information about different use-of-force modalities, and how they affect the health of individuals, could encourage investigation of a range of relevant phenomena and increase the number of high-quality publications examining these associations. Ultimately, a greater understanding of the interconnections and etiology of health outcomes relevant to CEW use would lead to improved knowledge of how CEWs influence potential physiological and health effects.

Supporting Large-Scale, Multi-Site, Population-Based Studies

Our body of knowledge would benefit from robust multi-national, prospective population-based studies, in which a broad range of health care professionals are trained in the nature and breadth of CEW injury and could therefore conduct consistent, comprehensive, and detailed medical examinations of individuals exposed to CEWs. To enable scientific analysis and reliable comparisons across events, research protocols would benefit from dynamic evidence-gathering methods that allow for the capturing of unforeseen events (and their characteristics) in neighbouring communities.

Improving Understanding of CEW Risk Relative to Other Use-of-Force Interventions

CEWs exist alongside (and can be used in conjunction with) many other devices and possible interventions used by law enforcement and public safety personnel. To properly assess the risk of CEWs in relation to other interventions, future studies should consider comparing sudden in-custody deaths (and other injuries) both related and unrelated to CEW incidents. Future studies would also benefit from exploring the risks of not using a CEW in a given situation and accounting for jurisdiction and context, the use-of-force techniques and protocols in place, and the related adverse health effects that include morbidity, its severity, and mortality.

Understanding Specifications of CEWS Manufactured by a Range of Companies

By studying and comparing a broader range of devices beyond those manufactured by TASER® International, researchers could better understand how distinct outputs (waveform specifications and deployment modes) from CEWs are associated with a range of physiological effects that vary in type and severity. Properly defining and articulating testing protocols for CEW devices would impose standard methods for assessing device performance over time. Enhancing knowledge in this area would help establish more robust information surrounding the safety parameters and technical specifications of the devices.

Furthering Ethical Laboratory-Based CEW Research

Despite the limitations in the generalizability of experimental research using computer, animal, and human studies, there are several advantages in conducting further laboratory-based research. Future computer and animal modelling would benefit from the application of novel approaches (e.g., bi-domain computer models) and larger sample sizes with proper comparison and control groups. Human studies would benefit from mimicking certain characteristics typical of subjects in the field (with appropriate ethical and safety constraints in mind), using more heterogeneous and larger study samples, and exploring extrapolation techniques.

9.4 FINAL REFLECTIONS

This report provides an overview of the state of knowledge concerning the physiological and health effects of CEWs. The conclusions reached by the Panel are based on its interpretation of the best available evidence, which is provided throughout the report. The Panel recognizes that gaps exist within the literature and undoubtedly this poses challenges when assessing the physiological and health effects of CEW exposures. The Panel also recognizes that as advancements in scientific understanding occur, perspectives may need to evolve to recognize any new body of evidence.

Currently, there are numerous chances to rethink how we assess and communicate the safety of CEWs and use-of-force interventions more broadly. Opportunities exist for redesigning and improving research methodologies, standardizing collection of information, and developing partnerships across disciplines, jurisdictions, and professional practices.

Educating the public, health care providers, popular media, and law enforcement will be essential to advance research and knowledge related to CEW use. To ensure that the public, media, and law enforcement are receiving and communicating the most up-to-date and robust scientific evidence, it may be beneficial to work on the development of standard ways for communicating about CEWs, risk, and health implications. Drawing on the fields of public health and stakeholder engagement and management, along with literature related to risk perception, risk management, and safety assessments, standards for effective mechanisms for knowledge translation and communication could be established and ultimately improve transparency related to the health effects surrounding CEW use.

Although there are potential risks associated with CEWs, the devices may also have positive effects (e.g., reducing injuries) not only among those who are exposed to the devices, but also among the public and law enforcement officers. It will be important to assess outcomes if CEWs are not used in a given situation and to take into consideration broader socio-political factors and risk assessments beyond the potentially negative health effects of the devices.

This final assessment report is meant to provide an in-depth and authoritative statement on the state of knowledge about the relationship between CEW use and a range of health effects. In addition, the Panel acknowledges there are a number of factors that go into decision-making related to CEWs that are beyond assessing health effects and that these factors must also be considered in any large-scale assessment of their use. This report must therefore complement other work on testing and approval procedures, motivations and protocols for appropriate use, safety and effectiveness standards, appropriateness of the devices compared to other use-of-force interventions, and other socio-political considerations that make up the broader package of information needed to make sound decisions about policing and CEW use in Canada.

This assessment presents an opportunity to inform municipal, provincial, territorial, federal, and international law enforcement practices and provides a platform to encourage improved communication among these jurisdictions. It is the Panel's hope that the report will be used to continue dialogue among a variety of stakeholders on a science-based question of public health importance. Ultimately, public perception and emotion, while important considerations, should not lead the debate — a range of scientific inquiry, risk assessment, and evidence must guide policy surrounding the use of CEWs in Canada.

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Appendices

- **APPENDIX A** Summary of Main Findings from Past Evidence Assessments
- **APPENDIX B** Physical Injuries Following CEW Exposure
- **APPENDIX C** Summary of Animal Studies Examining Respiratory Dysfunction
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APPENDIX A
Summary of Main Findings from Past Evidence Assessments

Almond Report, Report of Advisory Panel to Minister of Justice on Use of CEWs by Law Enforcement in Nova Scotia (NSDOJ, 2008b)

Evidence	Health Outcomes	Key Health-Related Findings	Conclusions
• Peer-reviewed literature. • Grey literature.	Death, bodily injury.	• Risk of death or serious injury associated with CEW use on healthy individuals is low, but may not reflect the risk for vulnerable populations, such as those suffering from mental or physical health conditions or who are under the influence of drugs/alcohol. • No medical research established causal link between CEW use and death, though the science is still evolving.	Panel of medical/scientific experts should review evidence (with a separate panel of mental health experts to address the issue of excited delirium syndrome); advise Minister of Justice, policy-makers, and police annually. Policy formation hindered by lack of central CEW case data repository.

2011 DOMILL Statement on TASER M26 and X26 and Children and Vulnerable Populations (DOMILL, 2011)

Evidence	Health Outcomes	Key Health-Related Findings	
• Peer-reviewed literature. • Grey literature.	Death, injury, cardiac/drug interactions, excited delirium syndrome, stress, mental illness.	• Possible increased risk of harm for children, adolescents, low-body-weight persons: harmful cardiac arrhythmia; physiological harm from intense muscle contraction, pain, and stress induced by CEW; skin and soft tissue injury from CEW probe darts. • Risks to pregnant women and fetuses are not well-documented but could include injuries from uncontrolled falls and intense muscle contractions, which may lead to increased rate of caesarian section delivery and/or low birth weight babies. • Equivocal evidence indicating increased risk of CEW-induced seizures in individuals with epilepsy. • CEW interaction with pacemakers and implantable devices is not harmful. • Serious cardiac harm may be possible in presence of underlying cardiac disease or chemical intoxication.	

2005 DOMILL Statement of the Medical Implications of the Use of the M26 Advanced TASER (DOMILL, 2005)

Evidence	Health Outcomes	Key Health-Related Findings	Conclusions
• Peer-reviewed literature. • Grey literature. • Lab research.	Death, injury, cardiac/drug interactions, excited delirium syndrome.	• Possible hypersensitivity to CEW from interaction with illegal drugs. • Probability of damage to implanted devices/pacemakers is very low. • Small human data sample sizes are an impediment to research.	Risk of life-threatening or serious injuries from the M26™ TASER® appears to be very low.

House of Commons Report, Canada, Study of the Conductive Energy Weapon – TASER (House of Commons of Canada, 2008)

Evidence	Health Outcomes	Key Health-Related Findings	Conclusions
• Expert testimony.	In-custody deaths, excited delirium syndrome, ventricular fibrillation, bodily injury.	• Witnesses' testimony: 962 field deployments of CEWs, 0.3% severe injuries, 99.7% mild or no injury. • 20 deaths following TASER® application in Canada as of 2008. • TASER®-induced ventricular fibrillation only documented in animal models.	No established causal link between CEW application and death. Need government commissioning/funding of independent, scientific, peer-reviewed CEW research.

continued on next page

Kiedrowski Report, An Independent Review of the Adoption and Use of Conducted Energy Weapons by the RCMP (Kiedrowski *et al.*, 2008)			
Evidence	**Health Outcomes**	**Key Health-Related Findings**	**Conclusion**
• Peer-reviewed literature. • Grey literature. • Police records/ other police documents. • Interviews with RCMP/other police services.	Death, injury, cardiac capture and arrhythmia, neuromuscular function, excited delirium syndrome.	• Human studies: no clinically significant changes in recordable cardiac electrical activity, body temperature, or serum markers of muscle injury/acidosis. • Pig studies: lengthy transcardiac TASER® X26™ discharges could result in ventricular fibrillation or tachycardia.	No necessary and sufficient causal link between CEW and death in healthy adults. Individuals with low body weight, pre-existing medical conditions, intoxication, acute psychosis, or acute stress may face a higher risk of harm or death following CEW exposure. The term excited delirium "should not be included in the RCMP operational manual unless subsequently formally approved by the RCMP after consultation with a mental-health policy advisory body."

Manojlovic Report for the Canadian Police Research Centre, Review of Conducted Energy Devices (Manojlovic *et al.*, 2005)			
Evidence	**Health Outcomes**	**Key Health-Related Findings**	**Conclusion**
• Peer-reviewed literature. • Grey literature. • Detailed summary of two reports by the BC Office of the Police Complaints Commissioner, which used expert testimony.	Death, injury, seizure, superficial skin damage.	• Research gaps: death proximal to restraint, physiological effects of excited delirium syndrome; effective restraint and treatment of excited delirium sufferers. • Excited delirium syndrome not a universally accepted diagnosis.	Risk of cardiac harm is very low. No definitive research evidence showing causal relationship between CEW and death. Excited delirium syndrome "is gaining increasing acceptance as a main contributor to deaths proximal to [CEW] use."

Synyshyn Report for Canadian Association of Police Boards, A Select Review of Medical and Policy Review Literature (Synyshyn, 2008)			
Evidence	**Health Outcomes**	**Key Health-Related Findings**	**Conclusion**
• Peer-reviewed literature. • Grey literature.	Ventricular fibrillation, cardiac capture, CEW probe wounds.	• Human laboratory experiments cannot entirely reproduce in the field scenarios. • Ethical considerations are main challenge in research on co-risk factors and vulnerable populations.	Research has not shown conclusive link between CEWs and death. There is still disagreement in the research community regarding applicability of pig studies of CEW risks to cardiac health.

2011 National Institute of Justice, Study of Deaths Following Electro Muscular Disruption (NIJ, 2011)			
Evidence	**Health Outcomes**	**Key Health-Related Findings**	**Conclusions**
• Peer-reviewed literature. • Grey literature. • Expert testimony. • Coroner records. • Police records.	Death, serious injury, cardiac arrhythmia, excited delirium syndrome.	• "There is currently no medical evidence that [CEWs] pose a significant risk for induced cardiac dysrhythmia in humans when deployed reasonably." • There is anecdotal evidence that CEWs can cause cardiac arrhythmia in field deployments. • Risk factors include intoxication, excited delirium syndrome, acidosis, and cardiac pacemakers, but the literature has not conclusively demonstrated any causal relationships; more research on the role of these factors in sudden death proximal to CEW use is needed.	No conclusive medical evidence indicating high risk of injury or death from short CEW exposure in normal, healthy adults. Risk of death proximal to CEW use is less than 0.25%; risk of injury or death is probably less than 1%. Drive-stun mode should not be repeated on subjects exhibiting abnormally high pain tolerance. Most deaths proximal to CEW use involve prolonged or multiple discharges; law enforcement should avoid this type of deployment.

APPENDIX B
Physical Injuries Following CEW Exposure

<table>
<tr><th colspan="4">EPIDEMIOLOGICAL STUDIES</th></tr>
<tr><td colspan="4">(Bozeman et al., 2009b)</td></tr>
<tr><td>Study Design
Prospective population-based multi-centred study of individuals exposed to CEWs at 6 law enforcement agencies</td><td>Sample Size
1,201</td><td colspan="2">Findings
• 83% of the cases resulted in superficial puncture wounds
• 2 cases of head injuries occurred, sustained during falls related to CEW use</td></tr>
<tr><td colspan="4">(Gardner et al., 2012)</td></tr>
<tr><td>Study Design
Retrospective study using information from a multi-centred database of CEW uses in the field, focusing on a sample of minors (age 13 to 17)</td><td>Sample Size
100</td><td colspan="2">Findings
• 20% sustained injuries that were mostly a result of superficial puncture wounds
• Less common injuries included superficial abrasions, minor lacerations, and nose bleeds</td></tr>
<tr><td colspan="4">(Haileyesus et al., 2011)</td></tr>
<tr><td>Study Design
Retrospective study using 2 national databases describing injuries sustained during use-of-force incidents resulting in emergency room treatment</td><td>Sample Size
~300,000</td><td colspan="2">Findings
• Of ~300,000 non-fatal injuries resulting from use-of-force interventions, 11% were CEW-related injuries that involved probe puncture wounds, contusions/abrasions, foreign bodies, and lacerations</td></tr>
<tr><th colspan="4">CASE SERIES/CASE REPORTS</th></tr>
<tr><td colspan="3">(Chandler et al., 2011)</td><td rowspan="4">Both case reports demonstrate that the length of a CEW dart can be sufficient to allow brain penetration</td></tr>
<tr><td>Study Design
Case report</td><td>Sample Size
1</td><td>Findings
• Probe embedded in the forehead after CEW deployment from a distance less than 5 feet</td></tr>
<tr><td colspan="3">(Le Blanc-Louvry et al., 2012)</td></tr>
<tr><td>Study Design
Case report</td><td>Sample Size
1</td><td>Findings
• CEW probe penetrated skull and underlying frontal lobe</td></tr>
<tr><td colspan="4">(Chen et al., 2006)</td></tr>
<tr><td>Study Design
Case report</td><td>Sample Size
1</td><td colspan="2">Findings
• Perforating eye injury resulting in retinal detachment</td></tr>
<tr><td colspan="4">(Han et al., 2009)</td></tr>
<tr><td>Study Design
Case report</td><td>Sample Size
1</td><td colspan="2">Findings
• Perforating eye injury resulting in temporary vision loss</td></tr>
<tr><td colspan="4">(Giaconi et al., 2011)</td></tr>
<tr><td>Study Design
Case report</td><td>Sample Size
1</td><td colspan="2">Findings
• Acute trauma (tearing) to certain lower body tendons following CEW exposure in the thigh</td></tr>
<tr><td colspan="4">(Mangus et al., 2008)</td></tr>
<tr><td>Study Design
Non-consecutive case series</td><td>Sample Size
4</td><td colspan="2">Findings
• Probe penetration into the skull and various injuries resulting from falls including skull and facial fractures, concussion, and laceration</td></tr>
<tr><td colspan="4">(Hinchey & Subramaniam, 2009)</td></tr>
<tr><td>Study Design
Case report</td><td>Sample Size
1</td><td colspan="2">Findings
• Subject experienced a mild to moderate pneumothorax (collapsed lung) as a result of CEW incident; authors suggest it was caused by the CEW probe, but could not rule out the fall resulting from CEW incapacitation as a potential cause</td></tr>
<tr><td colspan="4">(Sloane et al., 2008)</td></tr>
<tr><td>Study Design
Case report</td><td>Sample Size
1</td><td colspan="2">Findings
• Compression fracture of a thoracic vertebrae resulting from intense muscle contractions and consistent with compression fractures resulting from seizure</td></tr>
<tr><td colspan="4">(Bui et al., 2009)</td></tr>
<tr><td>Study Design
Case report</td><td>Sample Size
1</td><td colspan="2">Findings
• Subject experienced a seizure as a result of a CEW shot to the head, and showed evidence of a concussion likely resulting from a fall to the ground</td></tr>
</table>

APPENDIX C
Summary of Animal Studies Examining Respiratory Dysfunction

Subject and Exposure Time	Measurement	Observations Pre-Exposure	Observations Post-Exposure	Conclusions
(Jauchem *et al*., 2006) 6 pigs exposed to single discharges for 5-s, followed by a 5-s period of no exposure, repeatedly for 3 min	pH	7.42	6.95	• Blood pH significantly decreased for 1 h following exposure • Acidosis believed to be a result of leg muscle contractions (which caused increased lactate and metabolic acidosis) and decreases in respiration (which caused increased PCO_2 and respiratory acidosis) • Lactate was highly elevated, with a slow return (time course greater than 1 h) to baseline
	Lactate (mmol/L)	1.05	14.5	
	PCO_2 (mm Hg)	~ 45	~ 100	
(Dennis *et al*., 2007) 11 pigs, two 40-s discharges	pH	7.45	6.81	• Breathing stopped during exposure • Two deaths resulting from cardiac arrhythmias • Significant acid-base disturbances • Unlike Jauchem *et al.* (2006), animals were mechanically ventilated (except during 40-s discharges) so increased PCO_2 was believed to be caused by impaired circulatory function rather than decrease in respiration
	Lactate (mmol/L)	1.6	22.1	
	PCO_2 (mm Hg)	45.3	94.5	
(Jauchem *et al*., 2009b) 10 pigs, 30-s discharge	pH	7.39	7.04	• Breathing stopped during exposure • Decrease in pH • Increase in lactate • Increase in PCO_2
	Lactate (mmol/L)	1.6	14.1 (10 min post-exposure, and 8.2 three hours after exposure)	
	PCO_2 (mm Hg)	60	113 (immediately post-exposure)	
(Jenkins *et al*., 2013) 10 pigs, subjected to discharges of up to 30 minutes	pH	~ 7.4	~ 6.9	• Inhibition of spontaneous breathing in the first 60-90 seconds post-exposure • Animals developed mixed metabolic and respiratory acidosis • Four deaths occurred, likely due to mechanical cardiac muscle failure (not electrically induced arrhythmias) Values represent the average of 8 animals immediately following 5 min of continuous exposure, because data were incomplete at later time points
	Lactate (mmol/L)	~ 1.25	~ 16	
	PCO_2 (mm Hg)	~ 37	~ 100	

APPENDIX D
Summary of Animal Studies Examining Variable CEW Characteristics and Cardiac Dysfunction

	Subject	Probe Location	Probe Depth	Strength of Charge	Length / Number of Discharges	Outcome (and Reference)
Varied probe location	6 pigs (150 discharges total)	2 positions: one across the heart and one across the abdomen	Inserted just under skin	Standard	1 X 5-s and 1 X 15-s	Cardiac capture only occurred when current was delivered across the heart but ventricular fibrillation did not occur. Longer discharge (15-s) more likely to cause capture (Nanthakumar *et al.*, 2006).
	4 pigs (67 discharges total)	11 positions (on front and back), including some across the heart	12 mm	Standard	1 X 10-s	Cardiac capture occurred at a higher rate when current directly crossed the heart but transcardiac discharge was not required for capture. Two cases of ventricular fibrillation occurred, both when current was delivered across the heart (Valentino *et al.*, 2008a).
Varied probe depth	5 pigs	Performed surgery to place one probe above heart and allow for depth variation; other probe on abdomen	Varied dart-to-heart distance	Standard	1 X 5-s (each animal exposed multiple times at different dart-to-heart distances)	Average distance from tip of dart to heart that elicited ventricular fibrillation was ~6 mm (range 2–8 mm). In humans, if probe is fully penetrated and skin-to-heart distance is small, probe may be close enough to heart to cause ventricular fibrillation (Wu *et al.*, 2008).
Varied strength of charge	9 pigs (each exposed ~26 times)	Across the heart	Not specified	Varied	1 X 5-s (each animal exposed multiple times at different charge strengths)	A charge 15X stronger than that of a standard CEW was required to induce ventricular fibrillation even in smallest pig. Heavier pigs required higher charges (McDaniel *et al.*, 2005).
	2 pigs	Across the heart	9 mm	Varied	1 X 5-s (each animal exposed multiple times at different charge strengths)	Cardiac capture usually occurred with standard charge. Ventricular fibrillation induction occurred (in less than half of cases) only when charge was ~4X greater than standard (Kroll *et al.*, 2009).
Varied length of discharge	11 pigs (some controls)	Across the heart	10 mm	Standard	2 X 40-s	Cardiac capture occurred in all animals. Two cases of fatal ventricular fibrillation (Dennis *et al.*, 2007).
	14 pigs (some controls)	Across the heart	12 mm	Standard	2 X 40-s	Cardiac capture occurred in all animals. One case of fatal ventricular fibrillation (Walter *et al.*, 2008).
	6 pigs	Across the heart	One probe 10 mm from heart	Standard	Varied length (each animal exposed multiple times for different length of time)	A discharge of ~90-s is required for induction of ventricular fibrillation (Kroll *et al.*, 2010).
	10 pigs (5 for each group)	Across the heart	Not specified	Standard	1 X 30-s and 1 X 60-s	No episodes of ventricular fibrillation (Jauchem *et al.*, 2009a).
	10 pigs	Across the heart	Not specified	Standard	20 X 5-s (4 groups of 5 X 5-s, 5 min apart)	No episodes of ventricular fibrillation (Esquivel *et al.*, 2007).
	10 pigs	Across the heart	Not specified	Standard	Up to 1 X 30-min	Four deaths occurred (at 4, 4.5, 10 and 10.25 min). None of the deaths were attributed to sudden cardiac death caused by electrically induced ventricular fibrillation (Jenkins *et al.*, 2013).
Varied location and charge	13 pigs	5 positions, including 3 across the heart and 2 on the back	9 mm	Varied	1 X 5-s (each animal exposed multiple times at different charge strengths)	Ventricular fibrillation risk varied depending on position of CEW darts in relation to heart (but only occurred with an "enhanced" CEW that delivered a charge more than 4X greater than standard) (Lakkireddy *et al.*, 2008).

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