Human Factors and Mechanical Engineering for Defense and Safety (2022) 6:10
https://doi.org/10.1007/s41314-022-00047-y

ORIGINAL PAPER

Not Non-Lethal Weapons: the Counter-Personnel Behavioral Effects Weapons Framework for Armament Engineers

E. Mezzacappa[1,2] · G. Cooke[3] · K. R. Short[2] · N. Jovanovic[1,2] · D. T. Cheng[1,2] · J. J. Rodriguez[1,2]

Received: 20 December 2021 / Revised: 21 December 2021 / Accepted: 22 December 2021

Abstract
Behavioral effects weapons (BEW) are devices that are intended to change the behavior of their human target. The article describes the critical considerations and a framework to guide the development of BEW. Human physiology is the fundamental basis for the theoretical framework of BEW engineering. Effectiveness of BEW starts with the physiological effects induced by stimuli or energy generated by a weapon. These physiological effects, in turn, affect target behavior. Behaviors are altered by (1) changing the motivation of the targeted individual(s) to perform the behavior and (2) changing the ability of the targeted individual(s) to perform the behavior. In addition to the thresholds for effectiveness of BEW, the limitations due to risk of signification injury (RSI) define the solution space for armament engineers. Finally, ethical considerations for the armaments developer are presented. It is hoped that the information in this article will serve as a guide for the armaments engineering community in order to fill a critical weapon capability gap.

Keywords Non-lethal weapons · Armament engineering · Physiology · Motivation · Risk of significant injury

Introduction

Effective military responses to provocation below armed conflict recently have gained attention in the literature [1]. Older terms such as "irregular warfare" and newer concepts such as "hybrid warfare" refer to operations where adversaries "use sophisticated, incremental aggression" at intensities that fall below lethal response thresholds [2]. Non-lethal weapons or the broader more recent categories of "Intermediate Force Capabilities" (IFC) are critical for enabling successful engagements in this "gray zone" [3, 4]. Because of this capability gap, non-lethal weapons as a component of IFC are an active area of investigation by the USA and NATO countries [2, 5, 6]. The need for counter-personnel IFC is more dramatically demonstrated by clashes between migrants and security forces at the border between Belarus and Poland in the autumn of 2021.

In the USA, despite establishment of DoD components with the mission of supporting NLW (or "less-lethal weapons" (LLW)) development in the mid-1990s, several observers have noted a lackluster development of this class of weapons [7–11]. Several explanations have been proposed [9, 12, 13]. We propose that the very name of these armaments poses an impediment to their creation. A better designation for the devices that fill the counter-personnel armament capability gap is "Behavioral Effects Weapons" (BEW).

The difference in terminology (BEW versus NLW/LLW) reflects an emphasis of *what the weapon does* (affect target behavior) rather than *what it is not supposed to do* (kill), especially because weapons categorized as non-lethal do result in fatalities. The current nomenclature implies that this class of armaments does not kill, leading to the perception that these weapons are somehow less important than lethal weapons. Alternatively, the standard designation leads to the erroneous belief that NLW result by simply dialing down the power on "real" weapons.

Weapon developers, however, face challenging design choices in these armaments. The intent of this brief article

✉ E. Mezzacappa
elizabeth.s.mezzacappa.civ@army.mil

1 Tactical Behavior Research Laboratory, DEVCOM AC, FCDD-ACE-QE, Building 3518, Picatinny Arsenal, NJ 07806-5000, USA

2 US Army Armament Graduate School, DEVCOM AC, Building 3411, Picatinny Arsenal, NJ 07806-5000, USA

3 West Point Simulation Center, Department of Military Instruction, United States Military Academy, 745 Brewerton Road, West Point, NY 10996, USA

Published online: 27 April 2022

is to give armament engineers a short introduction into the concepts of engineering counter-personnel BEW. This article proposes a theoretical framework for armament engineers to organize their thoughts and efforts. The hopes are to stimulate novel methods and approaches to weapons that affect the target's functions, systems, and behavior. This work is based on a 14-week course taught in the Army's Armament Graduate School, offered since 2015 by scientists and engineers from the Tactical Behavior Research Laboratory (formerly known as the Target Behavioral Response Laboratory).

Understanding the Human Factors Side of Behavioral Effects Weapons (BEW)

Human physiology is the fundamental basis for the theoretical framework of counter-personnel BEW engineering. Effectiveness of BEW starts with the physiological effects induced by stimuli or energy generated by a weapon. Therefore, the first critical step for serious programmatic research and development efforts for BEW is the study of human physiology.

Of course, a comprehensive or even a brief survey of human physiology is well beyond the scope of a journal article. A multitude of relevant undergraduate textbooks is found on bookshelves [14, 15]. The study of basic human physiology, sensation and perception, and neuroscience will provide armament engineers a broad, solid foundation to investigate approaches to BEW development. The engineer can manage the Herculean task by identifying physiological processes specifically related to their respective operational requirements. Following an overview, the next sections propose that engineers focus on physiological processes underlying motivated adversarial behaviors.

Overview: Measures of Performance, Measures of Effectiveness for BEW

Figure 1 represents the possible paths through the underlying mechanisms of the effects of BEW fires. Beginning with physiological effects of BEW fires, the next responses may interfere with capabilities or induce pain with attendant changes in emotion, cognition, and stress levels. Further responses relate to inducing motivational changes or behaviors to terminate the aversive stimuli. The final desired response is the behavior as planned by the commander's intent. The figure also suggests appropriate measures of performance (MoP) and measures of effectiveness (MoE) for research and development and testing and evaluation of BEW. For each step in the process that can be measured, metrics should be included in research and testing activities. That is, measures of physiological responses, intermediate psychological responses, and decrements in capability, as well as measures of operational effectiveness, should be recorded. If there are indeed causal relationships, then investigation into these intermediate effects can help focus weapon improvement efforts.

BEW Targets: Behaviors

Commanders employ BEW to deny access into or out of an area, move, disable, or suppress individuals [16–18]. Therefore, BEW fires are intended to deny, move, disable, or

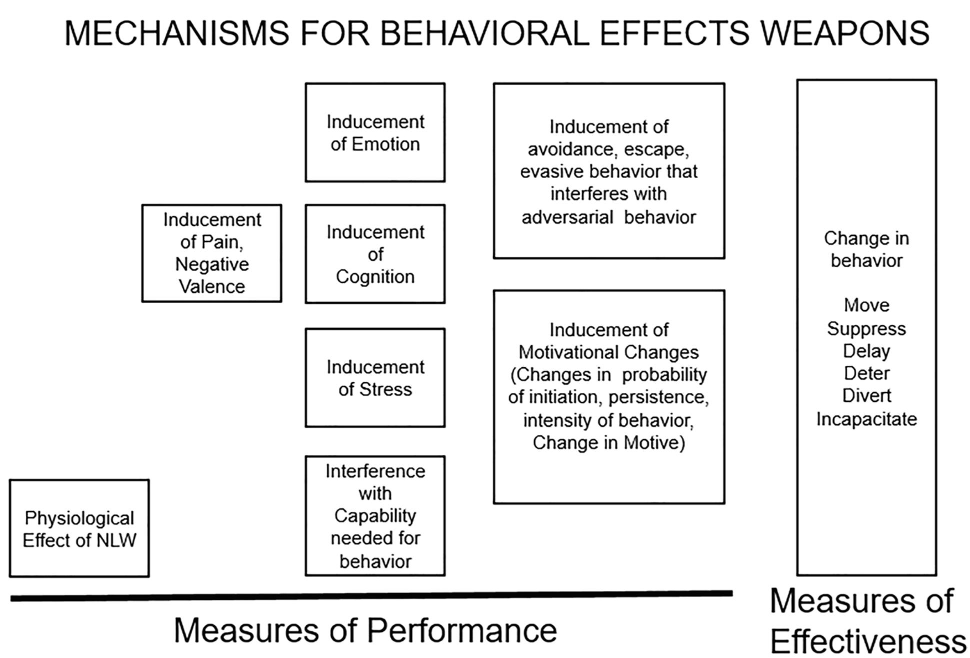

Fig. 1 Mechanisms from physiology to operational effectiveness suggesting appropriate measures of performance and measures of effectiveness

suppress human targets. More specifically, BEW are weapons intended to affect execution of adversarial behavior.

From the target's point of view, the effects are simply intended to alter what the target is doing. Behaviors are altered by (1) changing the motivation of the targeted individual(s) to perform the behavior and (2) changing the ability of the targeted individual(s) to perform the behavior. Changing the motivation of the targeted individual(s) includes (1) creating repelling forces away from protected areas or actions or (2) creating attractive forces toward alternative areas or actions. Changing the ability of the targeted individual(s) to perform an adversarial behavior includes (1) removing a capacity or (2) inducing another behavior that interferes with the adversarial behavior. Note that a BEW that alters the ability to perform an adversarial behavior does not act solely through decreasing motivation to perform the adversarial behavior. That is, BEW can be designed to affect behavior independently of motivational effects. Each of these two approaches, changing motivation and decreasing ability, is discussed in more detail in the following sections.

Changing Motivation

Motivation is "a person's willingness to exert physical or mental effort in pursuit of a goal or outcome" [19]. BEW are intended to affect a target's willingness to pursue an adversarial goal or adversarial outcome. Many BEW decrease motivation through application of stimuli that results in target distress. Recent BEW inventories reveal an overwhelming majority of BEW induce compliance through inducing pain and injury [18]. BEW lead to compliance by decreasing the motivation to engage in adversarial behavior through either the application or threat of application of aversive stimuli, pain, and injury. However, the relationships among pain, motivation, and changes in behavior are not straightforward [20, 21]. Therefore, motivational constructs are another critical aspect in the theoretical framework of BEW development.

Although there are many theories of motivation within behavioral science, inside the BEW community, Lewinian field theory has been used to reason about motivation [13, 22–25]. A sufficient treatment of the tenets of this framework is beyond the scope of this article, but a relevant skeletal summary can be presented. Critical constructs include attractive forces toward or repulsive forces away from goal regions that are real (e.g., the embassy, the police precinct) or irreal (e.g., honor, equality). Barriers further constrain locomotion. Barriers can be real and physical like razor wire which or irreal and psychological such as social disapproval. In most cases, BEW present the physical barrier (repulsive forces) to the target's real goal regions, but the target's irreal goals provide the motivation (attractive forces) that affects compliance with BEW. Attractive forces toward the defended goal are decreased by a perceived reduction in the probability of reaching the goal or a reduction in the desirability of the goal. The calculation of "resultant" forces can assist in predicting the locomotion of the crowd or the decision to act. Assuming that all forces are taken into account, when the repulsive forces are greater than the attractive forces, the adversarial behavior will cease. BEW application of pain affects motivation by inducing repulsive forces to move people away from a physical goal region (defended area).

On a theoretical level, this motivational calculus could be thought of as simplistic. In the case of locomotion (i.e., movement) to or from an area, the theoretical framework becomes practical, in terms of predicting or directing locomotion (into/out of an area). That is, the area of effect or the direction from which the BEW fires are coming and barriers that are present in the environment will constrain locomotion. For example, BEW that are engineered for use in prisons differ from those for use in open fields, the former having insurmountable barriers to locomotion, and the latter having relatively few restrictions to movement.

Motivational principles and the construct of irreal forces may help explain and predict unintended psychological consequences of BEW use. For example, self-preservation is a readily understandable psychological motive. However, the self-preservation motive may induce confrontation instead of the compliance that BEW use intends. That is, targets also follow an escalation of force paradigm comparable to that of the commander's. For example, a lower power on target may induce the desired compliance, while a higher power on target may induce confrontation and retaliation (perhaps out of an irreal sense of the injustice at the inappropriate force level). Thus, consideration of the psychological contexts and motivational forces should guide engineering of BEW.

Decreasing Ability

In order for a target person to perform a behavior, the person must be physically and mentally able to carry out the behavior. BEW change the ability of the target to execute adversarial behaviors by (1) inducing behaviors that are incompatible with the adversarial behavior and/or (2) interfering with the physical or mental capacities needed to perform the adversarial behavior.

Inducing Incompatible Behaviors

Concepts from reinforcement theory could also present an approach or mechanism through the induction of behaviors incompatible with adversarial behaviors [21]. The concept of self-preservation serves again as an example. Application of aversive stimuli may produce a motive to avoid or escape BEW fires, i.e., the motive to flee. Fleeing is incompatible with approaching. Therefore, if the target decides to execute this alternative behavior of fleeing rather than approaching, then area denial is achieved. Pain-based BEW work at least in some part through these processes. A caution that will be repeated later is that engineers should never assume that pain-based BEW will inevitably result in avoidance and escape behaviors. Again, the relationships among pain, motivation, and changes in behavior are not straightforward [20, 21].

Interference with Abilities Needed for Adversarial Behavior

An examination of the State of the Art Report for Counter-Personnel Non-Lethal Weapons Technologies [18] shows that the majority of BEW is pain-based and therefore works mainly through motivational impacts, including inducement of incompatible behaviors (i.e., fleeing). However, less attention has been given to incapacitating physiological processes that underlie physical and mental abilities to carry out adversarial behavior. For example, for a target to remove a mine, that person needs to be able to see the mine to approach, and to be able to walk. To be able to walk, the person needs to be able to maintain balance, move muscles and joints, and have a normal functioning motor cortex. If a person cannot see the mine or walk toward it, or maintain balance, the person cannot remove the mine—resulting in suppression of the mine removal behavior. If a device interferes with the relevant individual ability, it will interfere with the downstream adversarial behavior. If a weapon can deny, disable, or suppress the specific capacity or capacities (e.g., to see, to hear, to move), the weapon can deny, disable, or suppress the entire human target. Human electro-muscular incapacitation devices that induce tonic muscular contractions that interfere with volitional muscular contractions are exemplars of this class of BEW. Tables 1 and 2 show other examples that are more detailed.

This framework for BEW development supports the idea of simultaneously targeting multiple physiological processes to interfere with an adversarial behavior. Organizing potential targeted capacities in this manner naturally leads to concepts of BEW systems that leverage multiple approaches, whose effects may be interactive or multiplicative. The approach provides a rationale for the combinations of energies that should be pursued.

A better understanding of human anatomy and physiology will encourage novel engineering approaches to designing BEW. Relevant physiological processes underlying behavior typically are those of processes of sensation and perception (e.g., hearing, seeing, balance) and processes of movement (e.g., muscle movement). The neural pathways (from transduction of external stimuli to action potentials) subserving these abilities are complex and, thus, have multiple points of vulnerability that can be exploited by BEW. Initially, there is a large literature that can be used to identify candidate approaches or concepts of operations of a novel BEW. Verification is however needed—engineers must verify through test and evaluation that the technology developed affects the function, system, capacity, and finally the targeted behavior in the intended manner to be considered effective.

Figure 2 illustrates the overall concept for developing ideas for novel BEW. Target adversarial behaviors are identified through capability gap documents and operational requirements. Human capacities that make the adversarial behavior possible are then explored. Finally, the anatomical

Table 1 Example of identifying physiological functions that may suppress rock throwing

Targeted physiological function	Targeted system	Targeted capacity	Targeted adversarial behavior
Detection	Visual system	Ability to see target, judge distance	Aiming
Sense of joint position	Proprioception	Capacity for body movement	Bending down to pick up objects to throw
Contraction	Musculature	Arm movement, joint movement	Throwing

Table 2 Example of identifying physiological functions that may deny approach

Targeted physiological function	Targeted system	Targeted capacity	Targeted adversarial behavior
Rhodopsin regeneration	Visual	Capacity to see restricted area	Pathfinding
Contraction	Musculature	Walking, running	Locomotion
Otolith function	Vestibular	Staying upright	Locomotion

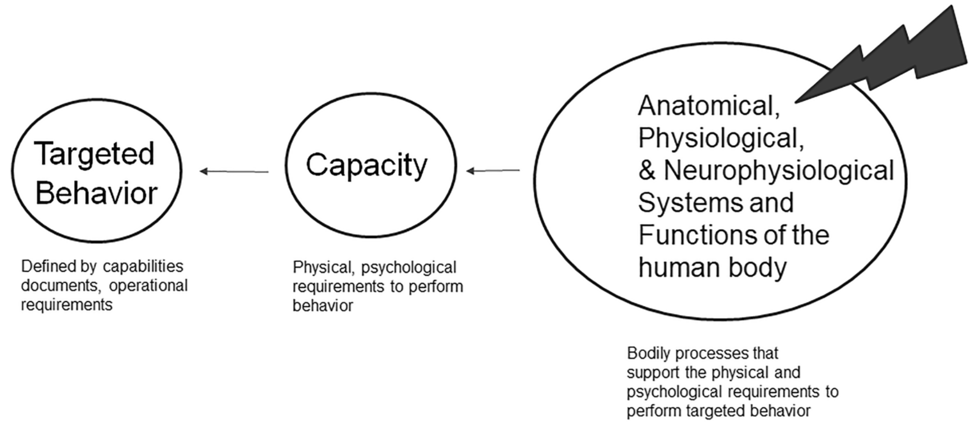

Fig. 2 Path from physiology to operational effects

structures, physiological and neurophysiological systems, and the functions of the body that underlie the set of capacities are identified. Possible energies, stimuli, and methods for affecting those structures, systems, and functions can then be discovered.

Risk of Significant Injury

BEW designers have an additional factor to consider that traditional lethal armament designers do not—risk of significant injury. The risk of significant injury (RSI) is the "potential of a BEW to cause direct injury requiring Health Care Capability (HCC) Index 1 (on a scale of 0–2) or higher treatment, permanent injury, or death. RSI is the parameter used to describe reversibility of a BEW as it relates to human effects" (DODI 3200.19). The HCC index aids in determining the severity of injury and qualifies an injury as significant or not. Injuries of an HCC Index 1 require treatment by a first responder: resuscitation, stabilization, and emergency care. Thus, the RSI is expressed as the probability of injuries of at minimum HCC index treatment level 1, permanent injury, or death due to BEW fire. Alternatively, the RSI for a BEW can also be expressed as the probability that if any injury takes place that the injury will be qualified as significant, as previously defined [26]. If a BEW has more than one mechanism for injury (e.g., auditory and visual injury from flash bang devices), then the probabilities for each individual mechanism are combined. This requirement can further complicate evaluating RSI depending on the interaction between differing injury mechanisms. Depending on the BEW, risk analysis may not necessarily end with the initial firing. Injuries can further be exacerbated based on compounding effects of repeated exposure; in addition to situational factors including: how environmental conditions affect power on target, the range to target, the duration of the effect, and the time it takes for the effect to be reversed [18]. Thus, the BEW developer must evaluate the acceptable RSI considering these conditions, the goals of the weapon, and effectiveness.

Solution Space

It is the BEW engineer's challenge to design devices that effectively target and disrupt operationally relevant physiological functions. One of the first steps is to identify the solution space that has both sufficient efficacy to be useful and an acceptable RSI [27]. Analyses for armaments and other items, such as pharmacologic agents, can be analyzed using variants of a "dose–response" probability curve. The x-axis of a dose–response curve for a BEW will be the metrics related to the performance of the BEW, for example, impact velocity, power on target, and decibels. The y-axis reflects response (actually probability of response within a population) to stimuli at that level. Like medical applications, but unlike typical lethal weapon applications, there are two curves that need to be generated for the graphs representing a BEW—one for effectiveness and the other for the risk for significant injury [28]. That is, application of the power on the target can have both intended (reduced adversarial behavior) and unintended effects (significant injury or death). Therefore, the dose–response curves for both effectiveness and risk for significant injury must be included in any evaluation of a BEW.

Note that the solution space graph characterizes terminal ballistics of BEW. That is, the level of energy resulting in indicated effectiveness or probability of injury is the levels measured at the target. The x-axis depicts, for example, the force of impact on the skin or the power on impinging on the eye or ear. Like any other armament, BEW engineering must take into account the internal and external ballistic factors that result in the desired terminal ballistic properties (i.e., impact force or power on target).

Typically, the optimal solution space for BEW occupies the area between the two curves [28]. That is, application of the BEW fires dosage should be above the threshold for effectiveness but below the limit for significant injury. An idealized theoretical graph depicts sigmoidal functions where the limits dictated by risks of significant injury are higher than the thresholds for effectiveness (Fig. 3). However, it is not unreasonable to assume that if real data could be gathered, the real world graphs would be much different. Further complications arise when effectiveness and risk of injury are dependent on different mechanisms measured in different units.

There are also a few assumptions in the idealized graph. The first is that effectiveness is detected at levels lower than levels that inflict injury. This may not be the case. For example, in the case of blunt impact, significant damage can occur before a target ceases to advance (Fig. 4). A second assumption is that the functions are sigmoidal. This may also not be the case. For example, effectiveness may be linear or plateau at certain levels (Fig. 5), such as with the density of a fog obscurant preventing visual perception of a goal. The third assumption in the graphic is that there is only one mechanism for significant injury; this may not be the case with multimodal BEW (Fig. 6). The final assumption is that the mechanisms underlying effectiveness and mechanisms underlying injury are one and the same, or *coupled*, addressed in the next section.

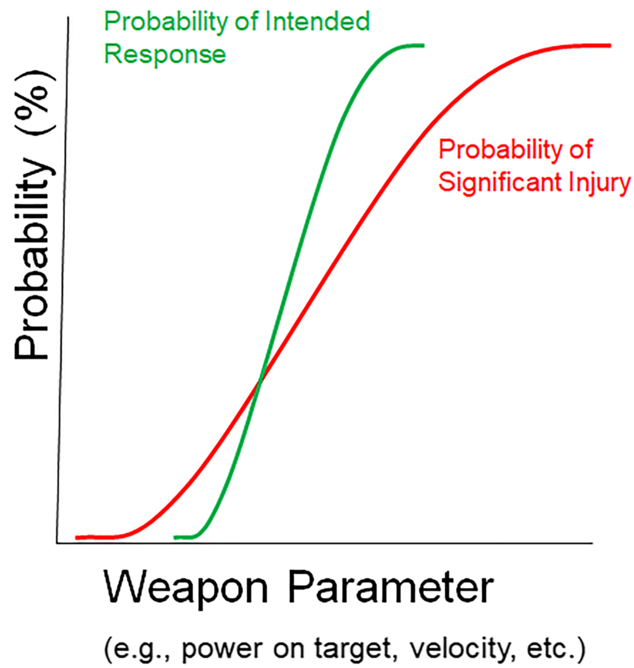

Fig. 4 Significant injuries may occur at levels lower than levels showing effectiveness

Coupling

Coupling captures the concept that the mechanisms of effectiveness are the same as those of injury. In other words, the *x*-axis of both the effectiveness and risk for significant injury graph share the same parameter. An example is an acoustic-based BEW, where lower decibels may result in the desired temporary threshold shift, but higher decibels may result in the unintended permanent threshold shift or loss of hearing. Conversely, the concept of uncoupled mechanisms reflects

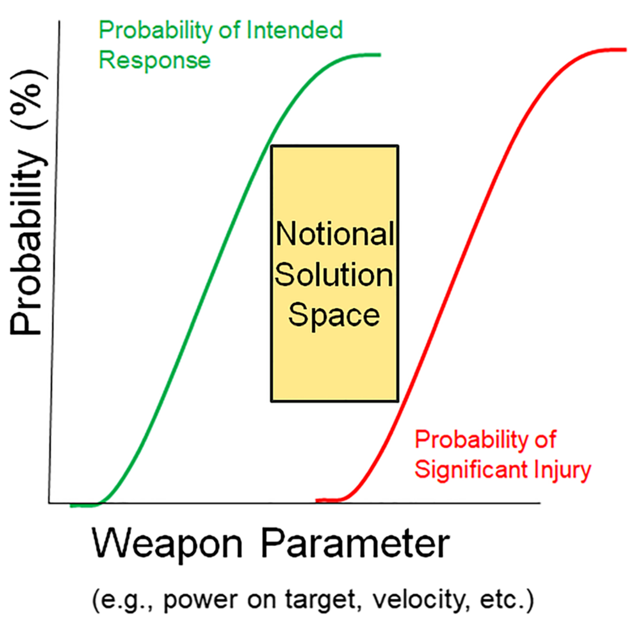

Fig. 3 Idealized solution space

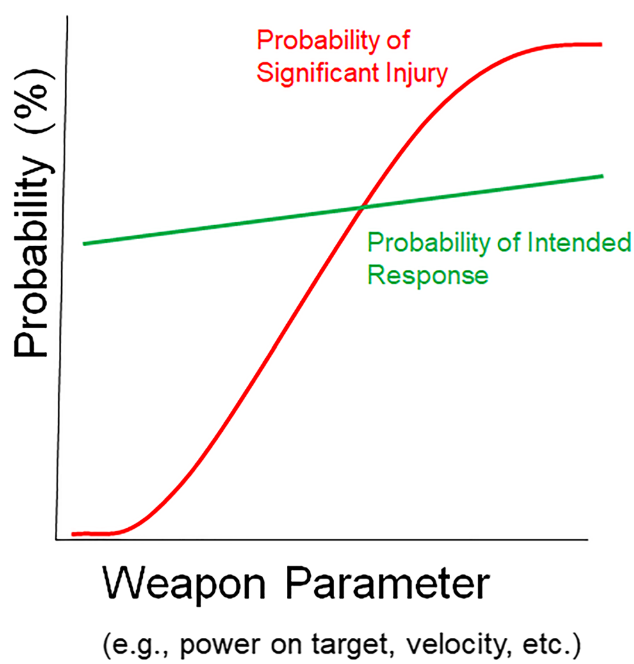

Fig. 5 Linear, asymptotic effectiveness

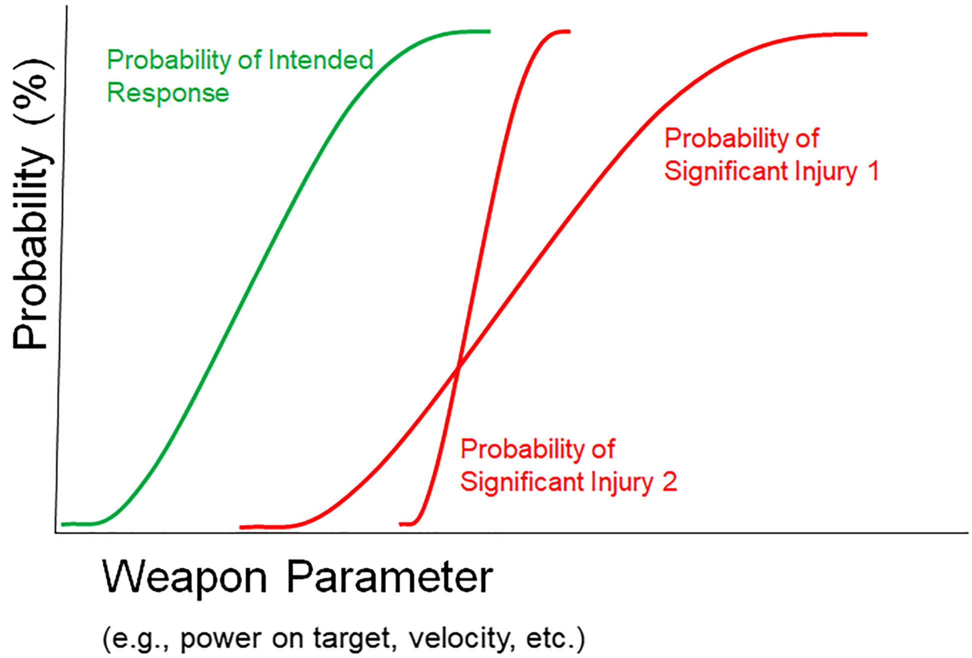

Fig. 6 Multiple risk of significant injury curves

the concept that the x-axis of the effectiveness graph is not the x-axis of the risk of significant injury. It may be useful for the engineer to aspire to the creation of devices where the mechanisms for injury are independent from the mechanisms for effectiveness. An example of such a BEW is low-lying fog, which produces visual obscurant effects due to light-scattering effects [29], while injury threat is due to inhalation of potentially toxic components, such as glycerin or propylene glycol. Developmental engineers may be inclined to develop BEW where effectiveness and injury mechanisms are uncoupled so that optimization of effectiveness and minimization of risk of injury can be separate problems to solve.

Data to Construct Curves

Creation of a solution space assumes that there are data to analyze and populate the dose–response curves. Curves are generated by a literature search of applicable information, by direct empirical observation and experimentation, or through validated modeling and simulation techniques. A review of the literature will reveal a lack of information on the effects or risks of BEW energies on a target. It is reasonable to expect that there is a large medical literature on curing physiological deficits and very little on causing physiological interference. Engineers are urged to look beyond the direct BEW literature and the defense community into clinical, biomedical, occupational health literatures, or other areas for information. However, in reading these sources, engineers should keep in mind that the factors of safety applied in these contexts differ from that found in BEW scenarios.

This guidance is especially important for novel energies and stimuli, where there may be no data with which to generate either curve. Experimentation, then, is a critical line of effort in developing the solution space for BEW creation. Guidelines for BEW experimentation, including human subjects research protections can be found in other articles [13, 30, 31].

Ethical Considerations: Principles of War and BEW

Armament engineers developing BEW must also give attention to the ethical aspects of BEW. During wartime, participating countries are expected to follow basic principles of war in order to be effective in their fight as humanely as possible [32]. The five basic principles are military necessity, unnecessary suffering, proportionality, distinction, and honor. These principles confirm the need for BEW, but also suggest specific design features for BEW.

Principles Confirming the Need for BEW

The principle of unnecessary suffering, which calls for humanity or humane treatment even in the midst of conflict, most directly points to the need for BEW. The principle of unnecessary suffering restricts soldiers from excessively injuring opposing forces to achieve the mission when the same result could be obtained with less force. Obviously, compared with other typical weapons, the intended non-lethal nature of BEW is in keeping with the principle of unnecessary suffering.

Almost as direct is the principle of proportionality. The principle of proportionality holds that the anticipated loss of life must not be excessive in relation to the advantage expected to be gained. BEW are touted for giving commanders options for "escalation of force" [13, 15] which are in keeping with the principle of proportionality—with BEW, the force that can be applied may be better calibrated to fit the military need.

The principles of distinction and honor also demonstrate the need for further development of BEW. The principle of distinction requires soldiers to identify an enemy combatant accurately prior to engaging. This is a challenging principle to adhere to because of how our recent adversaries operate. Terrorist groups typically do not have a uniform for soldiers to identify which has made it difficult to identify them from civilians. Therefore, BEW may be the preferred weapon of soldiers when they have difficulty in telling adversary from innocent. For example, the composition of a large crowd may be comprised of both bad actors and innocent civilians. In such a situation, a BEW may be preferred to a lethal weapon in order to mitigate innocent casualty.

With respect to the principle of honor, countries demand a certain level of respect for their property, cultures, traditions, and infrastructure. Soldiers are expected to honor this respect and not to upset the norm within the country where the conflict is taking place. Religious and traditional places of value must not be disturbed as long as it is not being used for military applications. BEW, with the typically low rates of collateral damage, allow Soldiers to adhere to this principle.

Principles Suggesting Design Features for BEW

The principle of military necessity leads commanders to consider whether if an attack is quick and efficient in defeating an enemy. A soldier must analyze the lawfulness of an attack based upon many factors. For example, a BEW such as tear gas should not be utilized in areas that have small children. However, if the circumstance requires the aerosol-based BEW to save the lives of the children in the area, then the principle of military necessity applies. Future technology development should support customizable features that allow users to tailor fires to the scenario in order to adhere to this principle of war.

Again, the principle of unnecessary suffering restricts soldiers from excessively injuring opposing forces to achieve the mission when the same result could be obtained with less force. It is unlawful to cause severe suffering while disabling an enemy to prevent further fighting. It is understood that suffering will inevitably occur in combat; however, the amount of suffering and how long it lasts is what should be regulated. Most BEW have reversible effects that are temporary. For example, human electro-muscular incapacitation devices were developed with the intent of creating a weapon that is capable of disabling an enemy combatant without causing permanent injury or extreme pain.

The principle of proportionality also provides guidance for soldiers in regard to collateral damage. If a soldier attacks a specific area, is it expected that the loss of civilian life or property is proportionate to the mission requirements. For example, it is understood that an attack on an area with a large civilian population is generally not allowed, unless the area is being used by enemy forces for military operation. Precision control of BEW levels targeting a general area would assist in minimizing collateral damage and provide our troops the appropriate amount of force for each individual mission. An example of a BEW that has a good capability of dose management is a "fogger-style" tear gas ejector. This BEW has a lever that allows the user to calibrate the output, that is, squeeze harder for more output, or not as hard for a slower distribution in a large area.

The Tool of Tactical Construct Method

Required sets of physical and mental capacities to carry out behavior vary from one adversarial behavior to another. Therefore, the appropriate capacities to target will differ according to targeted behavior and the operational scenario. This section presents a framework for identifying candidate stimuli, taking into account the operational scenario. The framework also provides guidance in creating sensitive testing and evaluation paradigms for research and development.

A higher level tool for assisting in the development of behavioral effects weapons is the "Tactical Construct Method" (TCM). The aim of the analytical tool is to take into account the tactical aspects of the missions, the characteristics of the human targets and the desired responses, and the possible technologies to affect those targets in the specific mission [17, 33]. In short, the tool assists engineers with thinking about the fit of the technology to the commander's intent. Moreover, the TCM tools identify tactically relevant testing situations to assess the effectiveness of prototypes and devices. That is, the exercise supports development of measures of effectiveness and measures of performance to aid in research and development, and testing and evaluation activities supporting engineering and acquisition decisions. Figures 7 and 8 show an outline of the tool. The initial step is to describe all that is known about the commander's intent for the use of the weapon, in the specific tactical scenario, and the desired outcome. Subsequent steps define the characteristics of the target, including the behavior that should be induced or reduced. These steps should point to behavioral metrics

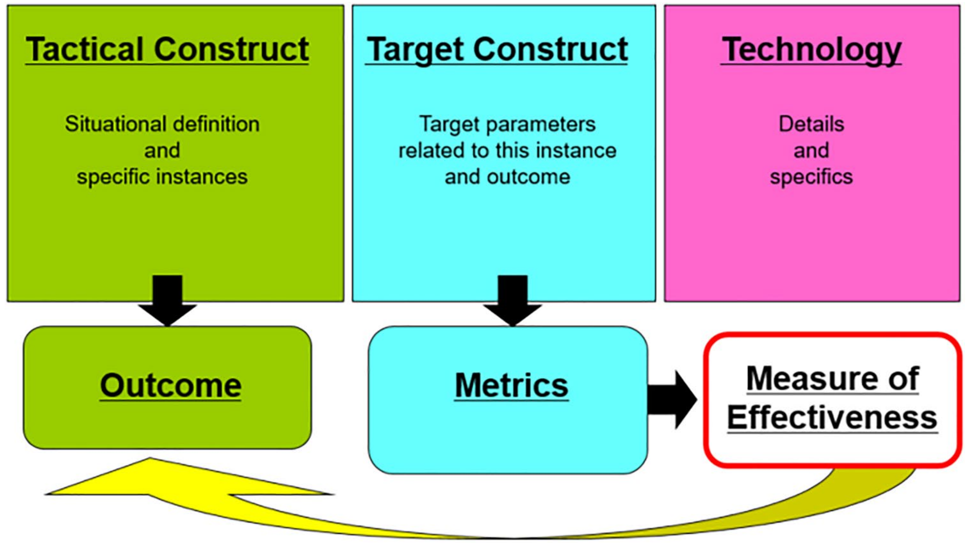

Fig. 7 Overview of the tactical construct method (TCM)

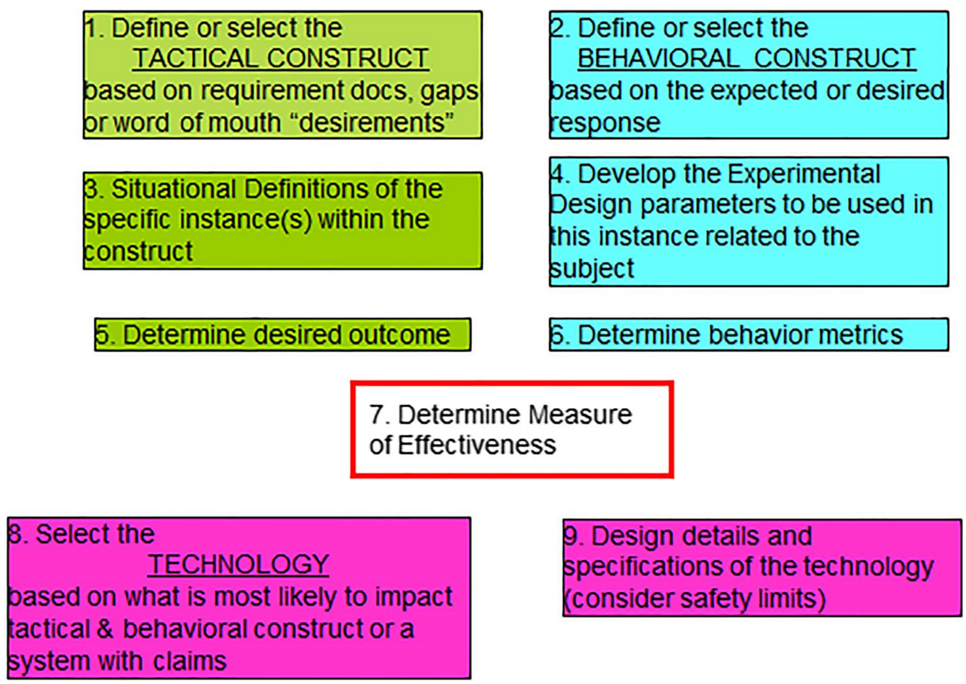

Fig. 8 Steps of the tactical construct method

that can be measured in the laboratory. These behavioral metrics should bear some resemblance to the targeted adversarial behavior in the field and yield operationally relevant measures of effectiveness.

Next are the steps of identification of the technology that is most likely to affect the tactical and behavioral constructs identified in the prior steps, including any safety limitations in the use of the technology. Organized using these methods, the information provides guidance on appropriate, iterative research and development, and testing and evaluation activities for the innovation of novel BEW.

A Caution

Engineers must be vigilant in proposing explicit underlying mechanisms, most especially those that involve motivational channels, specifically through aversion. Case in point are early claims of the effects of laser dazzlers and acoustic weapons. The initial intended effects of these weapons were to induce pain, aversion, and confusion in targets. Subsequent reports failed to support the claims, and now these devices are billed as non-lethal weapons functioning as communication or "hail and warn" devices.

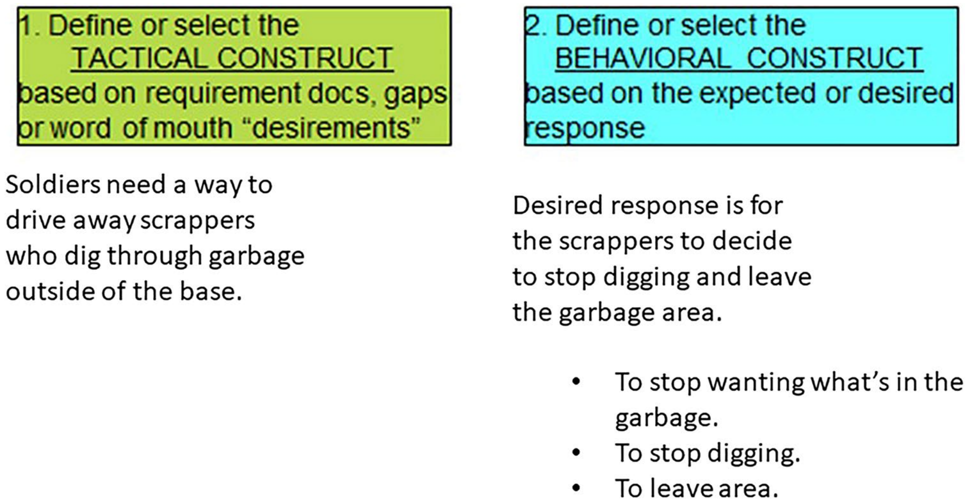

Fig. 9 Scrapper example for the TCM, steps 1–2

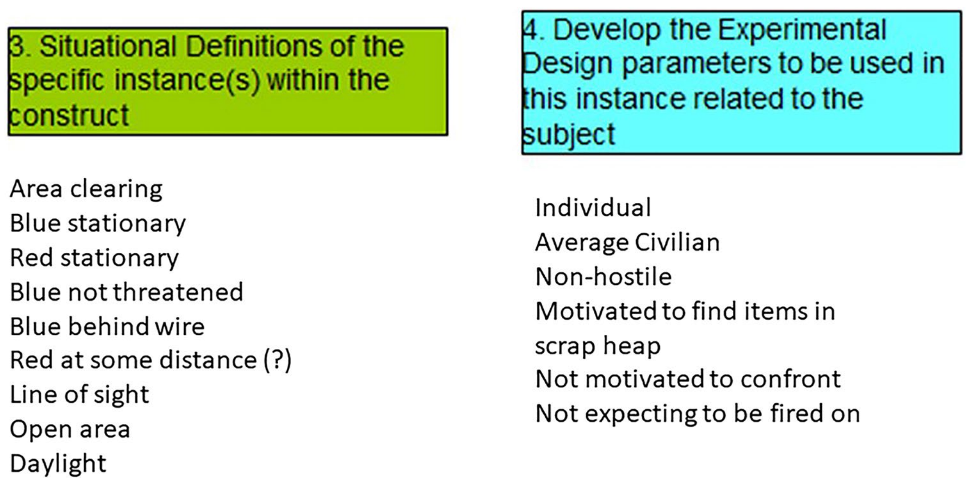

Fig. 10 Scrapper example for the TCM, steps 3–4

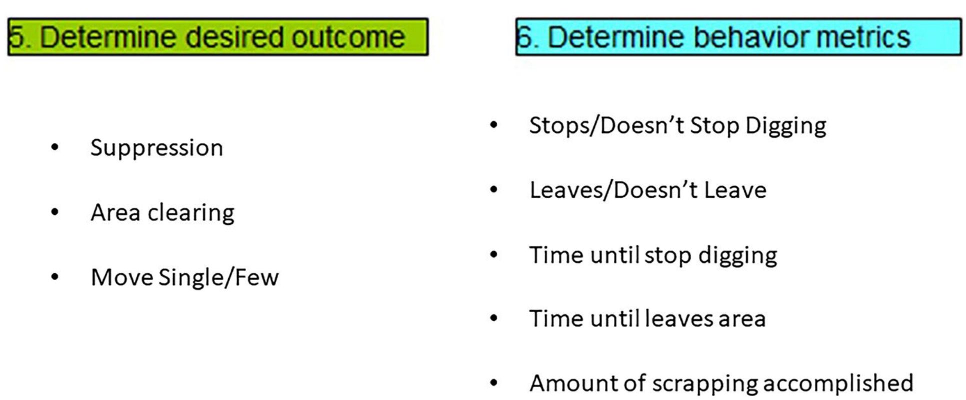

Fig. 11 Scrapper example for the TCM, steps 5–6

Thus, in development, engineers would do well to *never assume that any energy on target actually causes the psychological state critical to the operational effectiveness.* The critical questions to answer are (1) "Will the BEW do the job if it does not create sufficient changes in motivation?" (2) "Will the BEW do the job if it does not create

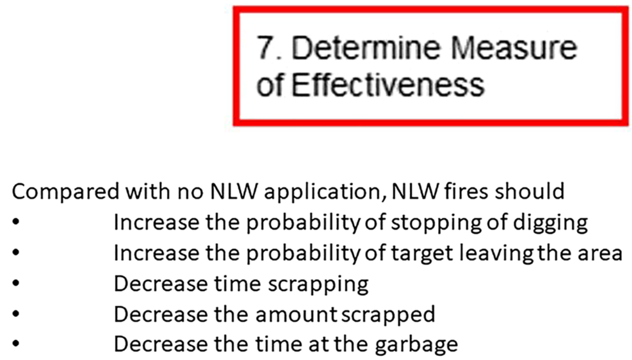

Fig. 12 Scrapper example for the TCM, step 7

pain, distress, or aversion?" If the answers are "No", developmental testing requires confirmation that those effects actually occur in the target.

An Example: Scrappers

An example for both the TCM and MoPs and MoEs is shown from Figs. 9, 10, 11, 12, 13, 14, 15, and 16. Soldiers have reported a problem with local civilians, "scrappers", who root through the refuse outside the base foraging for useful items that have been thrown away. Figures 9, 10, 11, 12, 13, and 14 demonstrate an application to this scenario, showing

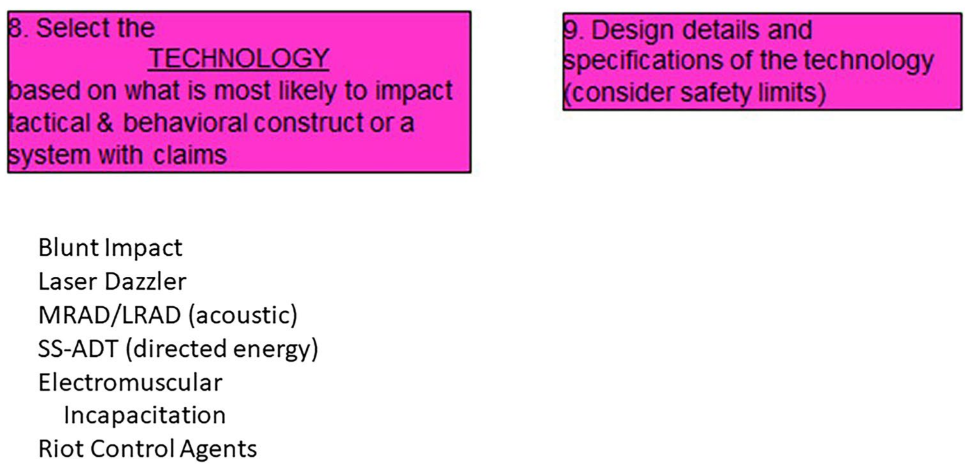

Fig. 13 Scrapper example for the TCM, steps 8–9, showing candidate technologies

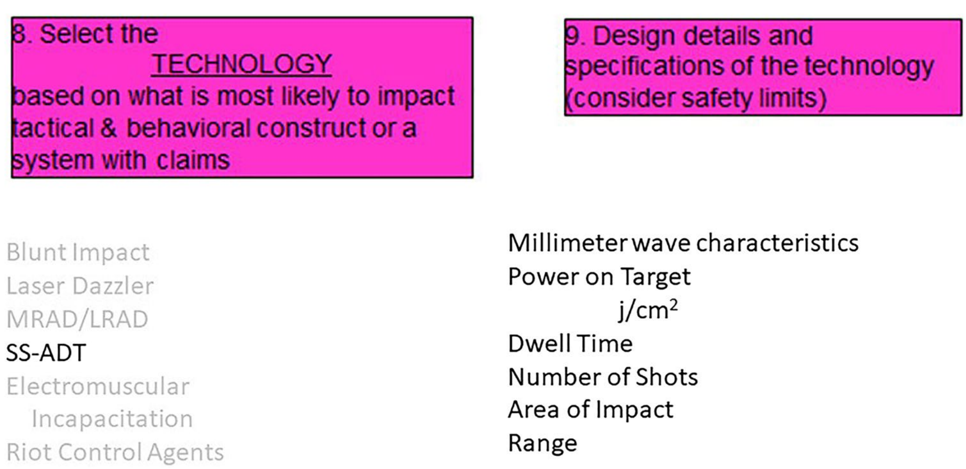

Fig. 14 Scrapper example for the TCM, steps 8–9 with SS-ADT selected as the technology

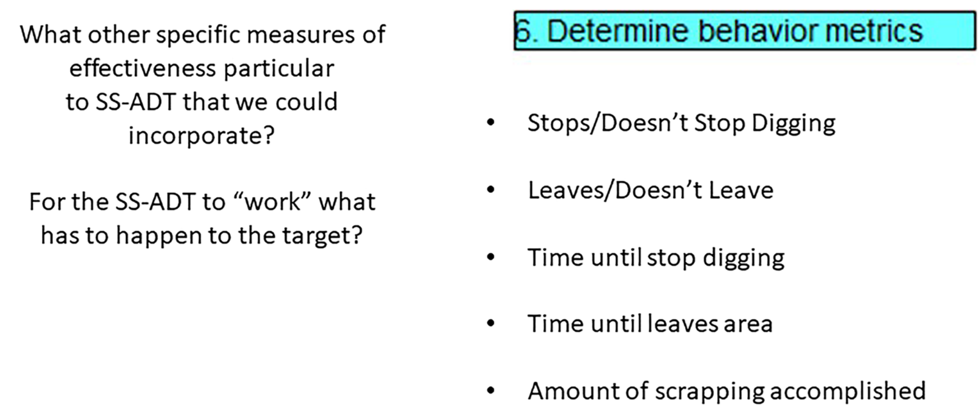

Fig. 15 Scrapper example for the TCM, revisiting step 6 to arrive at MoPs and MoEs specifically for SS-ADT

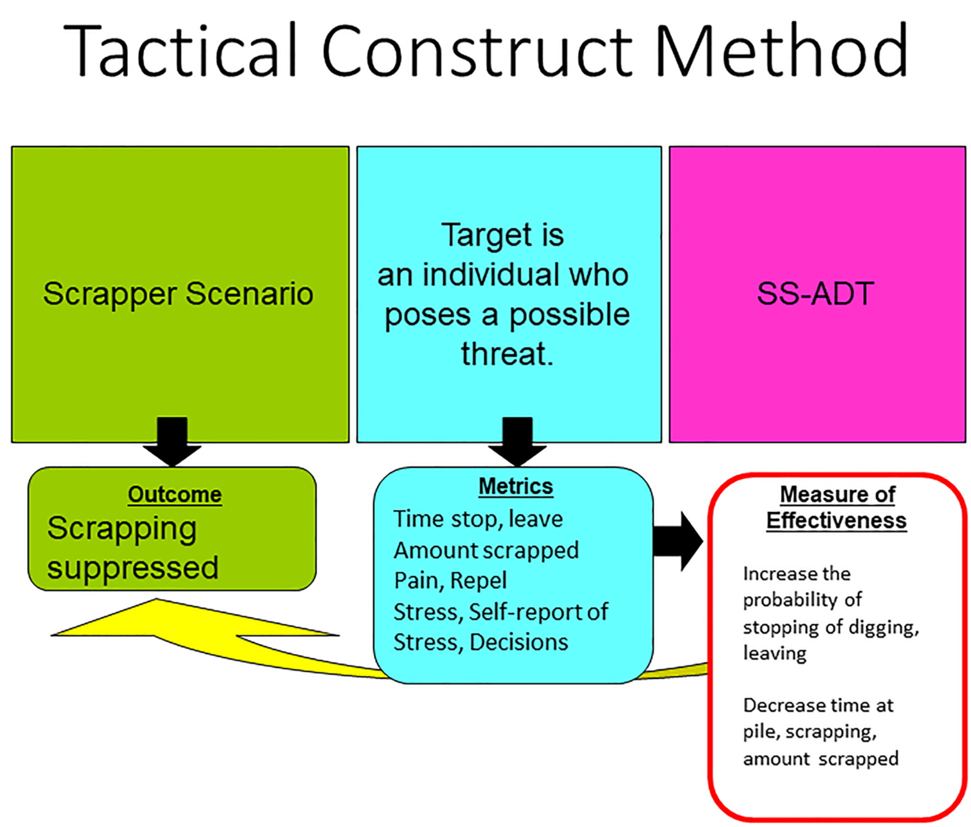

Fig. 16 Final overview of TCM for the use of SS-ADT in the scrapper scenario

Table 3 Measures and metrics of performance and effectiveness for SS-ADT effectiveness

Processes	Measures	Metric
Physiological effect	Heating	Change in skin temperature, infra-red camera
Physiological effect	Pain	Pain rating
"Repel" reflex	Behavioral observations	Coding of video recording
Escape, avoidance, evasion	Behavioral observation	Coding of video recording
Inducement of emotion, cognition, stress	Self-report	Questionnaire
Change in motivational state	Behavioral observations	Coding of video recording
Change in motivational state	Self-report	Questionnaire

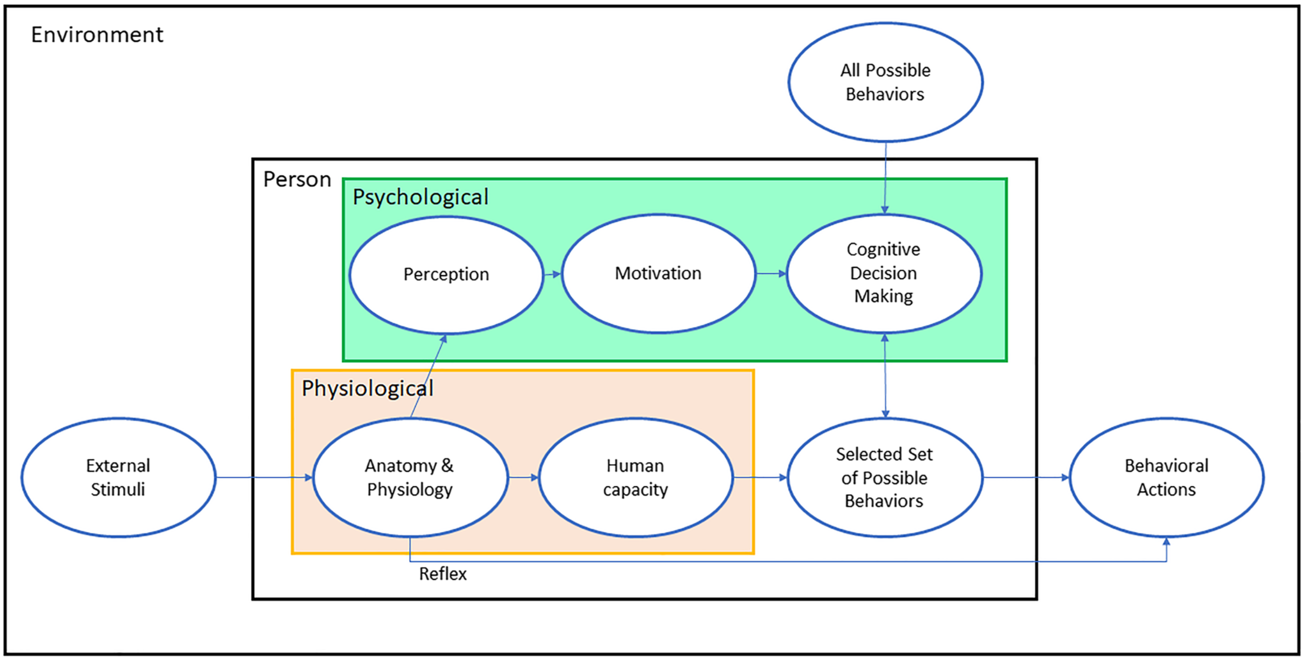

Fig. 17 Overview of BEW theoretical framework for armament engineers

the tactical, target, and technological considerations in arriving at a possible candidate solution. Table 3 and Fig. 15 show how specific MoEs and MoPs that can be associated with testing and evaluation of the candidate solution, in this case, directed mm-wave energies of the solid-state active denials technology (SS-ADT). Figure 16 shows the final overview TCM outline for the scrapper scenario.

Summary and Conclusion

A framework to assist in the development of novel behavioral effects weapons has been presented (Fig. 17). The main features are an emphasis on understanding the human physiological and behavioral responses, relevant ethical considerations, and designing a weapon with this knowledge in mind. This framework reveals possible mechanisms that can be leveraged and reveals the possible solution spaces reflecting known thresholds for effectiveness and limits for safety. Finally, the tactical construct method has been presented for aligning commander's intent, mission context, target behaviors, and candidate technology solutions.

For engineers, the BEW framework presents a way to organize information to identify gaps in knowledge and to trace the effects of power on target through underlying mechanisms to measures of operational effectiveness. We hope that this work provides support to armament engineers to address capability gaps in this challenging space.

Acknowledgements The authors would like to acknowledge the founders of the Target Behavioral Response Laboratory and the Tactical Behavior Research Laboratory, as well as the present and past staff.

References

1. Joint Chief of Staff (2018) Joint concept for integrated campaigning. Department of Defense, Washington DC, USA
2. US Department of Defense Non-lethal Weapons Program (2020) Intermediate force capabilities: bridging the gap between presence and lethality. Joint Intermediate Force Capabilities Office, Quantico
3. Annati M (2019) Non-lethal weapons have an important role in the majority of current operations. Military Technology, pp 33–35
4. Votel JL (2015) Statement of General Joseph L. Votel, U.S. Army Commander, United States Special Operations Command before the House Armed Service Committee Subcommittee on Emerging Threats and Capabilities

5. Christensen KD, Dobias P (2021) Wargaming the use of intermediate force capabilities in the gray zone. J Defense Model Simul Appl Methodol Technol 1–14
6. Headquarters Supreme Allied Commander Transformation (2020) NATO International Concept Development and Experimentation Conference 2020 Synopsis. Norfolk, VA
7. Kaurin PMS (2015) And next please? The future of the NLW debate. Case West Reserve J Int Law 47:217
8. Koplow DA (2015) Red-teaming NLW: a top ten list of criticisms about non-lethal weapons. Case West Reserve J Int Law 47:229
9. Fridman O (2015) Nonlethal weapons: a technological gap or misdefined requirements? Joint Force Q 76(1):71–77
10. D'Agostino DM (2009) DOD needs to improve program management, policy, and testing to enhance ability to field operationally useful non-lethal weapons. GAO Reports, Preceding.: p 1–64
11. Carter BW (2016) Non-lethal weapons: a technology gap or lack or available systems, training, and proper application. US Army Command and General Staff College Fort Leavenworth United States
12. Tafolla TJ, Trachtenberg DJ, Aho JA (2012) From niche to necessity: integrating nonlethal weapons into essential enabling capabilities. Joint Force Q 66(3):71–79
13. Mezzacappa E, Cooke G, DeMarco RM, Reid GV, Tevis K, Sheridan C, Short KR, Jaffery N, Riedener JB (2017) Effectiveness test and evaluation of non-lethal weapons in crowd scenarios: metrics, measures, and design of experiments. Defense Acquisition Res J 24(3)
14. Carlson NR, Birkett MA (2016) Physiology of behavior. Pearson
15. Goldstein EB, Brockmole J (2016) Introduction to perception, in sensation and perception. Cengage Learning, Boston
16. Joint Non-lethal Weapons Program (2009) Initial capabilities document for counter-personnel joint non-lethal effects
17. North Atlantic Treaty Organization (2009) NATO NLW Capabilities-based assessment (SAS-078)
18. Metz D, Smardzewsk R, Lochner C (2019) Counter-personnel (CP) non-lethal weapons (NLW) technologies DSAIC
19. American Psychological Association, *Motivation*. 3 July 2021; Available from: https://dictionary.apa.org/motivation
20. Short KR, Bergen MT, DeMarco RM, Chua FB, Servatius RJ (2006) Blunt impact as deterrent: Human approach-avoidance behaviors and other stress responses studied within a paintball gaming context. In: Enabling technologies and design of nonlethal weapons. International Society for Optics and Photonics
21. Short K, Reid G, Cooke G, Minor TR (2010) Can repeated painful blunt impact deter approach toward a goal? (ADA633181). Proceedings of the 26th Army Science Conference, December 2010
22. Lewin K (1997) Resolving social conflicts and field theory in social science. American Psychological Association
23. Mezzacappa E, Cooke G, Sheridan C, DeMarco R, Tevis K, Short K, Reid G, Jaffery N, Riedener J (2017) A behavioral experiment on the effects of nonlethal weapon parameters on crowd rock-throwing behavior. Mil Oper Res 22(4):17–34
24. Cooke G, Mezzacappa E, Sheridan C, DeMarco R, Tevis K, Short K, Reid G, Jaffery N, Riedener J (2010) Topology and individual location of crowds as measures of effectiveness for non-lethal weapons (ADA633178). Proceedings of the 26th Army Science Conference, December 2010
25. Lewin K (1946/1997) Behavior and development as a function of the total situation Reprinted. Field Theory in Social Science: Selected theoretical papers
26. Burgei W, Foley S, Pandullo M, Nass-Flores M, Fischer GL, Huntzinger H, Beier E, Heerema B (2017) Implementation guidance document: properties and types of significant photothermal retinal lesion injuries. Joint Non-Lethal Weapons Directorate, Quantico
27. North Atlantic Treaty Organization Research and Technology Organization (2009) RTO-TR-SAS-060 Non-lethal weapons effectiveness assessment development and verification study (ADA511388)
28. Joint Non-lethal Weapons Program (2016) Joint non-lethal weapons program science and technology strategic plan. Quantico
29. Mezzacappa E, DeMarco R, Reid G, Dominguez L, Moderski I, Dyer S, Sheridan C, Jaffery N, Robinson A, Cooke G (2019) Target behavioral response analyses for the development of delay munitions: obscuring fog for non-lethal anti-personnel landmines. Hum Fac Mech Eng Def Saf 3(1):1–15
30. Mezzacappa E (2014) Effectiveness testing of non-lethal weapons. J Def Model Simul 11(2):91–101
31. Mezzacappa ES (2020) Human subject research protection ethics in the research and development (R&D) of non-lethal weapons. J Milit Ethics 19(3):241–258
32. Preston SE, Taylor RS (2016) Department of Defense Law of War Manual, General Counsel of the Department of Defense Washington United States
33. Yagrich K (2003) Nonlethal weapons requirements definition– a difficult task requires a true team effort. Military Police