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Causal Analysis Model

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Updates to the Flashbang Causal Model

A. Executive Summary

This report provides updates to the causal analysis model originally formulated in "Path Analysis of Human Effects of Flashbang Grenades" (IDA Document D-9270). The model outlines the physiological and physiological effects of flashbang grenades and describes the central role of the stress response on human characterization of the weapon system. The updates, which reflect key findings from an interdisciplinary array of literature (e.g., neuroscience, psychology, sociology), focus on acoustic, vision, and overpressure effects and the stress response. The performance outcomes are also updated.

B. Background

In 2003, the National Research Council (NRC) reviewed non-lethal weapons (NLW) studies and initiatives in order to identify promising areas of research in the science and technology (S&T) underlying the use of such weapons.[1] Although the NRC committee's review did not include flashbang devices,[2] their conclusions and recommendations regarding S&T gaps broadly applied to all NLWs. Despite the research regarding health and human effect outcomes (which focus on injury and mission effectiveness, e.g., crowd dispersal), the committee concluded that NLW effectiveness was poorly understood. For example, given that the objective of NLW deployment is to change the behavior in a targeted group or individual, little evidence regarding the cognitive and psychological effects on behavioral outcomes due to NLW exposure exists. The committee identified the need for additional research in "fundamental biomechanical and physiological response mechanisms; translation of effects on individuals into effects on groups and/or effects associated with repeated exposure; development of effects models; and implementation of the models in experiments, testing, and wargaming environments (p. 6)" (National Research Council, 2003).

Prior work conducted by IDA on the human effects of flashbangs includes Madhaven & Dobbins (2018) who developed a theoretically-driven causal analysis model that isolated the physiological and psychological effects of flashbangs. The causal diagram identified five immediate effects of flashbangs: 1) overpressure effects – the physiological effects of sudden increases in air pressure following the detonation of a flashbang, 2) acoustic effects – the

[1] This work, commissioned by the Joint Non-Lethal Weapons Directorate (JNLWD) and the Office of Naval Research (ONR), included a number of tasks, including a review of JNLWD program of record to the identification of programs that either duplicate efforts in the area or could benefit from the leveraging of other resources

[2] Because JNLWD and ONR sponsored the study, the committee focused on mission areas of interest for the sponsor. Thus, the NLWs reviewed fell into six categories: 1) kinetic-energy technologies, 2) chemical and materials technologies, 3) directed-energy technologies, 4) acoustic technologies, 5) electrical technologies, and 6) barriers and entanglements (NRC, 2003, p. 24).

consequences of sudden loud bursts of sound characteristic of the “bang” component on the human neural and motor systems, 3) startle effects – the shock or “startle” element associated with flashbangs and psychological and physiological distress it might trigger (see Madhaven and Srinivasan 2017, for a comprehensive review of the startle response to flashbangs), 4) StartReact – a potential improvement in the performance of planned motor movements, and 5) vision effects – the consequences of sudden blinding bursts of light characteristic of the “flash” component on the human oculomotor and other systems. Based on these five immediate effects, Madhaven and Dobbins (2018) developed a detailed causal diagram that illustrates the sequential steps in human responses starting with deployment of a flashbang and ending with final performance outcomes (see page 7 for complete (updated) model).

The goal of the current memo is to outline key evidence-based modifications to the causal analysis model, present a “trimmed” version of the model highlighting those causal paths that are experimentally testable, and finally provide two tables outlining areas of focus for future human subject’s experiments.

C. Methodology

We used two approaches in order to modify the causal analysis model and propose future directions for experimentation and research: 1) Adopting a list of questions proposed by the National Research Council in assessing the development and effectiveness of NLW systems, and 2) Conducting an in-depth literature study synthesizing research from a number of relevant and interdisciplinary fields.

Part of modifying the causal model is understanding which paths are worthy of experimentation. To assess which areas are most fruitful to study, we need to also know the current research landscape for FBG and gaps in knowledge. Due to poor understanding of NLW effectiveness, the NRC committee noted that system concepts and assessments are underdeveloped and subsequently comprised a list of questions that provide insights into overall system effectiveness (see NRC, 2003, Table 3.1). Since there are many dimensions to assessing the effectiveness of flashbangs, to organize our approach, we adopted this set of questions from the NRC to organize the current state of research for FBG. We have modified this list of questions to focus on the target effects of flashbang devices. Specifically, we reviewed existing research to address each question and identified knowledge gaps which can be addressed with additional targeted research (see Table 1). Further, we included comments that either provide clarifying information regarding the question and research gaps or provide additional considerations for study development in addressing the stated gaps. An iterative research process is required to address some of the research questions. For example, in order to collect sufficient data/results to understand the human effects, systematically planned studies that examine the effects of each flashbang component in both individuals and groups on cognitive, behavioral, and social outcomes are needed. In the planning of such studies, the research team will need to define and justify the validity of the operational context that each study simulates, the metrics of interest, the desired performance outcomes/objectives, etc. Researchers should also consider human subjects testing policies when developing these studies.

Overall, this approach allowed us to systematically outline the research that needs to be done to provide richer insight into flashbang grenade effectiveness. The proposed research for flashbangs consists primarily of human subject experiments progressing from testing first order sensory effects to testing cumulative effects of flashbang components. In addition to behavioral experiments, we also identify key areas that need further exploration in the form of literature reviews and analysis (e.g. the role of stress).

Table 1. Questions on the effectiveness of flashbang devices

Effectiveness of NLW questions	Existing Research	Needed Research	Comments
Is there a solid understanding of the scientific principles behind the observed weapon effects?	• Causal analysis is a start	See below • Examine video footage of FBG deployment in different operational contexts; can this be used to model crowd behavior?	Need to define “effects.” Can be (at individual and group levels): • Behavioral/cognitive • Sensory • Physical (e.g., injury)
Is there a solid understanding of how it affects the human body?	• Startle paper • Causal analysis • Risk of significant injury work	• Risk of significant injury work continued • Examine effects of each component individually to understand sensory effects • Exposure-response data regarding exposure to the weapon and time it takes to return to baseline functioning. • Examine effects of combined components	This question is read as focusing on physical effects. We have dose-response data on sound (dB) exposure and tinnitus, but not on: • Sound exposure (tinnitus and TTS) and time it takes for hearing to return to normal (e.g., duration of physical effects). • Light exposure and time it takes for vision to return to normal (flash blindness)

Is there an understanding of why the weapon has the human effects observed?	N/A	• Examine effects of each component to understand individual and group (where applicable) sensory effects in terms of:
		  • Behavioral/cognitive outcomes
		  • Social outcomes
		• Examine effects of combined weapon components
			This question is read as focusing on behavioral/cognitive/social effects. We need to:
			• Define operational context, metrics, performance outcomes, etc.
			• Identify the critical weapon component(s) that maximizes degradation of human performance (i.e., identify which component(s) is critical to maximize operational effectiveness of weapon)
			• Include operational context and objective of the use of the weapon in study development
			• Consider social psychological impacts on observed human effects (e.g., motivation, group identity and loyalty, crowd dynamics)
			• Consider human subjects testing for study development
			• Mezzacappa et al. (2017) measured effectiveness, not WHY effects are observed

Is there sufficient scientific data/results supporting the understanding of why weapon has the observed human effects?	N/A	• Continue examining why weapon has observed human effects until there is sufficient confidence in the findings (e.g., reproducibility, validation)	• Consider validity of study paradigms and reliability of findings. • Iterative research process – repeat studies to understand why weapon has human effects observed until sufficient confidence in findings obtained.
Are there benefits from combining new technology with others to create synergies?	N/A	• Revisit previous questions and conduct aforementioned studies looking first at varying frequency, intensity, duration of weapon components. • Next, examine effects of the combinations of weapons.	• Iterative research process – as new technologies are combined (or components are varied), will need to develop solid understanding of how new weapon affects human body, why it has the observed human effects, if there is sufficient scientific data supporting why weapon has observed human effects.

D. Updates to causal model

In reviewing the literature regarding the scientific principles behind the observed flashbang device effects, we re-examined the causal analysis of flashbang grenades by Madhavan and Dobbins (2018). We looked for additional evidence to support our understanding of how flashbang devise exposure affects the human body, not only in terms of sensory and potential injury effects, but also from the perspective of the cognitive and psychological effects of exposure on desired behavioral outcomes. Based upon our review of the psychophysical effects of flashbang device exposure, we made the following updates to the causal analysis (See Figure 1):

1. Acoustic

Although some disorientation may result from tinnitus and/or temporary threshold shift, literature on chronic tinnitus and permanent threshold shift show that these psychophysical outcomes serve as cognitive distractions (vs. disorientating factors). The causal analysis has been updated to reflect this finding.

2. Vision

Both flash blindness and presence of an afterimage result from bleached photopigments - the revised causal analysis accurately depicts this relationship.

3. Overpressure

The first update for overpressure focuses on cardiorespiratory dysfunction: The cardiorespiratory dysfunction and vasovagal reflex are related. Specifically, the vasovagal reflex results in bradycardia, increased respiration, and hypotension, all of which signal cardiorespiratory dysfunction. The updated causal analysis reflects this change.

The second update for overpressure focuses on dizziness: The literature suggests that dizziness can result from vestibular system damage from blast overpressure and/or from a combination of the stress response and subsequent affective shift. The updated causal analysis reflects this finding.

4. Stress

One of the more significant updates regards the placement and role of stress. The stress response can be activated by exposure to the bang, the flash, and/or the overpressure, therefore, it has been repositioned as a separate effect and no longer as an effect coming only from overpressure. The centuries of animal and human psychological/cognitive literature on the stress response highlights its potential importance in the behavioral outcomes of flashbang exposure. IDA recommends additional research regarding the role of the stress response for flashbang effects.

5. Performance outcomes

There are two changes to performance outcomes: 1) We combined targeting accuracy with target detection, as targeting accuracy would not be a relevant metric if the target is not detected, and 2) We included dispersal or exit as a performance outcome as crowd dispersal can be a key objective for the use of flashbang devices.

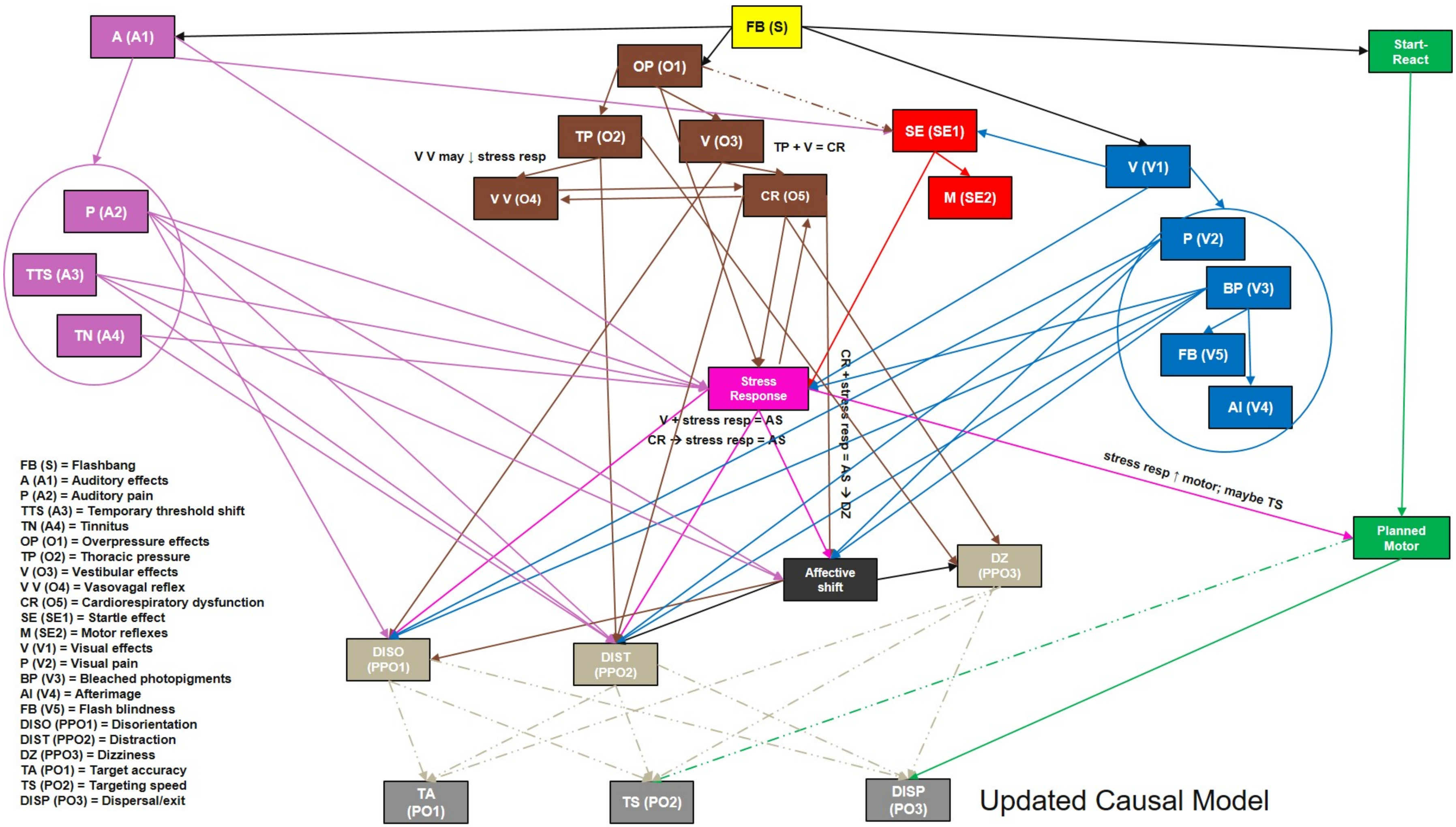

Figure 1. Updated flashbang device path analysis

E. Proposed outline of studies based on causal model

In order to determine whether there are any benefits to combining other NLW technologies with flashbang devices, it is necessary to first conduct the systematic studies needed to understand how and why flashbang deployment results in the observed human effects and to identify which component (or combinations of components) are critical to maximize operational effectiveness of the flashbang device. Once sufficient findings/results are collected, studies that vary the critical component(s) of flashbang devices can be undertaken. For example, researchers can vary the frequency, intensity, or duration of the flash or bang components or remove components that prove to be irrelevant to the intended outcome, which in turn, require additional studies to understand how and why the manipulation of the components lead to the observed physical, cognitive, psychological, and behavioral human effects.

We reanalyzed the causal analysis using the National Research Council's (2003) list of NLW effectiveness questions to identify which component effects, psychophysical outcomes, and performance outcomes were suitable for empirical examination (See Figure 2). We removed all components of the causal analysis that are not feasible to study due to human subjects protection policies. We then used this information to develop a list of studies that:

1. Examine the first order effects of single flashbang components in order to identify which component(s) is critical for affecting human performance (or flashbang operational effectiveness) (See Table 2) and
2. Examine the cumulative effects of flashbang components in order to identify the critical combination(s) of components for affecting human performance (or flashbang operational effectiveness) (See Table 3).

The list of potential studies includes the sensory effects that can be experimentally induced and examples of relevant outcome measures. We do not suggest that each study is required to understand the cognitive, psychological, and behavioral effects of flashbang exposure. For example, it may be that the presence of an afterimage has no impact on the desired operational outcomes of flashbang exposure, however, no empirical evidence exists at this time to confirm (or disconfirm) this conclusion. Additional research on the psychophysical effects of the components can address known literature gaps such as exposure-time to recovery data on tinnitus, temporary threshold shift, flash blindness, and cardiorespiratory function due to acute stimuli presentations such as those created by FBGs. In other words, dose-response data exist regarding sound (dB) exposure and the presence/appearance of tinnitus but no such data exist in terms of sound exposure and time it takes to return to baseline functioning (e.g., duration of psychophysical effects).

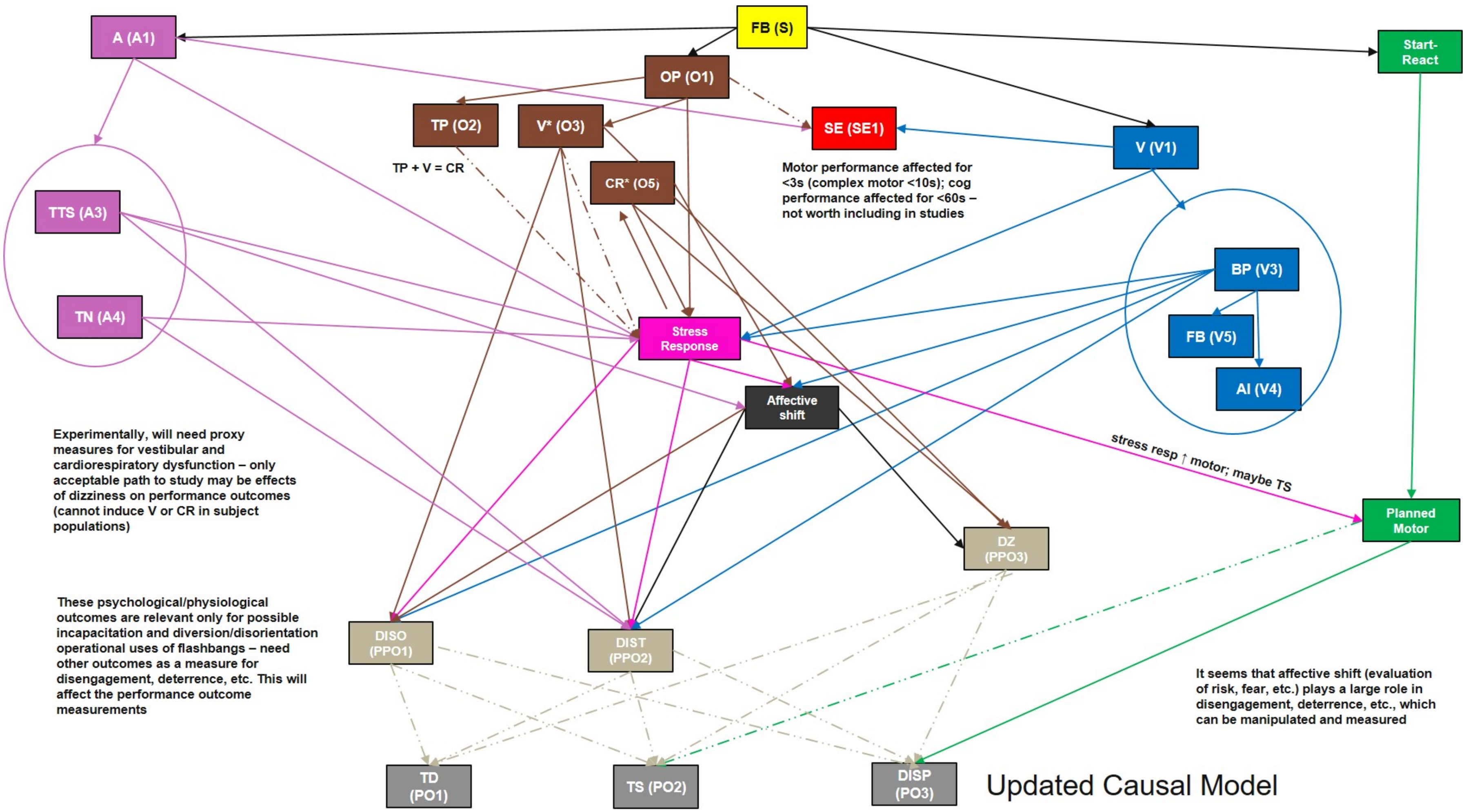

Figure 2. Possible experimental variables from flashbang device path analysis

Table 2. Potential first order effectiveness experiments for flashbang devices

Goal and objective: To understand first order effects of single flashbang components with the objective to identify critical components that are likely to degrade human performance

Component	Sensory effects focus of study	Possible Measures/Areas of Inquiry	Comments

Auditory (bang) – include measures of stress response	• TTS
	• Tinnitus
		• Auditory task:
		  • TTS and/or tinnitus (separately) effects on distraction
		  • Distraction effects caused by TTS and/or tinnitus (separately) on auditory targeting accuracy, speed of detection (speech comprehension; sound localization)
		• Visual task (does bang affect visual tasks?):
		  • TTS and/or tinnitus (separately) effects on distraction
		  • Distraction effects caused by TTS and/or tinnitus (separately) on visual targeting accuracy, speed of detection
		• Effects of TTS and/or tinnitus on stress response (and affective shift)
		• Distraction effects caused by stress response due to TTS and/or tinnitus on targeting accuracy and speed (using both auditory and visual targets separately)
			Tikuisis et al (2009) show that aiming and shooting behaviors can be delayed by 1-2.5 sec in response to sound bursts of 110, 120, and 130 dB – so sound can affect visual accuracy and targeting speed.

Overpressure – include measures of stress response	• Vestibular dysfunction
	• CardiorAespiratory
	• Thoracic pressure
		• Balance task (proxy for vestibular dysfunction [VD]):
		  • Time to recover balance (i.e., duration of VD)
		  • VD effects on cardiorespiratory measures (HR, respiration, BP - can be collected simultaneously with other measures)
		  • VD effects on disorientation, distraction, and dizziness and role of stress response (and affective shift) on these physiological outcomes
		  • Effects of physiological outcomes (dizziness, distraction) caused by VD on targeting accuracy and speed (using both auditory and visual targets separately)
		  • Effects of physiological outcomes (dizziness, distraction) caused by stress response due to VD on targeting accuracy and speed (using both auditory and visual targets separately)
		• Effects of thoracic pressure on stress response, cardiorespiratory measures
		• Distraction effects caused by thoracic pressure on targeting accuracy, targeting speed, and dispersal
		• Distraction effects caused by stress response due to thoracic pressure on targeting accuracy and speed (using both auditory and visual targets separately)
			There is a min and max level of pressure that can be associated with a flashbang – the min amt is an engineering issue (strength of explosion) and max amt is enough to not cause vestibular/auditory injury or mTBI. In other words, there seems to be little we can manipulate in regards to pressure.

Visual – include measures of stress response	• Afterimage
	• Flash blindness
		• Visual task:
		  • Afterimage (AI) and/or flash blindness (FB) (separately) effects on distraction and disorientation
		  • Distraction effects caused by AI and/or FB (separately) on visual targeting accuracy, speed of detection
		• Auditory task (does flash affect auditory tasks?):
		  • Distraction and disorientation effects due to AI and/or FB (separately)
		  • Distraction effects caused by AI and/or FB (separately) on auditory targeting accuracy, speed of detection (speech comprehension; sound localization)
		• Effects of FB and/or AI on stress response (and affective shift)
		• Distraction effects caused of stress response (and affective shift) due to FB and/or IA on targeting accuracy and speed
			Flash blindness lasts for only a few seconds (up to <2 minutes) in daylight and partial recovery occurs between 3-10 min. In low-light, flash blindness lasts longer. But, due to defensive reflexes that kick in within msecs, exposure to the flash will be minimal in both regular and low-light conditions. It would be useful to understand how long the flash blindness and/or afterimage affect performance.
			
			It is an empirical question as to which (afterimage or flash blindness) impairs performance more.

Table 3. Potential effectiveness experiments for cumulative components of flashbang devices

Goal and objective: To understand cumulative effects of flashbang components in order to identify critical combinations of components that are likely to degrade human performance

Component	Sensory effects focus of study	Possible Measures	Comments

Auditory (bang) + Overpressure – include measures of stress response	• TTS
	• Tinnitus
	• Thoracic pressure or vestibular dysfunction
	• Cardiorespiratory
		• Auditory task:
		  • Bang (TTS or tinnitus) and thoracic pressure (or vestibular dysfunction [VD]) effects on distraction, disorientation, and dizziness
		  • Effects of physiological outcomes (distraction, disorientation, dizziness) caused by bang and thoracic pressure (or VD) on targeting accuracy and speed using both auditory and motor/balance targets separately
		• Effects of bang and thoracic pressure (or VD) on cardiorespiratory measures (HR, respiration, BP can be collected simultaneously with other measures)
		• Effects of physiological outcomes (distraction, dizziness) caused by stress response due to bang (TTS or tinnitus) and thoracic pressure (or VD) on targeting accuracy, targeting speed, and dispersal (using both auditory [speech comprehension; sound localization] and motor/balance targets separately)	

Visual + Overpressure – include measures of stress response	• Afterimage
	• Flash blindness
	• Vestibular system
	• Cardiorespiratory
		• Visual task:
		  • Flash (after image [AI] or flash blindness [FB]) and thoracic pressure (or vestibular dysfunction [VD]) effects on distraction, disorientation, and dizziness
		  • Effects of physiological outcomes (distraction, disorientation, dizziness) caused by flash and thoracic pressure (or VD) on targeting accuracy and speed using both visual and motor/balance targets separately
		• Flash and thoracic pressure (or VD) effects on cardiorespiratory measures (HR, respiration, BP can be collected simultaneously with other measures)
		• Effects of physiological outcomes (distraction, dizziness, disorientation) caused by stress response due to flash (AI or FB) and thoracic pressure (or VD) on targeting accuracy, targeting speed, and dispersal (using both visual and motor/balance targets separately)
			There will always be a sound with the explosion (which will cause overpressure) – but it really depends on the timing of the flash and the bang – if the flash and bang occur simultaneously, the flash might be seen a split second before the overpressure is felt and then the explosion is heard

Auditory + Visual + Overpressure – include measures of stress response	• TTS
	• Tinnitus
	• Vestibular system
	• Cardiorespiratory
	• Afterimage
	• Flash blindness
		• Auditory task:
		  • Effects on distraction, disorientation, and dizziness using auditory target (speech comprehension, sound localization)
		  • Effects of physiological outcomes (distraction, disorientation, dizziness) caused by flashbang on targeting accuracy and speed using auditory target (speech comprehension, sound localization)
		• Visual task:
		  • Effects on distraction, disorientation, and dizziness using visual target
		  • Effects of physiological outcomes (distraction, disorientation, dizziness) caused by flash bang targeting accuracy and speed using visual target
		• Effects of flash bang on cardiorespiratory measures (HR, respiration, BP can be collected simultaneously with other measures)
		• Effects of physiological outcomes (distraction, dizziness, disorientation) caused by stress response due to flash bang on targeting accuracy, targeting speed, and dispersal (using both auditory [speech comprehension; sound localization], visual, and motor/balance targets separately)
			Other factors to consider:
			• Populations of interest – military vs. civilian
			• Variations in frequency, intensity, duration, stimulus presentation schedule (fixed vs. variable sequences) of critical components - the stress response (and associated affective shift might be the critical variable in human performance degradation. If true and depending on what the first-order and critical combination studies identify as the critical component(s) of flashbangs, these series of experiments may help to develop flashbangs with maximum effectiveness (human performance degradation)

F. Recommendations

This memo outlined key updates to the causal analysis model. The model serves to generate defensible and testable hypotheses for flashbang grenades in the form of behavioral experiments.

IDA makes the following recommendations:

- IDA should continue to work closely with JNLWD and JNLWD-funded performers to design and implement a range of human subject experiments:
  - IDA has primarily worked with AMERICAN SYSTEMS and GTRI in FY2019 in the pursuit of designing and implementing a novel virtual reality experiment exploring the acoustic effects of flashbangs on performance in an operational relevant scenario
  - IDA has begun working with ARA in a similar pursuit and will continue to do so in FY2020. ARA's behavioral experiment and test design needs assessing prior to testing
- IDA should focus research on the central role of stress and its related behavioral effects including research on potential moderator variables (e.g. exercise) that can affect behavioral outcomes, and consider research on predictable vs unpredictable stressors.
- IDA should focus research on cognitive and psychological aspects of flashbangs in an effort to better understand the role of cognition in flashbang effectiveness (e.g. determining effective ways to test "distraction", looking at perception, working memory, and communication)
- IDA should continue to develop an appropriate experimental and research roadmap
- IDA should assess the parts of the causal model the performers are testing

References

Madhavan, P., and Dobbins, C. (2018). Path analysis of Human Effects of Flashbang Grenades. Institute for Defense Analyses.

National Research Council (2003). *An assessment of non-lethal weapons science and technology*. Washington, DC: The National Academies Press.

Causal Analysis Model Briefing

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1/14/2020

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Background

- National Research Council (NRC) reviewed non-lethal weapons studies and initiatives in order to identify promising areas of research in S&T underlying the use of these devices.
- NLW effectiveness is poorly understood, especially regarding cognitive and psychological effects on behavioral outcomes due to NLW exposure.
  - This has also been noted by, e.g. NATO 2009, Mezzacappa et al. 2014 and 2017, Cazares et al. 2015, Rappert 2004, Silver 2005
- In order to assess the effectiveness of existing and newly developed NLWs, the committee comprised a list of questions that provide insights into overall system effectiveness
  - Similar questions are detailed in NLW effectiveness work, e.g., also see: NATO 2009

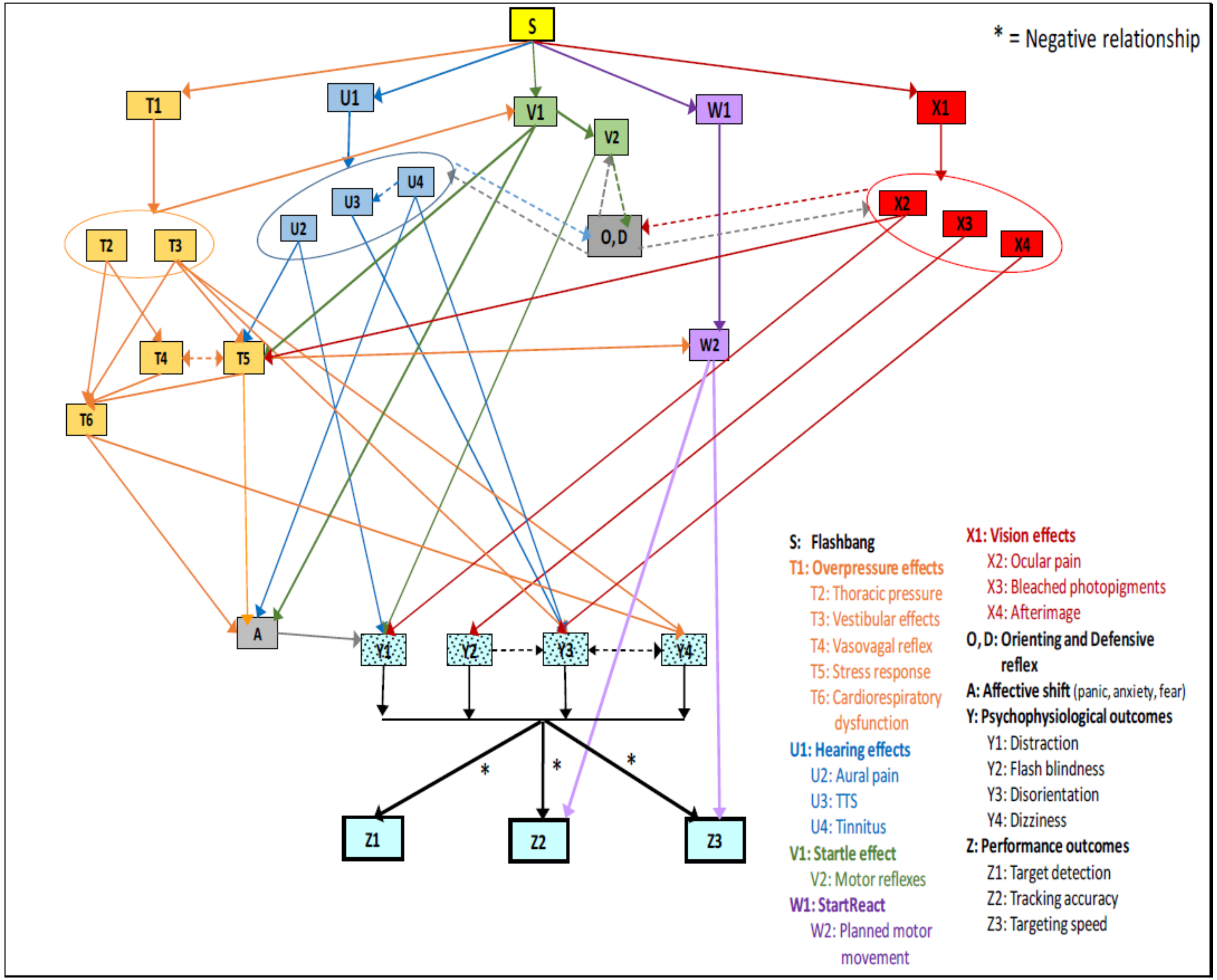
Silver (2005): Almost all research on the effects of non-lethal weapons that has been conducted and made publicly available has been studies of ballistic and safety effects and/or studies to assess the physical incapacitation effects of one of more weapons. Little systematic research has been conducted into the psychological and behavioral effects of non-lethal weapons though these are often precisely the effects of most importance to the potential uses of such weapons.

Effectiveness of NLW questions	Existing Research	Needed Research	Comments
Is there a solid understanding of the scientific principles behind the observed weapon effects?	• Causal analysis is a start	See below • Examine video footage of FBG deployment in different operational contexts; can this be used to model crowd behavior?	Need to define "effects." Can be (at individual and group levels): • Behavioral/cognitive • Sensory • Physical (e.g., injury)
Is there a solid understanding of how it affects the human body?	• Startle paper • Causal analysis • Risk of significant injury work	• Risk of significant injury work continued • Examine effects of each component individually to understand sensory effects • Exposure-response data regarding exposure to the weapon and time it takes to return to baseline functioning. • Examine effects of combined components	This question is read as focusing on physical effects. We have dose-response data on sound (dB) exposure and tinnitus, but not on: • Sound exposure (tinnitus and TTS) and time it takes for hearing to return to normal (e.g., duration of physical effects). • Light exposure and time it takes for vision to return to normal (flash blindness)

Is there an understanding of why the weapon has the human effects observed?	N/A	• Examine effects of each component to understand individual and group (where applicable) sensory effects in terms of:
		  • Behavioral/cognitive outcomes
		  • Social outcomes
		• Examine effects of combined weapon components
			This question is read as focusing on behavioral/cognitive/social effects. We need to:
			• Define operational context, metrics, performance outcomes, etc.
			• Identify the critical weapon component(s) that maximizes degradation of human performance (i.e., identify which component(s) is critical to maximize operational effectiveness of weapon)
			• Include operational context and objective of the use of the weapon in study development
			• Consider social psychological impacts on observed human effects (e.g., motivation, group identity and loyalty, crowd dynamics)
			• Consider human subjects testing for study development
			• Mezzacappa et al. (2017) measured effectiveness, not WHY effects are observed

Is there sufficient scientific data/results supporting the understanding of why weapon has the observed human effects?	N/A	• Continue examining why weapon has observed human effects until there is sufficient confidence in the findings (e.g., reproducibility, validation)	• Consider validity of study paradigms and reliability of findings. • Iterative research process – repeat studies to understand why weapon has human effects observed until sufficient confidence in findings obtained.
Are there benefits from combining new technology with others to create synergies?	N/A	• Revisit previous questions and conduct aforementioned studies looking first at varying frequency, intensity, duration of weapon components. • Next, examine effects of the combinations of weapons.	• Iterative research process – as new technologies are combined (or components are varied), will need to develop solid understanding of how new weapon affects human body, why it has the observed human effects, if there is sufficient scientific data supporting why weapon has observed human effects.

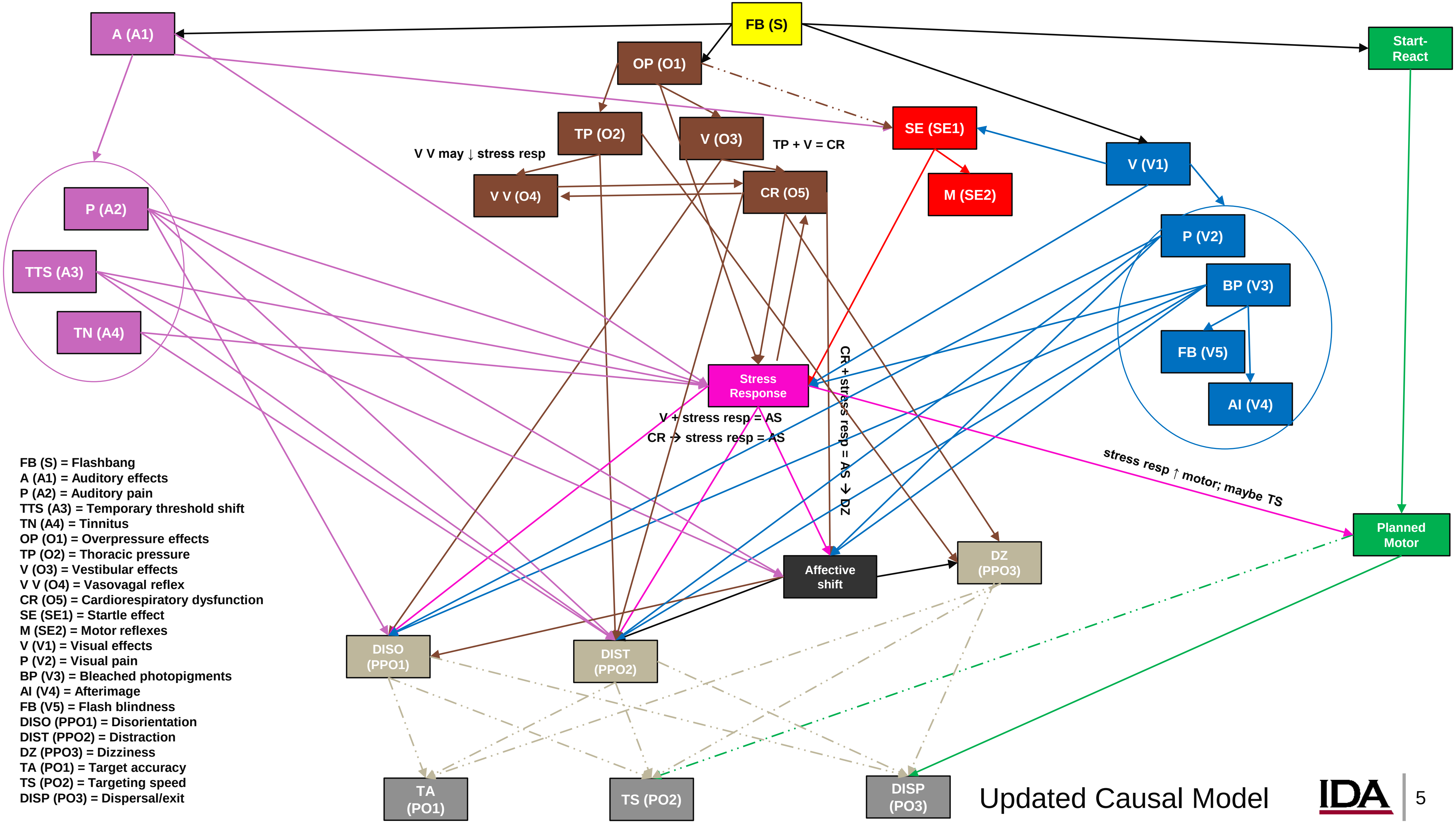
Original Causal Model



Proposed Updates to the Causal Model

- **Acoustic**: Tinnitus and/or temporary threshold shift primarily act as cognitive distractions, not disorientation
- **Vision**: Bleached photopigments lead to both flash blindness and presence of an afterimage (not just an afterimage)
- **Overpressure (1):** The cardiorespiratory dysfunction and vasovagal reflex are related. Specifically, the vasovagal reflex results in bradycardia, increased respiration, and hypotension, all of which signal cardiorespiratory dysfunction.
- **Overpressure (2):** Dizziness can result from vestibular system damage and/or a combination of the stress response and subsequent affective shift.
- **Stress:** The stress response can be activated by exposure to the bang, the flash, and/or the overpressure, therefore it has been repositioned as a separate effect. Centuries of animal and human psychological/cognitive literature on the stress responses highlights its potential importance in the behavioral outcomes of flashbang exposure.
- **Performance outcomes (1):** Tracking accuracy and target detection are now one metric – target detection. Tracking accuracy would not be a relevant metric if the target is not detected.
- **Performance outcomes (2):** Dispersal is now included as crowd dispersal can be a key objective for the use of flashbang devices.

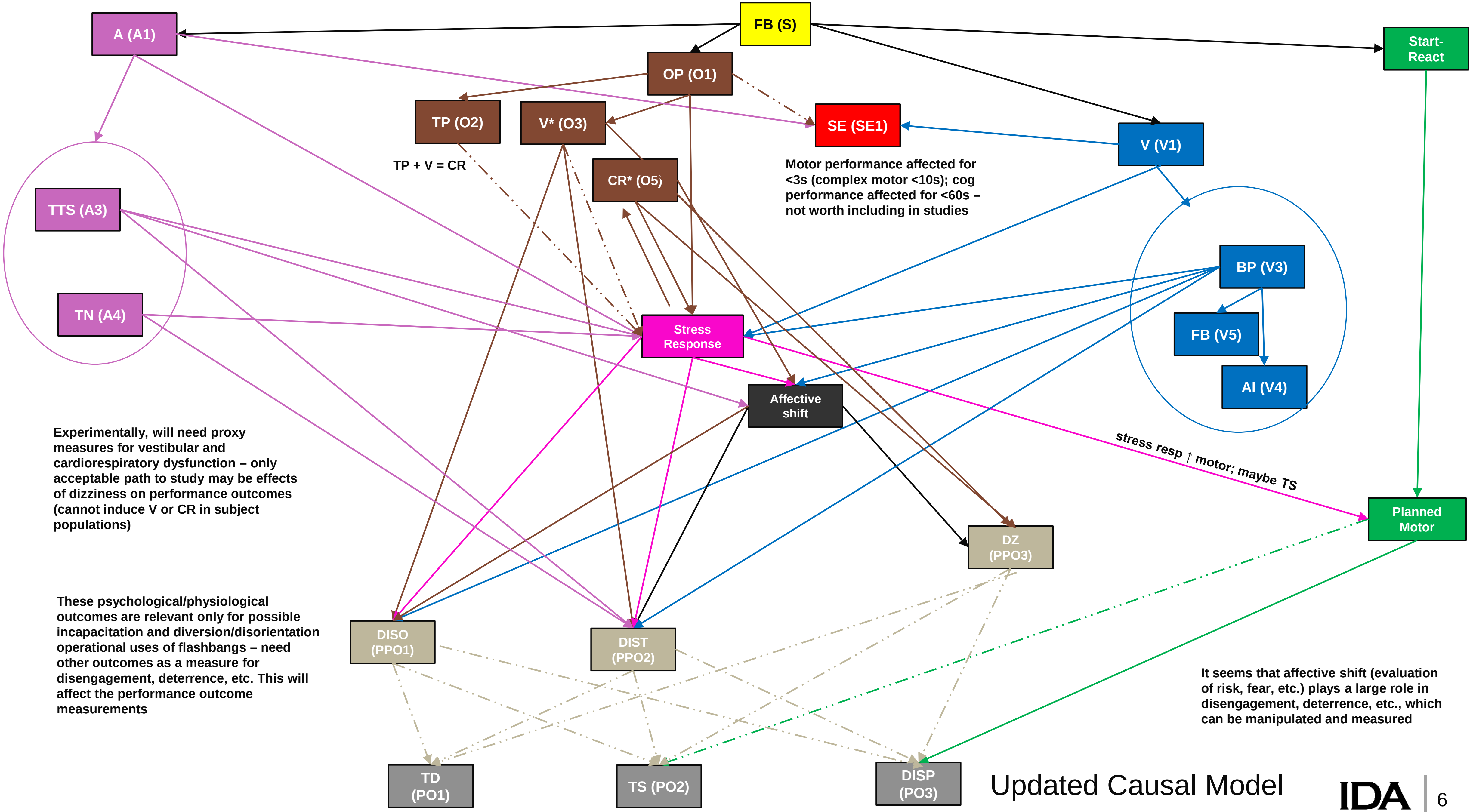
Updated Causal Model



FB (S) = Flashbang
A (A1) = Auditory effects
P (A2) = Auditory pain
TTS (A3) = Temporary threshold shift
TN (A4) = Tinnitus
OP (O1) = Overpressure effects
TP (O2) = Thoracic pressure
V (O3) = Vestibular effects
V V (O4) = Vasovagal reflex
CR (O5) = Cardiorespiratory dysfunction
SE (SE1) = Startle effect
M (SE2) = Motor reflexes
V (V1) = Visual effects
P (V2) = Visual pain
BP (V3) = Bleached photopigments
AI (V4) = Afterimage
FB (V5) = Flash blindness
DISO (PPO1) = Disorientation
DIST (PPO2) = Distraction
DZ (PPO3) = Dizziness
TA (PO1) = Target accuracy
TS (PO2) = Targeting speed
DISP (PO3) = Dispersal/exit

IDA

Updated Causal Model



Motor performance affected for <3s (complex motor <10s); cog performance affected for <60s – not worth including in studies

Experimentally, will need proxy measures for vestibular and cardiorespiratory dysfunction – only acceptable path to study may be effects of dizziness on performance outcomes (cannot induce V or CR in subject populations)

These psychological/physiological outcomes are relevant only for possible incapacitation and diversion/disorientation operational uses of flashbangs – need other outcomes as a measure for disengagement, deterrence, etc. This will affect the performance outcome measurements

It seems that affective shift (evaluation of risk, fear, etc.) plays a large role in disengagement, deterrence, etc., which can be manipulated and measured

First Order Effects of Flashbang Components

Goal and objective: To understand first order effects of single flashbang components with the objective to identify critical components that are likely to degrade human performance

Component	Sensory effects focus of study	Possible Measures/Areas of Inquiry	Comments

Auditory (bang) – include measures of stress response	• TTS
	• Tinnitus
		• Auditory task:
		  • TTS and/or tinnitus (separately) effects on distraction
		  • Distraction effects caused by TTS and/or tinnitus (separately) on auditory targeting accuracy, speed of detection (speech comprehension; sound localization)
		• Visual task (does bang affect visual tasks?):
		  • TTS and/or tinnitus (separately) effects on distraction
		  • Distraction effects caused by TTS and/or tinnitus (separately) on visual targeting accuracy, speed of detection
		• Effects of TTS and/or tinnitus on stress response (and affective shift)
		• Distraction effects caused by stress response due to TTS and/or tinnitus on targeting accuracy and speed (using both auditory and visual targets separately)
			Tikuisis et al (2009) show that aiming and shooting behaviors can be delayed by 1-2.5 sec in response to sound bursts of 110, 120, and 130 dB – so sound can affect visual accuracy and targeting speed.

Overpressure – include measures of stress response	• Vestibular dysfunction
	• Cardiorespiratory
	• Thoracic pressure
		• Balance task (proxy for vestibular dysfunction [VD]):
		  • Time to recover balance (i.e., duration of VD)
		  • VD effects on cardiorespiratory measures (HR, respiration, BP - can be collected simultaneously with other measures)
		  • VD effects on disorientation, distraction, and dizziness and role of stress response (and affective shift) on these physiological outcomes
		  • Effects of physiological outcomes (dizziness, distraction) caused by VD on targeting accuracy and speed (using both auditory and visual targets separately)
		  • Effects of physiological outcomes (dizziness, distraction) caused by stress response due to VD on targeting accuracy and speed (using both auditory and visual targets separately)
		• Effects of thoracic pressure on stress response, cardiorespiratory measures
		• Distraction effects caused by thoracic pressure on targeting accuracy, targeting speed, and dispersal
		• Distraction effects caused by stress response due to thoracic pressure on targeting accuracy and speed (using both auditory and visual targets separately)
			There is a min and max level of pressure that can be associated with a flashbang – the min amt is an engineering issue (strength of explosion) and max amt is enough to not cause vestibular/auditory injury or mTBI. In other words, there seems to be little we can manipulate in regards to pressure.

Visual – include measures of stress response	• Afterimage
	• Flash blindness
		• Visual task:
		  • Afterimage (AI) and/or flash blindness (FB) (separately) effects on distraction and disorientation
		  • Distraction effects caused by AI and/or FB (separately) on visual targeting accuracy, speed of detection
		• Auditory task (does flash affect auditory tasks?):
		  • Distraction and disorientation effects due to AI and/or FB (separately)
		  • Distraction effects caused by AI and/or FB (separately) on auditory targeting accuracy, speed of detection (speech comprehension; sound localization)
		• Effects of FB and/or AI on stress response (and affective shift)
		• Distraction effects caused of stress response (and affective shift) due to FB and/or IA on targeting accuracy and speed
			Flash blindness lasts for only a few seconds (up to <2 minutes) in daylight and partial recovery occurs between 3-10 min. In low-light, flash blindness lasts longer. But, due to defensive reflexes that kick in within msecs, exposure to the flash will be minimal in both regular and low-light conditions. It would be useful to understand how long the flash blindness and/or afterimage affect performance.
			
			It is an empirical question as to which (afterimage or flash blindness) impairs performance more.

- Possible measures listed are dependent on the operational context the study is designed to mimic, thus tasks will change depending upon the context.

Cumulative Effects of Flashbang Components

Goal and objective: To understand cumulative effects of flashbang components in order to identify critical combinations of components that are likely to degrade human performance

Component	Sensory effects focus of study	Possible Measures	Comments

Auditory (bang) + Overpressure – include measures of stress response	• TTS
	• Tinnitus
	• Thoracic pressure or vestibular dysfunction
	• Cardiorespiratory
		• Auditory task:
		  • Bang (TTS or tinnitus) and thoracic pressure (or vestibular dysfunction [VD]) effects on distraction, disorientation, and dizziness
		  • Effects of physiological outcomes (distraction, disorientation, dizziness) caused by bang and thoracic pressure (or VD) on targeting accuracy and speed using both auditory and motor/balance targets separately
		• Effects of bang and thoracic pressure (or VD) on cardiorespiratory measures (HR, respiration, BP can be collected simultaneously with other measures)
		• Effects of physiological outcomes (distraction, dizziness) caused by stress response due to bang (TTS or tinnitus) and thoracic pressure (or VD) on targeting accuracy, targeting speed, and dispersal (using both auditory [speech comprehension; sound localization] and motor/balance targets separately)	

Visual + Overpressure – include measures of stress response	• Afterimage
	• Flash blindness
	• Vestibular system
	• Cardiorespiratory
		• Visual task:
		  • Flash (after image [AI] or flash blindness [FB]) and thoracic pressure (or vestibular dysfunction [VD]) effects on distraction, disorientation, and dizziness
		  • Effects of physiological outcomes (distraction, disorientation, dizziness) caused by flash and thoracic pressure (or VD) on targeting accuracy and speed using both visual and motor/balance targets separately
		• Flash and thoracic pressure (or VD) effects on cardiorespiratory measures (HR, respiration, BP can be collected simultaneously with other measures)
		• Effects of physiological outcomes (distraction, dizziness, disorientation) caused by stress response due to flash (AI or FB) and thoracic pressure (or VD) on targeting accuracy, targeting speed, and dispersal (using both visual and motor/balance targets separately)
			There will always be a sound with the explosion (which will cause overpressure) – but it really depends on the timing of the flash and the bang – if the flash and bang occur simultaneously, the flash might be seen a split second before the overpressure is felt and then the explosion is heard

Auditory + Visual + Overpressure – include measures of stress response	• TTS
	• Tinnitus
	• Vestibular system
	• Cardiorespiratory
	• Afterimage
	• Flash blindness
		• Auditory task:
		  • Effects on distraction, disorientation, and dizziness using auditory target (speech comprehension, sound localization)
		  • Effects of physiological outcomes (distraction, disorientation, dizziness) caused by flashbang on targeting accuracy and speed using auditory target (speech comprehension, sound localization)
		• Visual task:
		  • Effects on distraction, disorientation, and dizziness using visual target
		  • Effects of physiological outcomes (distraction, disorientation, dizziness) caused by flash bang targeting accuracy and speed using visual target
		• Effects of flash bang on cardiorespiratory measures (HR, respiration, BP can be collected simultaneously with other measures)
		• Effects of physiological outcomes (distraction, dizziness, disorientation) caused by stress response due to flash bang on targeting accuracy, targeting speed, and dispersal (using both auditory [speech comprehension; sound localization], visual, and motor/balance targets separately)
			Other factors to consider:
			• Populations of interest – military vs. civilian
			• Variations in frequency, intensity, duration, stimulus presentation schedule (fixed vs. variable sequences) of critical components - the stress response (and associated affective shift might be the critical variable in human performance degradation. If true and depending on what the first-order and critical combination studies identify as the critical component(s) of flashbangs, these series of experiments may help to develop flashbangs with maximum effectiveness (human performance degradation)

IDA’s NLW Effectiveness Framework for Future Studies

Operational scenario/context

- What is the scenario?
- What are the constraints of the scenario?
- What actions could targeted personnel take that are relevant to scenario and are within the window of opportunity for weapon?

Metrics

- What metrics describe how the weapon influences the relevant actions?

Experimental plan

- Experimental subject pool – who, why?
- Protocol design – should be consistent with operational context/scenario
  - Instructions/training for protocol
  - Methodology – which instruments, measures/metrics – justification for study plan
- Data analysis plans with justification

Cazares et al., 2015

Additional Research to Consider

- In addition to human subjects experiments, in order to fully address flashbang effectiveness, we need the following literature reviews:
  - Synthesis of stress research as it relates to flashbang effects
    - Include research on potential moderator variables (e.g., exercise) that can affect behavioral outcomes
    - Consider research on predictable vs. unpredictable stressors
  - Synthesis of cognitive and psychological effects of flashbangs
    - Look at perception and information processing, attention, decision making, psychomotor performance, communication, etc.
    - Include research on moderator variables (e.g., prior exposure to flashbangs [PTSD])
  - Crowd behavior model

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14. ABSTRACT

This report provides updates to the causal analysis model originally formulated in "Path Analysis of Human Effects of Flashbang Grenades" (IDA Document D-9270). The model outlines the physiological and physiological effects of flashbang grenades and describes the central role of the stress response on human characterization of the weapon system. The updates, which reflect key findings from an interdisciplinary array of literature (e.g., neuroscience, psychology, sociology), focus on acoustic, vision, and overpressure effects and the stress response. The performance outcomes are also updated.

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