UNIVERSITY OF Southampton

EXAMINING THE STATE OF RESEARCH

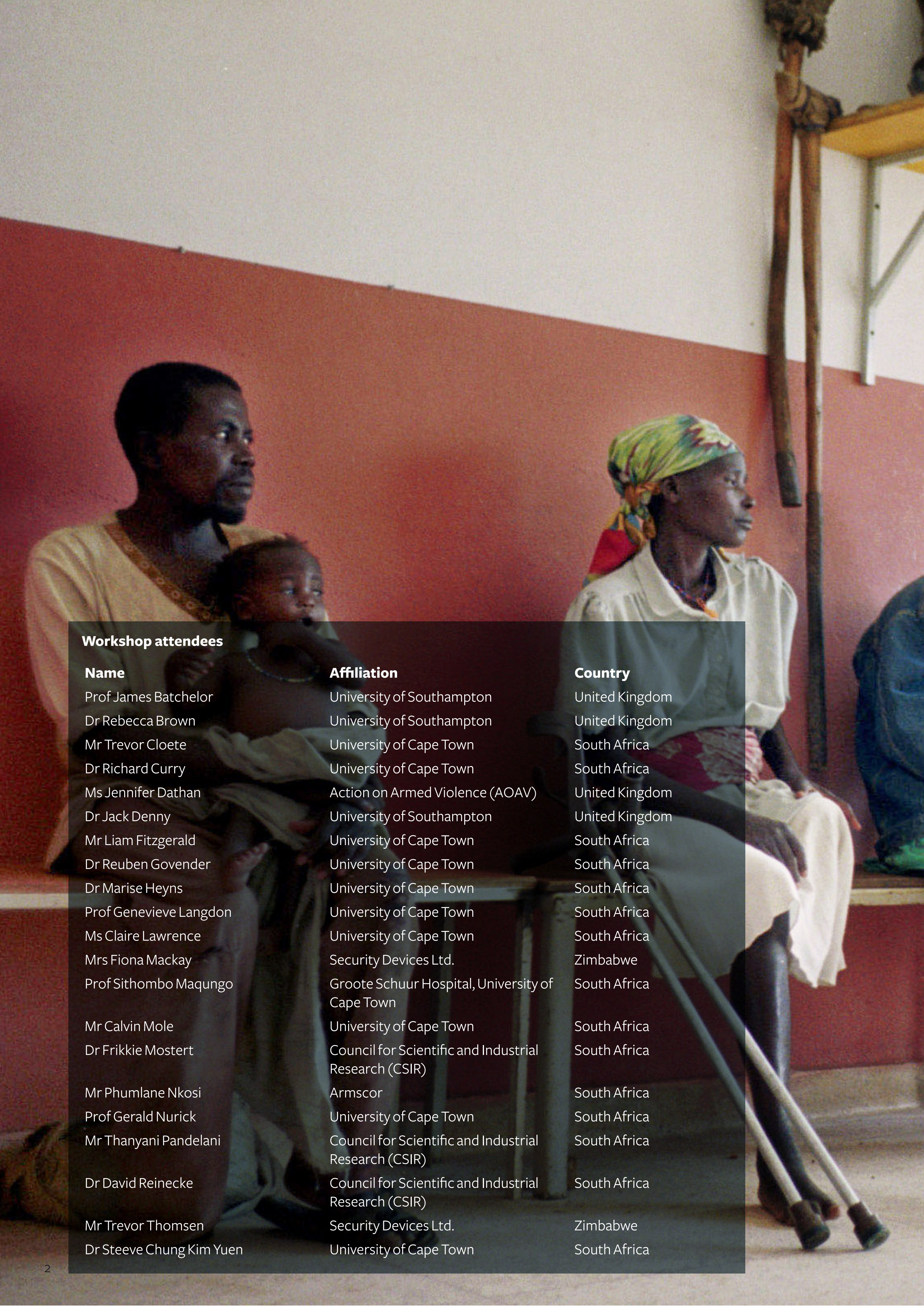
DEFINING THE CHALLENGES AND OPPORTUNITIES FOR BLAST INJURY RESEARCH

WORKSHOP REPORT

MARCH 2019, CAPE TOWN, SOUTH AFRICA

INTERNATIONAL BLAST INJURY RESEARCH NETWORK (IBRN)

Report Authored by:
Dr Jack Denny, Dr Rebecca Brown,
Prof Genevieve Langdon & Prof James Batchelor



Workshop attendees

Name	Affiliation	Country
Prof James Batchelor	University of Southampton	United Kingdom
Dr Rebecca Brown	University of Southampton	United Kingdom
Mr Trevor Cloete	University of Cape Town	South Africa
Dr Richard Curry	University of Cape Town	South Africa
Ms Jennifer Dathan	Action on Armed Violence (AOAV)	United Kingdom
Dr Jack Denny	University of Southampton	United Kingdom
Mr Liam Fitzgerald	University of Cape Town	South Africa
Dr Reuben Govender	University of Cape Town	South Africa
Dr Marise Heyns	University of Cape Town	South Africa
Prof Genevieve Langdon	University of Cape Town	South Africa
Ms Claire Lawrence	University of Cape Town	South Africa
Mrs Fiona Mackay	Security Devices Ltd.	Zimbabwe
Prof Sithombo Maqungo	Groote Schuur Hospital, University of Cape Town	South Africa
Mr Calvin Mole	University of Cape Town	South Africa
Dr Frikkie Mostert	Council for Scientific and Industrial Research (CSIR)	South Africa
Mr Phumlane Nkosi	Armscor	South Africa
Prof Gerald Nurick	University of Cape Town	South Africa
Mr Thanyani Pandelani	Council for Scientific and Industrial Research (CSIR)	South Africa
Dr David Reinecke	Council for Scientific and Industrial Research (CSIR)	South Africa
Mr Trevor Thomsen	Security Devices Ltd.	Zimbabwe
Dr Steeve Chung Kim Yuen	University of Cape Town	South Africa

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INTRODUCTION

A GLOBAL CHALLENGE

IN 2018, ACTION ON ARMED VIOLENCE (AOAV) RECORDED 32,110 DEATHS AND INJURIES FROM THE USE OF EXPLOSIVE WEAPONS AROUND THE WORLD [1]. AS WITH PREVIOUS YEARS, CIVILIANS BORE THE BURDEN OF EXPLOSIVE VIOLENCE WITH 70% (22,342) OF THOSE HARMED REPORTED TO BE CIVILIANS.

In recent years, the largest explosive threat is the use of improvised explosive devices (IEDs), which are estimated to be responsible for 52% of global explosive violence harm [1]. There is also the enduring issue of legacy landmines and explosive remnants of war (ERW). For example, in sub-Saharan Africa, previous and active conflicts have resulted in numerous countries contaminated with landmines and ERW. In 2017, landmines and ERW caused at least 7,239 blast-related casualties, of which, 87% were civilians and 47% children [2].

Blast injuries caused by conflict, landmines and ERW represent a global humanitarian challenge, posing a serious and ongoing threat to civilian populations. The threat of blast injuries affects millions globally, particularly vulnerable populations within low- to middle-income countries (LMICs). Explosions have potential to cause multi-system, life-threatening injuries that require extensive and prolonged medical care and rehabilitation, posing a considerable health system challenge. Blast injuries also have profound and long-term socio-economic and psychological impacts, hindering nations' post-conflict development.

Within defence and academia, blast injury and protection research has received considerable interest and attention in the last two decades, particularly in response to major conflicts. Predominantly driven by military needs, research has aimed to prevent or mitigate blast injuries through improved protection, clinical treatments and health outcomes in defence contexts despite the significantly higher number of civilian blast casualties. Resulting advances and understanding of how injuries occur, therapeutics, rehabilitative care and protective systems are typically directed to and for the benefit of military populations in high-income countries. The extent that such research can also benefit civilian populations and health systems is unknown.

The continuing issue of legacy landmines, urbanisation of conflicts and increase in terrorism presents complex blast engineering, protection and health challenges for researchers, defence and humanitarian organisations. This workshop aimed to gain broad oversight of the current state of the science to identify some of the key research challenges and to define future priorities.

THE WORKSHOP

The multidisciplinary research challenges of civilian blast injuries were discussed at the International Blast Injury Research Network's (IBRN) inaugural workshop, 'Examining the State of Research: Blast Injury Research Workshop'. The IBRN launch workshop was hosted by the Blast Impact and Survivability Research Unit (BISRU) and took place at the University of Cape Town's (UCT) Mechanical Engineering Department in South Africa on 27 March 2019.

AIM

The workshop aimed to gain holistic understanding of the current state of research (blast engineering, injury, protection and health) through discussing the challenges and knowledge gaps. This acted as a platform to collectively define future priorities and opportunities to improve the protection and health outcomes of civilians affected by landmines and explosive violence.
The workshop brought together colleagues from a wide range of disciplines and institutions from across South Africa, Zimbabwe and the UK. Attendees included scientists, clinicians and academics from the UoS and UCT, industry specialists from Zimbabwe who design personal protective equipment for humanitarian demining and global humanitarian organisations including the research charity, AOAV and demining charity, The HALO Trust.
For this workshop, presentations and discussion topics were organised into two themed sessions:

- Blast Injury Research
- Landmines & Protection

Taking a holistic view and drawing on multidisciplinary knowledge, participants discussed the role of research in addressing the global challenges of explosive violence and civilian blast injuries through round-table discussions.

WORKSHOP OUTCOMES

Current knowledge gaps, ideas and priorities proposed through presentations and round-table discussions enabled participants to define key recommendations and opportunities for future blast injury and protection research.

Following this workshop, the UoS and UCT launched a transdisciplinary network, the International Blast Injury Research Network (IBRN) [3]. This collaborative initiative aims to facilitate ongoing research cooperation between the fields of engineering and medicine to address the humanitarian aspects of blast injury and protection research and to promote wider collaboration between academia, industry, defence, clinicians and humanitarian organisations.

THIS REPORT PROVIDES AN OUTLINE OF THE PRESENTATIONS AND DISCUSSIONS THAT TOOK PLACE DRAWING ON MULTIDISCIPLINARY EXPERIENCE FROM SOUTH AFRICA, ZIMBABWE AND THE UK. IT **HIGHLIGHTS CURRENT KNOWLEDGE GAPS AND PARTICIPANT PERCEPTIONS** ABOUT RESEARCH PRIORITIES AND POTENTIAL **APPROACHES TO ADDRESS THE CHALLENGES**.

Funding Statement

This workshop was funded by the Global Challenges Research Fund (GCRF), Strategic Development Fund awarded by the University of Southampton, UK.

Abbreviations

AOAV	Action on Armed Violence
BISRU	Blast Impact and Survivability Research Unit
ERW	Explosive remnants of war
GCRF	Global Challenges Research Fund
IBRN	International Blast Injury Research Network
IED	Improvised explosive device
LMIC	Low- to middle-income country
PPE	Personal Protective Equipment
UCT	University of Cape Town
UoS	University of Southampton

PRESENTATIONS

A series of presentations provided evidence of the global trends in explosive violence, the civilian impacts, health issues and understanding of current approaches and challenges in conducting blast injury and protection research to support and provoke group discussions.

SPEAKERS

Ms. Jennifer Dathan, Researcher from AOAV, one of the world's leading research charities on the harm wrought by explosive weapons, spoke on the global humanitarian impact of explosive weapons, including the reverberating health impacts on civilian populations.

Dr Rebecca Brown, Research Fellow at UoS briefed participants on an applied research project as a collaborative effort between the Faculties of Medicine and Engineering that seeks to map the global portfolio and investment into blast-related research over the last 20 years.

Dr Jack Denny, Research Fellow at UoS briefed on an upcoming study that aims to review and map blast injury studies over the last 20 years in terms of key blast wave parameters to assess their relevance through comparison to real-world explosive threats.

Mr Thanyani Pandelani from the Council for Scientific and Industrial Research (CSIR), South Africa gave an overview of some of the CSIR's blast testing facilities and previous blast injury and protection research.

Mr Trevor Thomsen, Director of Security Devices Pvt., a demining protection manufacturer based in Harare, Zimbabwe, shared his experiences in designing and providing demining protective equipment to humanitarian organisations and previous academic collaborations.

Dr Richard Curry, Research Associate at UCT gave an overview of the world-class blast testing facilities at BISRU plus an overview of simulating buried charges through experimental and computational approaches.

The HALO Trust (presented in absentia by Prof James Batchelor) provided a presentation describing their mission in clearing landmines and emerging challenges corresponding to recent conflicts and shifting explosive threats.

THE DISCUSSIONS

Questions for Round-Table Discussion

Following presentations in each session, structured questions where proposed to participants to discuss their views:

1. What do you consider are the key knowledge gaps and challenges for blast injury research and how can we increase translation into improved health and protection?

2. What do you think are the main research priorities and opportunities to protect civilians from landmines and explosive violence to improve future civilian health?

CHALLENGES & KNOWLEDGE GAPS

COLLABORATIVE, MULTIDISCIPLINARY WORKING

Blast injury and protection research inherently requires a multidisciplinary approach spanning the fields of engineering and medicine across the defence and humanitarian sectors.

Multi-sector barriers

Participants described the challenges of working collaboratively with different disciplines and sectors; in the case of defence, it was highlighted that security clearance can often restrict collaborative working with other industries and academia. Participants agreed that improved methods should be established to break down the barriers between academia, industry, humanitarian and defence organisations.

Multidisciplinary discourses

It was suggested that collective understanding of blast injury and protection is sometimes hindered by different academic discourses from respective research disciplines i.e. discipline-specific, complex terminology and concepts. Researchers agreed that we need to improve, simplify and explain our discourses to ensure that the complex research issues are accessible and understandable. This was considered particularly important when engaging with clinicians and stakeholders outside of academia to enable effective collaboration.

Partnerships

Partnerships between industry and academia can be very useful in addressing real-world challenges. Industry colleagues explained that academic partnerships are still viewed as 'prestigious' and previous successful examples were described where collaborations had resulted in improved demining protection and commercialisation of products. It was explained that such partnerships generally require long-standing relationships and trust, with some suggesting that there needs to be improved methods to facilitate industry and humanitarian organisations proposing research questions to academia.

IMPROVED METHODS SHOULD BE ESTABLISHED TO **BREAK DOWN THE BARRIERS** BETWEEN ACADEMIA, INDUSTRY, HUMANITARIAN AND DEFENCE ORGANISATIONS.

RESEARCH FUNDING & STRATEGIES

Academic colleagues expressed the challenges in obtaining and sustaining research funding due to limited public and philanthropic investment and increasingly targeted and competitive grant calls. The various drivers of research funding and advocacy for projects to address humanitarian issues were also discussed. Some participants explained that research and developments in policy had historically been 'reactive' in the blast field, typically in response to high-profile terrorist attacks or conflicts. Despite being a global issue that continues to cause profound harm, some felt that the issue of landmines had 'lost its profile' in comparison to previous decades where activism was more prominent.

Preliminary findings from research being undertaken by the IBRN team at UoS suggest reason for improved strategy and coordination of blast injury and protection research and funding. Analysis of global research investments showed that over $1 billion of public and philanthropic funding has been invested into blast-related science between 2000 and 2018, comprising at least 1,188 individual research awards (Figure 1) [4]. The United States was the dominant funder, providing 94% ($963 million) of the total investment during this time with the United States Department of Defense providing 75% ($783 million), thus highlighting the defence-driven field [4]. Participants agreed that there needs to be increased visibility of what research is and has historically been undertaken to reduce duplication, inform future strategies and ensure a balanced portfolio of research.

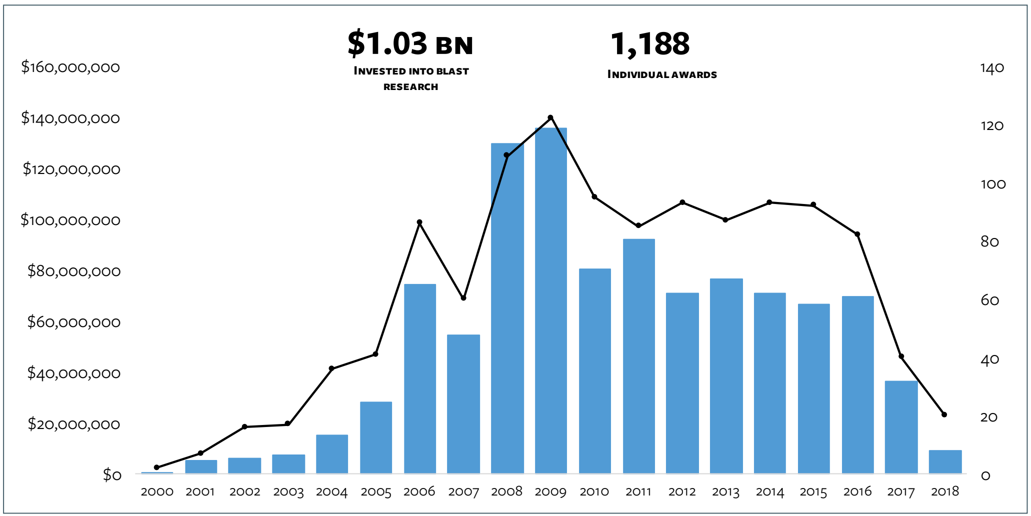

Figure 1. Annual public and philanthropic R&D funding for blast-related research (blue bar) and number of awards (black line).

DESPITE BEING A GLOBAL ISSUE THAT CONTINUES TO CAUSE PROFOUND HARM, **SOME FELT THAT THE ISSUE OF LANDMINES HAD 'LOST ITS PROFILE'** IN COMPARISON TO PREVIOUS DECADES, WHERE ACTIVISM WAS MORE PROMINENT.

BLAST RESEARCH CHALLENGES & KNOWLEDGE GAPS

This workshop concentrated on the blast engineering aspects of blast injury and protection. Groups discussed the challenges of undertaking blast experimental work and the knowledge gaps pertaining to simulation of different explosive scenarios.

Understanding of blast scenarios

Multiple reflective surfaces & confinement

Most understanding of blast loading and interaction assumes highly idealised scenarios where an explosive detonation occurs in free space or on an infinite surface. Presentations and discussions described that there is limited knowledge and predictive capacity to simulate more realistic explosive events that involve multiple reflective surfaces and confinement, as found in urban settings (Fig. 1). It was acknowledged that the influence of confinement (as found inside buildings and transport spaces) is not well understood and gives rise to complex loading that is challenging to characterise or predict using existing approaches.

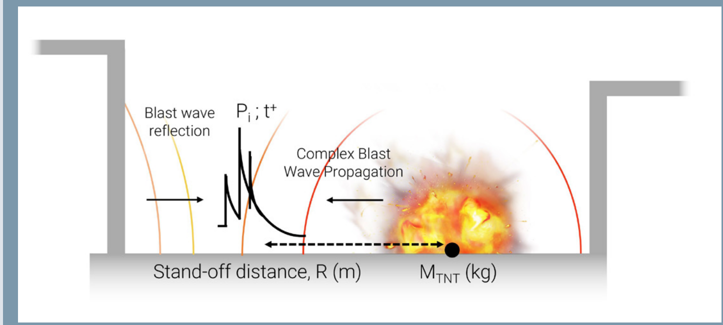

Fig. 1: Detonations occuring in urban and confined spaces remain dificult to model [5]

THERE IS **LIMITED KNOWLEDGE AND PREDICTIVE CAPACITY** TO SIMULATE MORE REALISTIC EXPLOSIVE EVENTS THAT INVOLVE MULTIPLE REFLECTIVE SURFACES AND CONFINEMENT, AS FOUND IN URBAN SETTINGS.

Buried charges

It was explained that there has been far more research investigating 'air blast' (i.e. blast waves propagating through air) than buried charges. Buried detonations that occur beneath the ground surface may include landmines, ERW and some IEDs (Fig. 2). Researchers explained that buried charge detonations are complex to characterise and predict as empirical models for idealised air blast loading can no longer be assumed. High-velocity soil ejecta and blast pressures are greatly influenced by the ground conditions (e.g. soil type, moisture and compaction) and the explosive charge burial depth. Experimental and computational modelling results were presented demonstrating the noticeable difference in loading and ejected sand depending on different boundary conditions e.g. burial depth and soil types. As a result, it remains very challenging to predict the effects of buried detonations (and injury outcomes) due to the vast number of variables arising from different charge sizes and environments.

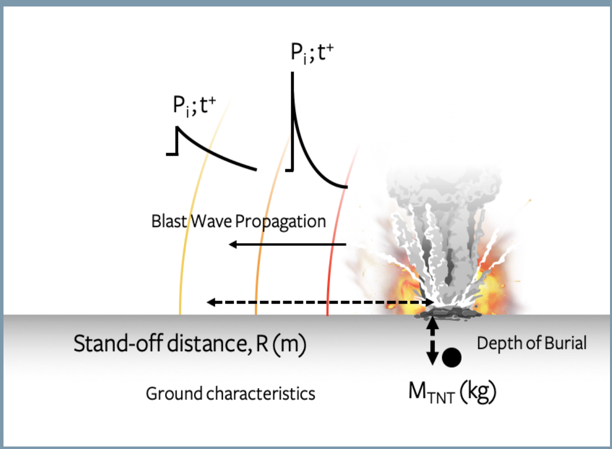

Fig. 2: Buried charge detonations (i.e. landmines and explosive remnants of war) are dificult to model [5]

Photo: Werner Anderson
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CHALLENGES
& KNOWLEDGE GAPS (cont'd)

BLAST RESEARCH CHALLENGES & KNOWLEDG GAPS (cont'd)

Blast injury experimental challenges

Participants discussed some of the challenges of undertaking pre-clinical (i.e. basic science) blast injury research.

Blast injury model biofidelity

Questions were raised over the biofidelity of blast injury experimental models (i.e. the degree that models reflect the real biological system that it is based on). The potential benefits and limitations of different organic and synthetic modelling approaches were discussed. The ethical issues of conducting experimental testing with organic tissues i.e. cadavers, in vitro (i.e. biological tissues) and in vivo (i.e. animal testing) models were highlighted as being a significant limitation within the field. Participants agreed that increasing model biofidelity (including the physiological response where possible) was important to produce meaningful findings that have healthcare relevance.

Simulating realistic & relevant threats

Presentations and conversations reiterated the importance of simulating relevant and appropriate blast effects to ensure that injury and protection models are examined under conditions that reflect real-world explosive threats. Preliminary data was presented from a review being undertaken by the UoS team which demonstrated inconsistent reporting of blast parameters within published blast injury literature, with some studies adopting unrealistic blast conditions [5].

Colleagues discussed the various blast simulation methods and agreed that it remains unclear which loading parameters are most appropriate for specific injury or protection studies or what conditions correspond to the most relevant threats encountered today. For example, presentations showed that 50% of blast related injuries in Syria were caused by air strikes [1], raising questions with participants about how such conditions could be simulated or approximated within research.

IT REMAINS UNCLEAR WHICH LOADING PARAMETERS ARE MOST APPROPRIATE FOR SPECIFIC INJURY OR PROTECTION STUDIES OR WHAT CONDITIONS CORRESPOND TO THE **MOST RELEVANT BLAST THREATS ENCOUNTERED TODAY.**

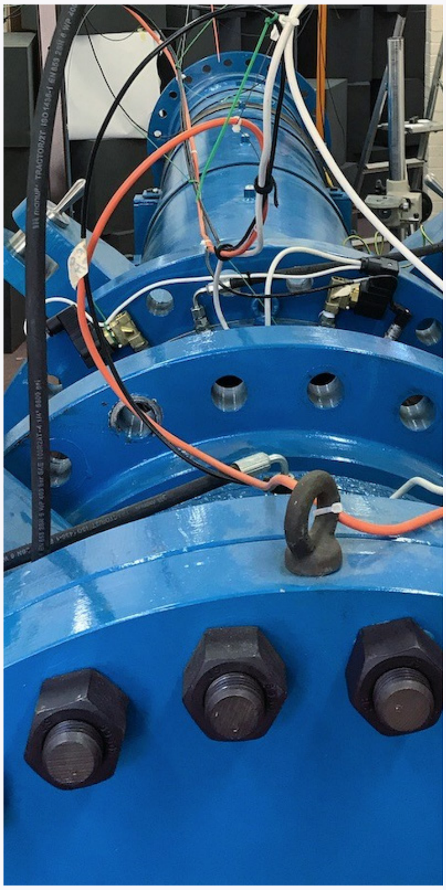
Simulating fragmentation effects

Participants discussed that previous research has focussed on air blast effects in the absence of fragmentation. It was explained that blast injuries typically result from a combination of different explosive mechanisms, particularly fragmentation in the case of landmines (i.e. high-velocity soil ejecta) and IEDs. Understanding and capability to simulate the combined effects of blast and fragmentation were therefore considered a knowledge gap in the field.

Greater focus on air-blast research was explained by participants as being due to greater availability of testing facilities and equipment, such as conventional arena testing, blast chambers, shock tubes and gas guns. Some of these testing approaches also have the benefit of being highly repeatable and can be installed indoors, making them suitable for research laboratories.

In contrast, blast and fragmentation effects were discussed as being far more challenging to investigate experimentally, requiring complex setups that subject instrumentation and specialist diagnostics to extreme conditions. Investigating fragmentation is hindered by the vast number of variables (fragmentation materials) and boundary conditions, with repeatability of experimental conditions difficult to achieve. Designing such fragmentation experiments were also described to be challenging due to the highly variable and dynamic nature of these blast threats (e.g. IEDs).

ACCURATE SIMULATION OF BLAST THREATS WITHIN **RESEARCH IS CHALLENGING** DUE TO THE SHEER **COMPLEXITY OF THE PROBLEM** AND EXPERIMENTAL APPROACHES ARE OFTEN DRIVEN BY FACILITY AND EQUIPMENT AVAILABILITY AND CAPABILITIES RATHER THAN SPECIFIC THREATS.



DEMINING PROTECTION CHALLENGES

Understanding practicalities

Demining and protection colleagues explained the importance of understanding and considering the practicalities for effective implementation of protection. It was explained that typical injuries caused by landmines and ERW are soft tissue loss caused by high-velocity sand and soil ejected by the explosion, classified by injury researchers as a 'secondary blast injury mechanism'.

The practicalities of protective visor design were described where it was explained that full-face visor coverage can interfere with some demining activities involving dogs, reducing the ability for dogs to respond to commands and facial expressions. Although mainly protecting from fragmentation (high velocity soil ejecta), it was explained that consideration of blast wave interaction with visors themselves was also important as they diffract blast pressures around the vulnerable ears and head.

Translating defence solutions

Considering humanitarian activities, the challenges of upgrading protection of civilian vehicles for demining operations were discussed. Colleagues described that despite significant advances in vehicle protection within defence, such designs (i.e. V-shaped hulls) are not feasible or economic for translation into humanitarian sectors when modifying existing civilian vehicles.

CHALLENGES
& KNOWLEDGE GAPS (cont'd)

DATA COLLECTION CHALLENGES

Recording blast scenarios

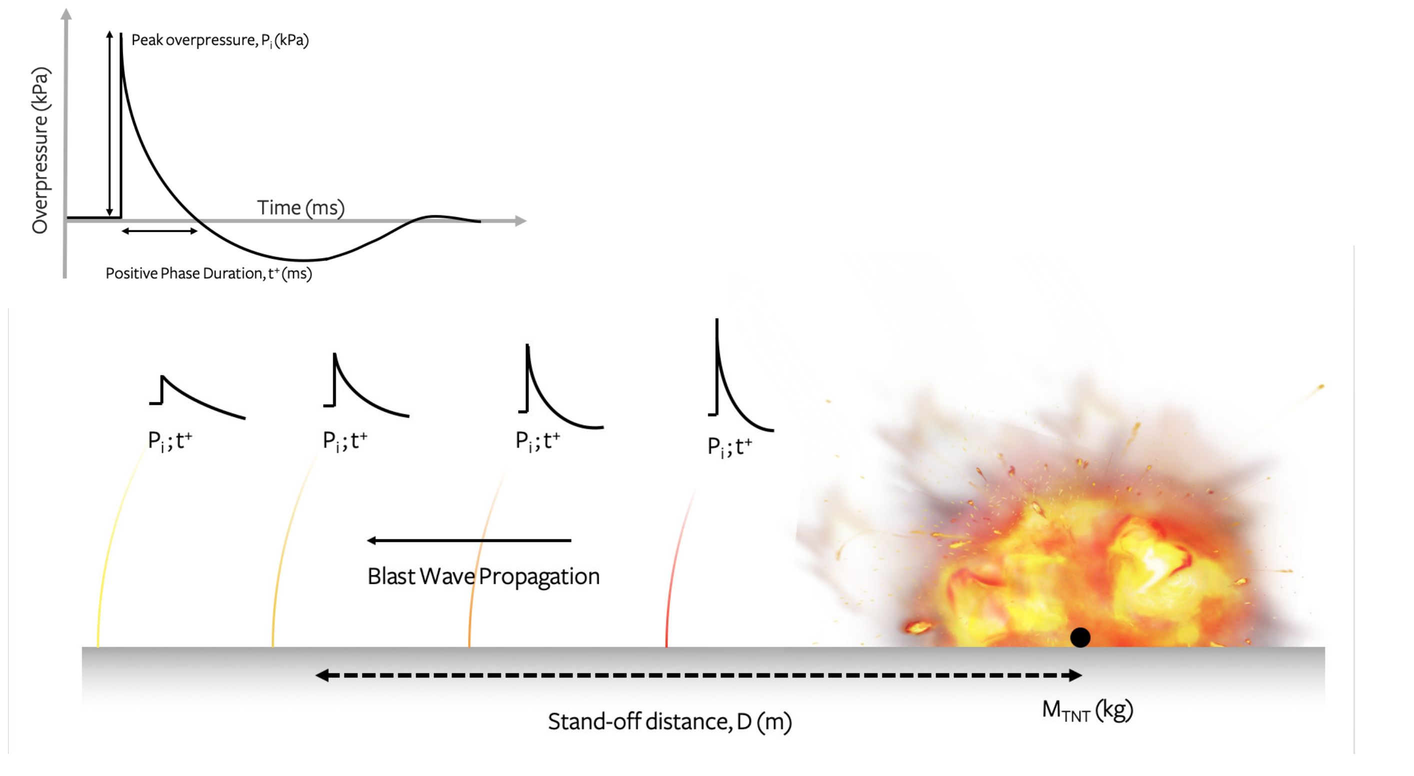
Colleagues described that it is challenging to design blast loading conditions within experiments without clear knowledge or available data on typical or previous blast events that have occurred. Ideally, such information would include key blast engineering parameters such as the approximate TNT equivalence, positioning of the detonation and environmental information including ground type, degree of confinement or presence of obstacles. This would allow further analysis of scenarios and allow researchers to determine appropriate blast wave parameters (i.e. peak over pressures, positive phase durations and impulses) to simulate within experiments or computational models.

Key blast terminology

TNT Equivalence
TNT equivalency is a convention for expressing the energy released in an explosion. This convention helps to compare the destructiveness and magnitude of a blast event with that of traditional explosive materials, of which, TNT is a typical example.

Blast Wave Parameters
Peak Incident Overpressure P_i (kPa)
Positive Phase Duration t^+ (ms)
Total Impulse, I_i (kPa.ms)

These vary greatly depending on:
How far away you are e.g. the stand-off distance (m)
How 'big' the explosion is e.g. the explosive charge mass M_{TNT} (kg)



Participants suggested that prospective data collection of blast incidents would have potential to improve the relevance of future blast injury and protection research although it was recognised that this will present significant challenges. Potential methods to capture high-quality data from future blast events were debated (including details relevant to the blast scenario) and participants discussed some of the challenges such as practicalities, reporting standards, data governance and security.

PROSPECTIVE DATA COLLECTION OF BLAST INCIDENTS WOULD HAVE **POTENTIAL TO IMPROVE THE RELEVANCE OF FUTURE BLAST INJURY** AND PROTECTION RESEARCH.

DATA COLLECTION CHALLENGES (cont'd)

Data collection & reporting

Detailed blast injury casualty data, particularly on civilian populations, is not readily available, collected or reported consistently. The most comprehensive datasets generally comprise military personnel data from recent conflicts, contained within registries such as the UK Joint Theatre Trauma Record.

Injury details are often recorded within health systems and coded using the World Health Organisation's International Statistical Classification of Diseases and Related Health Problems 10th Revision (ICD-10). Although this is a standardised method of recording clinical health data, data is often not easily accessible for public health purposes and recording can be inconsistent and varies regionally.

Public access to blast injury casualty data is restricted and there are limited datasets on civilian populations. Furthermore, limited epidemiology reports or published literature exist on the nature, patterns and prevalence of blast injuries, particularly in LMICs. Participants expressed that openly available blast casualty datasets lacked granularity or consistent reporting standards, making it difficult to link injury outcomes with blast scenarios.

ICD Codes

The International Classification of Diseases is the standard diagnostic tool for epidemiology, health management and clinical purposes. This is used to monitor the incidence and prevalence of diseases and other health problems, proving a picture of the general health situation of countries and populations.

PARTICIPANTS EXPRESSED THAT **OPENLY AVAILABLE BLAST CASUALTY DATASETS LACKED GRANULARITY** OR CONSISTENT REPORTING STANDARDS, MAKING IT DIFFICULT TO LINK INJURY OUTCOMES WITH BLAST SCENARIOS.

FUTURE PRIORITIES & OPPORTUNITIES

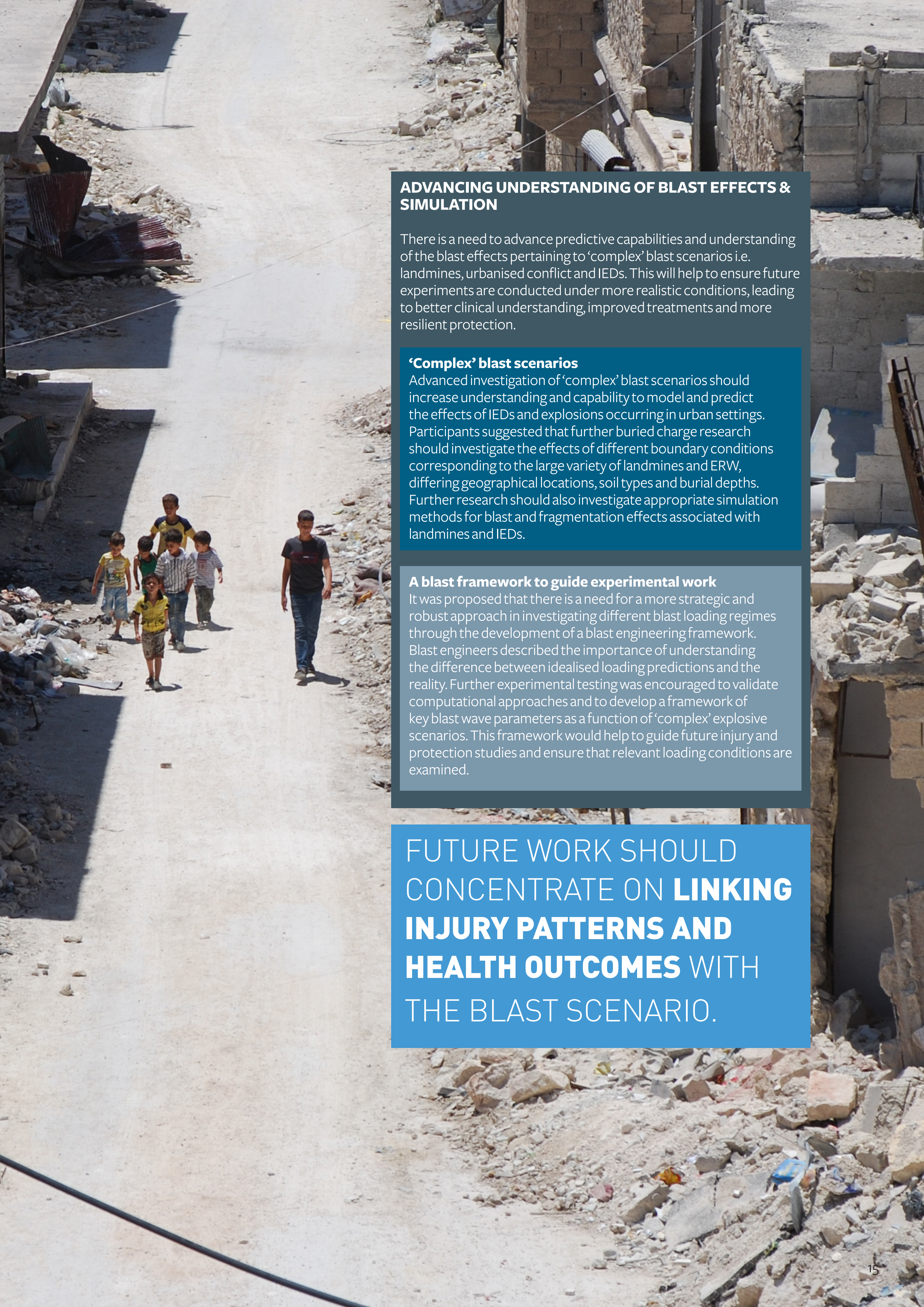
THE URBANISATION OF CONFLICT AND IED THREAT

The global threat and incidence of blast injuries, particularly concerning civilian populations, is shifting to urban environments. This is largely due to the urbanisation of conflict where explosive weaponry has been used directly within towns and cities in recent or active wars (i.e. Syria, Iraq, Libya), leaving behind unexploded ordnance in population centres. There is also the widespread and increasing use of IEDs which are estimated to be responsible for 52% of global explosive violence harm [1]. When explosive weapons are used in populated areas the casualties are overwhelmingly civilian; in 2018, 91% of those reported harmed by explosive weapons in populated areas were civilians [1].

Participants engaged in conversations about the challenges in responding to urban explosive violence, the rise of IED threats and how future research can best protect and mitigate civilian blast injuries. In the case of urban explosive violence and IEDs, participants discussed the current limitations of blast research and how such scenarios could be best modelled. IEDs are a significant challenge as they vary considerably in design, explosive charge, effectiveness and trigger mechanisms. Researchers described that this variability makes it difficult to model or simulate relevant threats within blast engineering, injury studies or inform health system preparedness. Humanitarian organisations seek practical methods to assist adaptation and preparation for this shifting threat as they are tasked with the decontamination of ERW and IEDs in populated regions following recent conflicts. Participants concluded that future blast engineering, injury and protection research must focus on addressing the contexts of urban explosive violence and IEDs.

WHEN EXPLOSIVE WEAPONS ARE USED IN POPULATED AREAS THE CASUALTIES ARE OVERWHELMINGLY CIVILIAN; DATA FROM AOAV SHOWS THAT IN 2018, **91% OF THOSE REPORTED HARMED BY EXPLOSIVE WEAPONS IN POPULATED AREAS WERE CIVILIANS** [1].

PARTICIPANTS CONCLUDED THAT FUTURE BLAST ENGINEERING, INJURY AND PROTECTION RESEARCH MUST FOCUS ON **ADDRESSING THE CONTEXTS OF URBAN EXPLOSIVE VIOLENCE** AND IEDS.



ADVANCING UNDERSTANDING OF BLAST EFFECTS & SIMULATION

There is a need to advance predictive capabilities and understanding of the blast effects pertaining to 'complex' blast scenarios i.e. landmines, urbanised conflict and IEDs. This will help to ensure future experiments are conducted under more realistic conditions, leading to better clinical understanding, improved treatments and more resilient protection.

'Complex' blast scenarios
Advanced investigation of 'complex' blast scenarios should increase understanding and capability to model and predict the effects of IEDs and explosions occurring in urban settings. Participants suggested that further buried charge research should investigate the effects of different boundary conditions corresponding to the large variety of landmines and ERW, differing geographical locations, soil types and burial depths. Further research should also investigate appropriate simulation methods for blast and fragmentation effects associated with landmines and IEDs.

A blast framework to guide experimental work
It was proposed that there is a need for a more strategic and robust approach in investigating different blast loading regimes through the development of a blast engineering framework. Blast engineers described the importance of understanding the difference between idealised loading predictions and the reality. Further experimental testing was encouraged to validate computational approaches and to develop a framework of key blast wave parameters as a function of 'complex' explosive scenarios. This framework would help to guide future injury and protection studies and ensure that relevant loading conditions are examined.

FUTURE WORK SHOULD CONCENTRATE ON **LINKING INJURY PATTERNS AND HEALTH OUTCOMES** WITH THE BLAST SCENARIO.

FUTURE PRIORITIES & OPPORTUNITIES (cont'd)

IMPROVING REPORTING & DATA COLLECTION

It was proposed that future work should aim to improve prospective data collection of blast injury casualties and blast scenario information.

Researchers from across disciplines agreed that there needs to be increased understanding and access to data on explosive events and resulting casualties, requiring high quality data collection at future incidents. This would have multi-sectoral benefit including the monitoring and surveillance of explosive violence, informing research strategies and increasing the relevance of future studies.

Blast incident & casualty reporting

Colleagues from the demining and protection sectors shared examples of the systems for reporting incidents for any demining accidents or personal protective equipment failures. Reporting methods were described to involve both detailed health and blast scenario information such as the ordnance category, blast type, nature of injuries sustained, medical notes and follow-up. Although small-scale and organisation-specific, such reporting systems within these humanitarian organisations are good examples for collecting valuable data and could potentially help to inform broader reporting standards in the future.

FUTURE WORK SHOULD ESTABLISH **UNIVERSAL DATA COLLECTION AND REPORTING STANDARDS** INCLUDING A 'MINIMUM DATASET' TO CAPTURE THE MOST IMPORTANT CLINICAL AND BLAST ENGINEERING INFORMATION FROM EXPLOSIVE INCIDENTS.

Participants recommended that future work should establish universal data collection and reporting standards including a 'minimum dataset' to capture the most important clinical and blast engineering information from explosive incidents. Colleagues suggested that this would require a change in emergency response and clinical practice as data collection strategies would involve new forms (paper or electronic) and guidelines to ensure consistent and high-quality reporting. Data governance, suitable registries to host the data and consideration of patient confidentiality would also be required.

Innovative data collection methods

Colleagues agreed that coordinated prospective data collection is more feasible than reviewing old medical records although questions regarding the methods to achieve this were raised. Clinicians voiced concerns about how to physically collect data with sufficient quality and consistency such that it does not interfere with emergency response or create cognitive overload for first responders and clinicians. This is particularly important during mass casualty events when saving and triaging blast-injured victims is a priority. Engagement with first responders and clinicians was deemed essential for any future initiatives to ensure data collection methods are feasible and practical. Methods such as verbal autopsy and digital interventions such as smartphone apps were suggested as potential methods to assist first responders gather data from blast incidents.

ENHANCING FUTURE PROTECTION & REHABILITATION

Technology and innovation

The potential for new technologies and innovation to assist with landmine clearance were discussed such as robotic demining and the use of unmanned aerial vehicles (UAVs) or drones. The role of 3D printing was also suggested as a potential opportunity to assist with blast injury rehabilitation such as prosthetic design.

Improved protective gloves

Improved protection for hands (i.e. gloves) was highlighted as a significant priority for demining personal protective equipment (PPE). It was described that blast injuries to the hand are common in demining accidents and are difficult and expensive to treat, requiring long-term rehabilitative care. It was explained that improved protective gloves should aim to provide enhanced resistance to the effects of both blast and fragmentation while maintaining comfort and tactility. Such improvements in hand protection would have significant impact and greatly improve the quality of life for those at risk or experience an accident.

Psychological impacts

The psycho-social impact of explosive violence, blast injuries and resulting disabilities are profound, placing a significant burden on health systems. Participants suggested that further work should better characterise the mental health and social impacts to civilians' welfare and explore potential methods for supporting psychological rehabilitation, acknowledging local contexts.

LINKING INJURY OUTCOMES WITH BLAST SCENARIOS

Participants suggested that future work should concentrate on linking injury patterns and health outcomes with the blast scenario. Current understanding and empirical relationships to predict injury outcomes are based on highly idealised blast conditions and are limited to specific injury types i.e. lung injuries. In combination with improved data collection, colleagues suggested that efforts should be made to increase understanding of the link between injury outcomes (nature, severity, treatments required and long-term outcomes) with blast scenarios (threat type, TNT equivalence, environment, approximate blast wave parameters).

Building these links would help to improve the impact of blast injury research (guiding experimental design and relevance of studies) and help to inform broader research strategies and priority-setting. Improved understanding would also translate into increased ability to predict health outcomes and protection requirements in a given explosive scenario, supporting health system emergency response (i.e. triaging) and preparedness.

As a complex, trans-disciplinary challenge, colleagues suggested that the long-term goal is to synchronise and link research strengths across disciplines. This for example, could involve connecting multi-physics computational and theoretical models i.e. buried charge blast models with biofidelic, soft tissue bioengineering models with forensic analyses, clinical diagnoses/post-mortems and epidemiology.

IMPROVEMENTS IN HAND PROTECTION WOULD HAVE **SIGNIFICANT IMPACT AND GREATLY IMPROVE THE QUALITY OF LIFE** FOR THOSE AT RISK OR EXPERIENCE AN ACCIDENT.

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SUMMARY OF RECOMMENDATIONS

Following presentations and round-table group discussions, participants defined key research priorities and recommendations for future research:

Addressing urban explosive violence
Future research should focus on addressing urban explosive violence through advancing understanding of blast scenarios and simulation approaches, strengthening health systems and increasing monitoring and surveillance to continuously inform future priorities.

Research coordination & advocacy
Greater awareness of the civilian harm caused by blast, increased support for challenge-led research and improved oversight of the research portfolio would help to ensure that future research and funding-decisions address priority areas and maximise impact.

Advancing understanding of 'complex' blast scenarios
Future blast research should address the knowledge gaps and advance predictive capabilities for 'complex' blast scenarios arising from landmines, urbanised conflict settings and IEDs. This will help to ensure that future blast injury and protection experiments are conducted under more realistic conditions, leading to better clinical understanding, improved treatments and more resilient protection.

Improving reporting & data collection
Future work should aim to improve prospective data collection of blast injury casualties and blast scenario information. This will involve establishing data collection and reporting standards including a 'minimum dataset' to capture the most important clinical and blast engineering information from explosive incidents. Such improvements will involve considerable challenges regarding reporting methods and technology, data governance, security and patient record confidentiality.

Linking injury outcomes with blast scenarios
In combination with improved data collection, future work should aim to increase understanding of the links between injury outcomes (nature, severity, treatments required and long-term outcomes) with a blast scenario (threat type, TNT equivalency, environment, approximate blast wave parameters). This will help to drive more relevant research, protective systems and predictive models to improve health system preparedness.

Facilitating effective multidisciplinary working
Continued trans-disciplinary working is critical to tackle the issues and there needs to be improved mechanisms to facilitate collaborations between different stakeholders, sectors and disciplines. Discussions highlighted that collaboration with humanitarian organisations, defence, clinicians and people on the ground will be essential for ensuring healthcare and protection developments are practical and fit for purpose.

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For more information

www.blastinjurynetwork.com

Contact:
Dr Jack Denny, jack.denny@soton.ac.uk
Dr Rebecca Brown, rebecca.brown@soton.ac.uk