Collective Dynamics

Understanding Crowd Responses to Perceived Hostile Threats: A Multidisciplinary Approach

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Abstract People facing threat may evacuate, help others, share information, confront the source of threat, ignore the threat and the plight of others, or enact a combination of these behaviours. Accurate conceptual models of crowd behaviours must consider why and when these behaviours occur, as well as how people's responses may vary across different scenarios. Researchers have investigated crowd responses to threats using a variety of methods such as interviews, observational analysis and virtual reality experiments. Each methodology offers benefits to understanding collective responses to threats but each methodology also has limitations. Importantly, very little research has explored crowd responses in false alarm situations where crowd members misperceive that a threat exists. In this paper, we describe a new multidisciplinary programme of work which combines approaches from safety engineering and social psychology to gain a thorough understanding of crowd behaviour in response to real and misperceived threats, and the processes underpinning the behaviour. We focus on how we identified and addressed the similarities and differences in our research questions, conceptual approaches to research, and

methodological abilities. We demonstrate how our multidisciplinary approach provides a framework for combining diverse research methods that collectively build knowledge to create more accurate models of crowd responses to (mis)perceived threats.

Keywords Crowd behaviour · evacuation · collective dynamics · qualitative methods · quantitative methods

1 Introduction

How and why people in crowds respond to real and misperceived threats is a pressing issue faced by emergency management and public security professionals. Studies of events such as terror attacks [1], large-scale flooding [2], crushes at transport hubs [3], and false alarms [4] show how both real and misperceived threats can create confusion and fear. Crucially, however, they also show how crowd members can pull together to coordinate their response, help one another overcome or mitigate the threat, and save lives when in real danger.

Researchers in both safety engineering and crowd psychology have attempted to understand how and why crowd members behave the way they do in response to potential threats. For example, safety engineers have examined decision-making in emergencies such as fires [5] and behavioural responses to previous real-world threats such as earthquakes [6]. Similarly, crowd psychologists have focused on the processes underpinning collective responses such as group members' social relationships to one another which can lead to trust, expected support, and responsibility to help fellow group members in threatening situations (e.g., [7, 8]).

Despite the common interests about how and why responses occur, the research has predominantly occurred in disciplinary silos. We believe that collaboration across the disciplines affords the opportunity to enhance our methodological repertoire and therefore our knowledge of crowd behaviour and the reasons for that behaviour [9]. For example, in safety engineering an increasingly popular method is to use virtual reality technology for experiments (e.g., [10, 11]) which can help to understand how people in crowds behave. However, the methodology has not fully explored the social psychological processes underpinning behaviour. This gap could be filled by methodologies from crowd psychology such as analysing post-incident accounts of crowd members to understand how group relations affected helping (e.g., [8]).

Although there are examples of research in crowd psychology using virtual reality technology (e.g., [12, 13]), it is typically difficult to experimentally measure the processes underpinning crowd behaviour in response to perceived threats. Experiments require large numbers of participants to take part at once in carefully controlled conditions, and can face statistical issues of non-independent data points as well as ethical considerations such as ensuring participant safety. The ability to create immersive virtual environments offers a solution to these challenges, particularly since it has previously achieved similar results regarding social influence as real environments [14]. Thus, the disciplines separately offer promising methodologies that when combined can improve understanding of both how crowds behave and which psychological processes cause those behaviours.

Our multidisciplinary project 'Perceived threats and 'stampedes': a relational model of collective fear responses' [15] brought together methodologies from safety engineering and crowd psychology to address shared questions about how crowds behave in response to perceived threat. In this paper, we outline how we established our collaborative approach and combined multidisciplinary methodologies to generate new knowledge about crowd behaviour and its causes. We hope that our process of multidisciplinary collaboration can act as a roadmap for similar efforts in the field of crowd behaviour and safety science.

In Sec. 2, we outline the differences and similarities in the methodological and conceptual approaches of our fields. In Sec. 3 and Sec. 4 we describe the methodological approaches we took, how they contributed to our knowledge of crowd behaviour in response to threat and the processes underlying it, and the strengths the methodologies offer multidisciplinary researchers.

2 Establishing differences and similarities

Our first step in our multidisciplinary research was to establish our shared goals and research questions. This required ensuring that we fully understood the terminology used across the disciplines. To assist our discussions, we referred to the recent glossary for research on human crowd dynamics [16] which was produced by psychologists, safety engineers, sociologists, physicists, mathematicians, computer scientists and others. We established that the main goals for the safety engineers were to generate new knowledge for enhancing crowd safety across a range of threatening situations (e.g., human-made or other environmental hazards). The goal for the crowd psychologists was to understand why people respond in a given way in different types of threatening scenarios - including misperceived threats - which could then be used to enhance safety. Combined, the mutual research questions were understanding how and why people in crowds react to (mis)perceived threats.

Our second step was to evaluate the strengths and limitations of the methodologies commonly used in our disciplines. Much of the previous research on crowd behaviour in emergencies has used a singular methodology at any one time to understand why behaviour occurred. For example, it focused on post hoc accounts of threatening situations from survivors [8], observational data [17], or relied on case study analysis [18]. Each methodology separately offers valuable insights into why crowd behaviour occurs, but each methodology has limitations. Observational analysis can provide information about the direction of movement people chose or how long it took for someone to evacuate when faced with the threat of a fire. However, it cannot explain individuals' reasons for choosing these actions. On the other hand, interviews with people who experienced the threat provide insights into beliefs behind why actions were taken, but they do not generate exact data such as reaction times that are necessary for emergency planning.

Our third step was to understand the conceptual differences between our disciplines. A key difference in our research approaches was that safety engineering has started using data-driven approaches, whereas research in crowd psychology was predominantly

theory-driven.

The data-driven approach typically involves collecting data with or without a priori research questions and then retrospectively attempting to make sense of the data by identifying patterns. For example, research using machine learning has investigated big data concerning pedestrian movement and focused on identifying behavioural and movement patterns associated with varying conditions (e.g., crowd densities [19]). This information can then be used for real-time crowd monitoring and evacuation guidance [20]. Safety engineering research is not always entirely data-driven since knowledge related to human behaviour in evacuations can lead to testing key topics related to crowd behaviour (e.g., pre-evacuation delay). Nevertheless, the key characteristic of this approach is that it is predominantly exploratory and oriented towards practical application. The advantages of this approach are that the reasons for the behaviour do not have to be necessarily explained and it is possible to interpret large volumes of data on crowd behaviour to use for safety purposes. However, the approach cannot identify the key parameters which determine response. This lack of knowledge makes it difficult to extrapolate findings to other contexts and to design interventions to alter behaviour.

In crowd psychology, using a theory-driven scientific approach for quantitative research typically involves formulating a theory or hypothesis and then testing the hypothesis with data. For example, Drury et al. [12] hypothesised that feeling part of a group would reduce competitive behaviour when evacuating during a fire and tested this experimentally. Qualitative research in this area takes a deductive approach, such as in Ntontis et al. [2] whose study used a social identity approach and involved exploring how residents in areas affected by flooding came to identify as community members and support one another. This analysis also contained an inductive (data-driven) approach since unexpected findings were included in the analysis, but the primary approach was to develop theoretically informed questions in advance of analysis.

Conducting theoretically informed research can provide an understanding of patterns across different types of threats, offer generalisable knowledge that may be applicable to other emergencies, and allow researchers to isolate and test the effects of specific variables of interest. However, this approach can take time to iteratively build knowledge over a series of studies, and it is important to be open to other important findings when examining complex topics such as crowd behaviour.

Our project combined multidisciplinary methodologies and conceptual approaches to maximise our understanding of both how and why crowds respond to (mis)perceived threats. Below, we focus on how we combined specific methodologies to enhance this understanding: case studies using qualitative and observational data, and immersive experimental paradigms with self-report data.

3 Case study analysis

The first case study evaluated witness statements of the 1943 Bethnal Green tube shelter disaster to understand why the fatal crowd crush occurred [3]. The second case study sought to understand responses to a false alarm incident on Oxford Street, London, in

November 2017, using triangulated data such as eyewitness and participants accounts, videos, and broadcast news online (for a full description of the data collected, see [21]). The third case study involved video analysis of crowd behaviour in response to a marauding knife attack in a London tube station [22].

The interviews and analysis of witness statements provided insight into the experiences of the people who were present during the two incidents and gave clear reasons for behaviour from their perspectives. For example, the Bethnal Green disaster occurred during World War 2 when local residents heard British rockets and a minority mistook them for German bombs. At this time, the public was generally advised by authorities to seek safety and the public followed this advice, but the ingress into the tube station was sudden and created a dense crowd on the station steps and a fall which led to a deadly crush. The data also demonstrates the diverse behaviours people reported taking, particularly in the Oxford Street example where some people looked to others for information, some fled, some hid, and some stayed in place and reassured others that there was not an emergency.

Together, the accounts from crowd members allowed us to understand their decision-making and how this was based on the information available at the time. This is an important step in building a theoretical model of the reasons for behaviour and can inform experimental study designs to establish causal relationships. However, this methodology cannot offer objective measures of behaviour, such as people's movement patterns. This is where the video footage of the crowd response at Oxford Street enabled us to create a timeline of the events and corresponding behaviour. Together, the triangulated data provided insight into what crowd behaviour occurred and why.

One limitation to the video data of the Oxford Street incident is that it was primarily taken from news reports [21] which are typically biased towards showing active moments of the response and do not provide full coverage. However, in another observational case study, we gained CCTV footage of an entire response to a marauding knife attack in a London tube station [22]. The analysis was primarily data-driven to identify behaviours of interest across the incident. In taking this approach, the researchers were able to create a timeline of the behaviours as the events unfolded and categorise how people responded, including counting how many people intervened to stop the attacker, helped others, and stopped others from entering the area.

The data in the project confirmed our theoretical argument that people tend to act collectively under threat, such as by helping each other when possible. Importantly, though, the combined data developed our theoretical model of crowd behaviour because it added knowledge about the range of activities that the public can take as the initial responders on the scene. Specifically for safety engineering, the case studies provide evidence that more provisions should be targeted towards spontaneous – or 'zero' - responders, and that computer models which give evacuees uniform and individualistic behavioural rules are neglecting the diversity of real behaviour. Together, the case studies provide a fuller picture of what information crowd members attend to in (mis)perceived threatening situations and how they commonly react.

4 Experimental manipulations and self-report data

Research in crowd psychology often uses stimuli to influence participants' perception and/or decision-making. Through vignettes or imagined scenarios they can, for instance, prime participants' perceptions of groups and individuals. However, the stimuli may not be sufficiently realistic or engaging to be effective primes and their effects may diminish throughout the experiment. Virtual reality technology provides a solution to this since it allows researchers to integrate stimuli into the environment with careful experimental control. Methodologies akin to priming stimuli are sometimes used in virtual reality experiments measuring social influence, such as by testing participant reactions when virtual agents are absent or are present but either stand still or run towards an exit [23]. However, they have not manipulated a key variable affecting social influence: social identification.

In our project, we combined priming techniques from crowd psychology with an online immersive virtual environment from safety engineering to create engaging primes with close experimental control. Prior to participants entering the virtual world, we used traditional stimuli from crowd psychology to manipulate how much participants felt part of a group with others they would see in the virtual world, as well as the perceived threat level facing those in the virtual world. We then consolidated the primes in the virtual world to keep them important to the participants, such as by having the participants read a virtual newspaper that discussed the threat level.

Moreover, the virtual reality technology allowed us to introduce and manipulate new stimuli in the environment, such as whether a noise played clearly indicated a threat (a gunshot) or was ambiguous (could be a door slamming). Thus, using virtual reality technology enabled us to keep primes important for the participants, introduce new primes later in the experiment, increase the ecological validity of the study, overcome logistical and safety challenges such as needing large numbers of participants at once, and keep close experimental control by having pre-programmed virtual crowd behaviour.

Our research builds on the methods used in Drury et al. [12] and researchers in the field of human behaviour in fire [5, 24] by testing psychological phenomena such as perceived threat and decision-making in real time. We took a number of crucial behavioural measures. For example, we tracked which virtual people in the environment our participants followed, their movement decisions such as which direction they first took, and how long it took them to reach the safe area.

Importantly, we also used a survey immediately after the immersive virtual scenario to capture self-reported reasons for the behaviour, such as whether participants felt in the same group as others in the environment and how threatening they found the noise. Thus, we combined conventional data collection methods from both disciplines to gain a fuller understanding of what crowd reactions occurred and why they occurred. Moreover, we were able to repeatedly test how different participants responded to the same conditions to increase our confidence in the cause of the reactions.

By combining methodologies, we found that participants predominantly followed the behaviour of the people in their social group, but this particularly occurred when the threat level was ambiguous. Moreover, it showed that people in potentially threatening situations use the behaviour of others as a diagnostic tool to assess the level of threat. For

crowd psychology, the findings demonstrated that both social identity and the clarity of the threat are important in guiding behaviour, particularly in ambiguous situations where participants looked to ingroup members to observe their behaviour and decide how to respond. For safety engineering, it showed that evacuation models with ambiguous threats should consider social influence and the contextual information available to the crowd.

5 Concluding remarks

There are clear research benefits to using our multidisciplinary approach. We learned new ways to address core questions (e.g., how crowd responses to threat develop in real-time under different conditions) and improved our methodological abilities (e.g., integrating primes into immersive virtual environments), and mitigated the limitations of using one single method at a time. Our multidisciplinary combination of case studies, immersive experimental manipulations and self-report data allowed us to build and test a theoretical model of how people in crowds respond to threats and the role that group processes play in decision-making. There are also clear practical benefits to our approach. Our research resulted in crowd safety recommendations for non-academic stakeholders, including an accessible guide to public behaviour [4], developing event safety courses, and holding workshops and talks with government bodies, transportation and event safety management practitioners. In summary, the approach we have developed will allow us to continue to build our theoretical knowledge of crowd behaviour and practical recommendations for stakeholders, and to develop multidisciplinary methodologies to address joint questions far into the future.

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