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Human Stampedes: A Scoping Review

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Statement

I hereby certify that this thesis entitled “Human Stampedes: A Scoping Review” is my own work.

All sources of information (printed, on websites, etc.) reported by others are indicated in the list of references in accordance with the guidelines.

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I, Johan von Schreeb, approve this thesis for submission.

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Acronyms and Abbreviations

CPR – Cardiopulmonary Resuscitation

DFY – Doctors For You

GPS – Global Positioning System

HSE – British Health and Safety Executive

IR – Infrared

m² – Square meter

MCI – Mass Casualty Incident

N – Newtons

N/m² – Newtons per square meter

Non-SMRP – Non-sports, music, religion or politics

PTSD – Post-Traumatic Stress Disorder

RFID – Radio frequency Identification

UK – United Kingdom

USA – United States of America

WLAN – Wireless Local Area Network

WHO – World Health Organization

WHOLIS – WHO Library Database

Abstract

Background and Aims

Human stampedes are a type of crowd disasters and among the major causes of mortality in mass gatherings. The body of literature regarding human stampedes has increased over the past years but still has not been reviewed. The aim of this study is to summarize available experience on the prevention, preparedness and response to stampedes and outline research gaps of the field.

Methods

A scoping review with set inclusion and exclusion criteria was conducted. Databases were searched for relevant published and grey literature documents, and a final of 64 documents were included in this review.

Results and Discussion

Conflicting definitions of human stampedes were found. Several causes for stampedes have been identified, described as a succession of events with a fatal outcome. Several strategies for prevention and preparedness as well as experiences from response to such events are presented. The majority of the documents retrieved were originally from high-income countries whereas stampede events occur mostly in low and middle-income countries, and therefore findings are difficult to generalize.

Conclusions

Human stampedes are a complex and multifactorial event. To better understand such events, and to improve prevention, preparedness and response, a multisectorial approach is needed. There is no commonly agreed definition of human stampedes. No improvement has been made in the independent reporting of human stampedes.

Keywords: stampede, crowd disaster, mass gatherings.

Introduction

Mass gatherings are a “concentration of people at a specific location for a specific purpose over a set period of time and which has the potential to strain the planning and response resources of the country or the community” (1). With population growth, improved transportation facilities, and because they bring many positive social and economic outcomes, mass gatherings are becoming more frequent and attract an increasing number of participants (2).

Mass gatherings may occur spontaneously such as at train stations during rush hour (2). They may also be planned like at sport, cultural, religious or political events (1).

The annual Hajj pilgrimage in Saudi Arabia and the Kumbh Mela in India, which occurs every three years, are the biggest mass gatherings worldwide that bring millions of pilgrims together (3, 4).

Mass gathering events may have negative effects on population health (2). Communicable disease transmission is a major public health concern due to the large concentration of people. Of particular concern are respiratory and gastrointestinal diseases (1, 2, 5). Environmental issues like heat and cold waves, air and water quality, and the potential for an extreme weather event are other threats (1). Intoxication resulting from illicit use of drugs or alcohol, injuries, severe acute cardiovascular events due to emotional stress, and crowd disasters are also of health concern (5).

The large concentration of people in mass gatherings strains the existing local health system and limits access by aid and rescue services. Therefore, despite organization and preparation, mass gatherings are prone to disastrous events (1, 6).

These disastrous events are sometimes termed as “crowd disasters” (6). Crowd disasters include the collapse of venue infrastructures, fire incidents, terrorist attacks, violence riots, and human stampedes (1, 7).

Stampedes are caused by the movement of individuals in a crowd “in response to a perceived danger, loss of physical space”, or “a will to attain something seen as gratifying” (4, 8, 9). They can also be described as a “disruption of the orderly movement of crowds resulting in irrational and dangerous movement for self-protection, leading to injuries and fatalities” (4).

Human stampedes are among the most feared crowd disasters. They are, besides of heat-related illnesses, the most common cause of mortality in mass gatherings, with a high fatality rate (5, 7). Between 1980 and 2012, 350 human stampede events have been reported, having caused over 10,000 deaths and 22,000 injuries, and this is believed to be an underestimation (10). Human stampedes also result in considerable structural damage and material loss (11).

In order to better understand this unique event, and to improve prevention, preparedness, and response, research is warranted.

A first attempt to synthesize information from scientific articles on human stampedes was performed in 2008. This study identified 20 relevant articles in the peer-reviewed literature since 1970, describing eight human stampede events, the majority in the United Kingdom and the United States. The study highlighted the lack of formal reporting of human stampedes events in international databases, suggesting the use of other information sources as a starting point for further research (8).

In response to this, a study incorporated non-traditional sources such as news reports to document the epidemiological characteristics of stampedes (12). A total of 215 reported human stampede events from 1980 to 2007 was identified. The majority occurred after 2000, and in low-income countries from South-Asia and Africa. Stampedes occurring in these “developing countries” had a 7.75 times higher fatality rate compared to in “developed countries”. This study also showed that the fatality rate could be until 40 times higher when stampedes did not occur at sports, musical, religious or political (non-SMRP) events (12).

Since these two publications, more articles have been published regarding human stampedes, frequently highlighting the importance of including non-traditional data sources in research (2, 4-6, 10, 13). Research has been conducted by a wide range of fields, such as engineering, social psychology, clinical medicine as well as public health. However, most of these articles describe past events or restate existing evidence, rather than suggesting further advances in the knowledge status and improvement in policymaking (14). For example, preventive strategies are, in general, based on expert opinions rather than on convincing evidence, leaving some doubts on their effectiveness in reducing the risks (8).

In 2010, a panel of experts met in Saudi Arabia during the Global Forum on Mass Gatherings. A research agenda was proposed, highlighting public health knowledge gaps that compromised effective management of such events. The research agenda focused more on the spread of infectious diseases rather than on crowd disasters and stampedes (15).

Despite an increasing number of studies regarding human stampedes and crowd dynamics, these events keep recurring with considerable frequency. Fatalities and injuries still occur even though stampedes are presumably preventable. For these reasons, experts believe stampedes are not fully understood (16, 17). Important research questions and problems have possibly not been formulated nor answered to “appropriately or at all”, and have become pertinent research gaps that still exist today (18).

To my knowledge, there is not an updated and comprehensive review of the heterogeneous literature about human stampedes that summarizes the current knowledge on this topic.

Aim(s)

The aim of this study is to summarize the literature on stampedes, their prevention, preparedness and response.

Material and Methods

1. Design

To summarize information and clarify definitions, conceptual boundaries, and research gaps in the heterogeneous body of literature regarding human stampedes, a scoping review protocol was used.

This scoping review is based on the methodology and framework proposed by Arksey and O'Malley and with the additional recommendations by Levac et al. in 2010 (19, 20). In accordance with this framework, the following steps were undertaken: after having identified the research questions (see table 1), a literature search was performed, and documents were selected according to pre-defined eligibility criteria. Data were extracted, charted, and analyzed.

Table 1: Research questions for conducting the scoping review

Main question	<i>What is described in the literature in regard to the prevention, preparedness and response to human stampedes?</i>
Subquestions	<i>How are stampedes defined and classified in the literature?</i>
	<i>How do stampedes occur and cause injuries and fatalities?</i>
	<i>How is the prevention/preparedness/response of human stampedes described?</i>

2. Eligibility criteria

Based on the aim and the background research, eligibility criteria were defined.

Inclusion Criteria:

- Documents specifically referring to human stampedes and related strategies. For the purpose of this thesis, and in order to detect as many relevant items as possible, a human stampede was considered a “disruption of the orderly movement of crowds” that could “lead to injuries and fatalities” (4).
- Documents published in the scientific literature: expert opinions, case reports, and peer-reviewed articles. This way not only research findings were summarized, but also experiences and definitions.
- In order to gather more experiences and descriptions on this topic, grey literature, i.e. documents where “publishing is not the primary activity of the producing body” (21), was included: government or national and international organization reports, academic works, and guidelines.

- Documents available until June 2016.
- Documents in English, Portuguese, French, Spanish, and Hindi.

Exclusion criteria:

- Documents regarding crowd evacuation models or crowd behavior not specifically referring to human stampedes.
- Events related to fire disasters and terrorist attacks, as they are another type of crowd disaster.
- News reports.
- Documents without full text available through the Karolinska Institutet Library.

3. Search

As part of the scoping review methodology, a comprehensive search of published and grey literature was conducted. After consulting with the Karolinska Institutet Library staff, the search engines and databases PubMed, Google Scholar, Web of Science, the WHO Library Database (WHOLIS), and ReliefWeb were used. The search terms “Stampede*” OR “trampling*” OR “Crowd Disaster” OR “mass gathering” were used in all fields.

4. Document selection

In the first round, and after removal of duplicates, titles were screened for relevance. At this stage any uncertainty did not exclude the document from going to the second stage. At the second round, titles, abstracts and summaries were read and their inclusion was decided based on the eligibility criteria. If any doubt remained, the full text was read for a final decision.

The initial search of all databases resulted in a total of 20,787 citations. At this stage, many documents using the term “trampling” related to vegetation alterations, as well as papers related to an oncology trial called “STAMPEDE” were identified and removed. After screening the titles for eligibility and removing obvious duplicates, 729 documents were eligible for the second round.

The next step consisted in skimming the abstracts and if doubts remained, reading the full manuscripts. More duplicates were identified and removed, as well as

documents in languages not considered in the inclusion criteria. Some studies had to be excluded from the analysis despite their relevance, as they were mainly abstracts from studies presented at conferences that did not have a full text available. One document found in the ReliefWeb Database was an organizational magazine dedicated to the subject of stampedes, accounting for five different documents. The WHOLIS database did not contribute with any eligible document to this research. In all cases the reviewer double-checked before any document was excluded. Finally, 64 documents were included in this analysis.

The flowchart in Figure 1 shows the different steps undertaken in the study selection, whereas figure 2 shows the distribution of the 64 documents according to search engine or database.

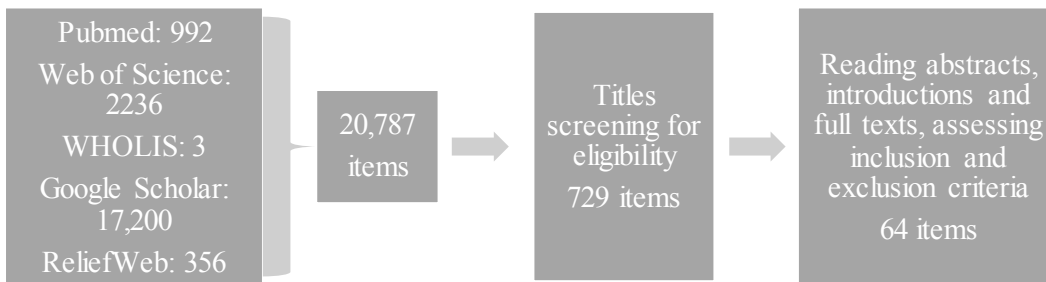


Figure 1: Flowchart showing steps undertaken in study selection

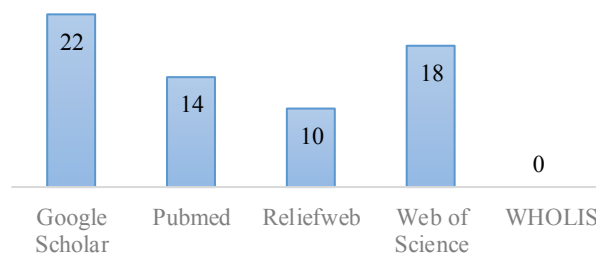


Figure 2: Number of documents retrieved by source

5. Data extraction and analysis

Data were introduced in a Microsoft Excel ® spreadsheet. Information regarding source, country of origin, date, type and purpose of the document, results, and research gaps mentioned by the author was extracted (see appendix 1 for more detailed description of the extracted information).

The mapping and charting of results as well as further analysis were inspired on the methods used in different benchmark articles (22-24).

An initial descriptive analysis was conducted as advised in the scoping review framework and in similarity to the benchmark articles (22, 24). Distribution of the documents by type, chronology, geography and study population was described.

Key findings from the documents were summarized and organized according to stampedes, their prevention, preparedness, and response. The benchmark article by Paul Arbon “Mass-Gathering Medicine: a review of the evidence and future directions for research” (23) provided guidance in the review process and the same approach in the presentation of results was used in this thesis.

Results

1. Description of gathered documents

A total of 64 documents were included in this study. Documents published in scientific journals accounted for 75% (n=48) of all included items. The oldest document retrieved was from 1987 (25). More than half of these documents (n=34) were published between 2013 and 2016.

All documents retrieved were in English. Most documents were originally from India (n=13), the USA (n=13), China (n=8), the UK (n=5), Germany (n=5), and Australia (n=4). The most frequent stampede event studied in the gathered documents was Germany's Love Parade stampede from 2010, with six case and empirical studies. The 1989 stadium stampede that took place in Hillsborough, UK, was described in four documents.

2. Review of the Literature

The information retrieved was grouped into four categories: stampedes, prevention, preparedness and response.

a) Stampedes

- **Definition and Classification of Stampedes**

No standard definition was found and it varied among authors, as shown in table 2.

The terms "crowd disasters", "trampling" and "crushing" are sometimes used interchangeably. The terms "mass crowded stampede-trampling accident" and "crowd quakes" have also been used with similar meanings (26, 27). Helbing et al. in 2012 suggest that stampede precedes crowd disaster. They also suggest that the term "crushing" relates to a crowd pushing towards a bottleneck, whereas "trampling" means people walking carelessly over others (17).

Table 2: Stampede definitions found in the Literature

Author	Definition
<i>Illiyas et al</i> 2013 (4)	“(…) the surge of individuals in a crowd, in response to a perceived danger or loss of physical space. It often disrupts the orderly movement of crowds resulting in irrational and dangerous movement for self-protection leading to injuries and fatalities”
<i>Ngai et al</i> 2009 (8)	“(…) an impulsive mass movement of a crowd that often results in injuries and deaths. Another commonly associated term is trampling that leads to infliction of crushing casualties”
<i>Hsieh et al</i> 2009 (12)	“(…) either trampling or asphyxiating crushes with mass casualties”
<i>Burkle</i> 2011 (9)	“Stampedes can take two forms: one occurs from panic attempts to escape a detected threat, whereas the second happens when the rush is toward something seen as gratifying”
<i>Helbing et al</i> 2000 (28)	“(…) induced by panic, often leading to fatalities as people are crushed or trampled. Sometimes this behaviour is triggered in life-threatening situations such as fires in crowded buildings; at other times, stampedes can arise during the rush for seats or seemingly without cause”
<i>Wieringa</i> 2015 (29)	“(…) an occasion when many people suddenly all move quickly and in uncontrolled way in the same direction at the same time, especially because of fear” (adapted from Cambridge Dictionary 2014) “A crush can result from a stampede that is caused by mass panic.”
<i>Sindhu Kollu</i> 2014 (30)	“a person might lose his balance and stumble, which when followed by trampling leads to a stampede.” Stampede is defined when the crowd density is above 5.26person/m ² ; or when the inflow of people is much higher than the outflow.
<i>Prasun</i> 2015 (31)	“(…) the humans when in crowd, they start behaving by animal instinct. Thus for a crowd, stampede is a situation when individuality is lost and individuals behave according to the crowd to get into a safer place. Stampede is a self-destructing human wave i.e. a panic situation, like fire or rumours, which starts at highly dense crowded area (10 people in an square metre area) and like a wave humans run to escape in a disorderly way.”
<i>Salamati & Rahimi-Movaghar</i> 2016 (32)	“There are two types of stampede. The first type is a panic behavior of people who afraid of a detected threat, while the second type takes place when a great number of people attack to get a pleasuring object”
<i>Bolia</i> 2015 (11)	“Stampede is particular instance of crowd disaster. ‘Stampede’ is derived from a Mexican-Spanish word ‘estampida’ which means ‘uproar’. Stampede is defined as “an act of mass impulse, which occurs in times of massive flight or massive craze response” (Chukwuma and Kingsley 2014).”
<i>Khana et al.</i> 2014 (33)	“A stampede is an act of mass impulse among herd animals or a crowd of people in which the herd or crowd collectively with no clear direction or purpose”; “This is also referred to as crowd crush.”

Ngai et al. proposed a stampede classification based on magnitude, the scale being reported deaths (see table 3). It has been argued that using absolute number of deaths has its limitations by not considering other factors such as injuries, fatality and injury rates, and material losses (8, 12, 34). Nevertheless, a unified classification could facilitate research and levels of response (8).

Table 3: Stampede Classification according to Ngai et al.(8)

Class I	Mild	Injuries, 0 deaths
Class II	Moderate	1 to 10 deaths
Class III	Severe	11 to 100 deaths
Class IV	Devastating	101 to 1000 deaths
Class V	Catastrophic	More than 1000 deaths

- **Causes of Stampedes**

The retrieved documents identify different reasons why stampedes occur. Many authors observe that stampedes do not occur for a single reason but rather as a chain of events (17, 35).

Triggers:

Rumors of a terrorist threat or a fire are a frequent trigger for human stampedes and are a major cause (31). They may also be triggered by the sudden notice of something desirable by the crowd, such as the distribution of free tickets or food or even the change of platforms at a train station (4, 36, 37). Sudden and loud sounds can mimic the sound of bomb explosions or gun shots and cause fear in the crowd which can lead to a stampede (37). Some authors suggest the use of tear gas by crowd control staff in an overcrowding situation as a possible trigger (34).

Crowd characteristics:

Overcrowding is a major factor for the occurrence of a stampede. However, more than the absolute number of attendees, it is crowd density that influences the outcome (38). Even if the global density of a mass gathering may be low, the local density in

specific locations can be very high (39), as the crowd is not distributed evenly throughout the entire venue (40).

Other factors of the crowd include the direction of the flow and the duration of the high crowd density (41). The capacity of the venue and the density of the crowd depend on the body sizes, culture, and religious beliefs. It is therefore specific to type and location of the event (39).

Stampedes have been reported in schools (13, 33). The reasons for this are not known, although the relatively low age of the crowd has been considered as a potential factor (33).

Venue characteristics:

Closing entrances or exits, the existence of congestion and bottlenecks, and deficiencies in safety barriers are reported as underlying causes for the occurrence of crowd stampedes (9, 16, 42). Lack of coordination with local authorities may potentiate these flaws and contribute to the development of a stampede (9).

When the event takes place in isolated or rural locations, or in low resource settings, the vulnerability increases. Narrow lanes, ambulant sellers on the sides, steep and muddy floors, dead ends, and convergence of pedestrian flows occur more frequently in and represent a risk (4, 31).

Crowd Behavior:

Stampedes were initially described as the result of an irrational or even animal behavior of a crowd caused by panic (17, 25, 42, 43).

An attempt to describe this “escape panic” was made in 2000. At first, people try to move faster than normal, they start pushing and interactions become physical. Moving and passing bottlenecks becomes uncoordinated, and arching and clogging are observed at exits. Physical interactions cause pressures up to 4450 N/m². Because people start falling, they become obstacles, and the movement is further slowed. People start adopting a mass behavior and often overlook alternative exits (28). However, experts still claim that the behavior of the crowd during panic situations is not fully understood (28, 44-48).

This irrational and dangerous behavior associated with stampedes has been contested. Qualitative studies including the victims of the Hillsborough Stadium disaster in the United Kingdom (UK) and from the stampede at the Who concert in

Cincinnati, show that the crowd behaved rationally and cooperated (17, 25, 42, 43). It has been suggested that, even with the perception of a risk, a crowd may feel safe and reduce the risk of a stampede through self-organization. It is believed that psychological unity, or identification with the rest of the crowd, may influence this behavior (49).

Some types of crowds, like football fans, are associated with violence, alcohol and drugs intake. When stampedes occur in those settings, such behaviors are instinctively mentioned as a cause (43). However, in the aftermath of the Hillsborough stadium disaster, post-mortem blood tests of the victims showed unremarkable levels of drugs and alcohol, contradicting many beliefs and accusations by the organizers and the media (42).

- **Mechanism**

Analyses of videos from the Mina crowd disaster from 2006 showed that even at crowd densities of 10 people/m², a person's individual speed never reached zero (39). Many density thresholds have been mentioned in the literature; for example Sindhu Kolli defines stampede at a density of 5.26 persons/m² (30). Another author, Ibrahim, suggests metrics to characterize the crowd: Loose crowd 1 person/m²; dense crowd 2 persons/m², very dense crowd 4 persons/m² (50).

It has been suggested that the crowd pressure, a product between the density and the variance of the densities, gives better information about critical areas and times of the stampede (39, 51).

The mechanism leading to stampedes is believed to follow a pattern (39, 52): in normal situations, the crowd moves in a free or laminar flow. When density increases, a coordination problem changes the flow to "stop-and-go waves". This can lead to loss of movement control by the crowd and individuals are pushed randomly – "crowd turbulence". When a person loses balance and stumbles, or is pushed down, the people surrounding fall due to sudden forces imbalance. People at the bottom or squeezed eventually die of traumatic asphyxia. Trampling happens when people step on others when they try to avoid falling (17). It has been reported that the transition from stop-and-go waves to turbulent flows still needs to be appropriately assessed and simulated because it is not well understood (39, 45).

Stampedes have also been described to occur in unidirectional flow or turbulent flow (random movements in different directions). Unidirectional flows can occur due to the

sudden increase in force, such as a congested bottleneck or exit, or a decrease in force, like the sudden collapse of a security barrier (8).

A study focusing on a group trample in an escalator showed that the severity of the situation is influenced by the initial location of the trample, the time at which counter-measures are taken, the pedestrian velocity, the escalator velocity, and the standing up duration. The recovery rate (the time a person needs to stand up again) and the propagation rate (the velocity at which people start falling after the first one) were other parameters that could influence the outcome (41). It has not been explained how complex behaviors, like a person stopping to help another, influence the movement of a crowd (28, 41).

- **Epidemiology**

Because there is no independent reporting of human stampedes, current data collection methods include information obtained through news reports in the media. Two search methods are described in the literature. The Ngai search method consists of a LexisNexis® search with a secondary hand-search of important news agencies. The Roy search method searches data from major Indian newspapers and has only been applied in this country (10).

Two studies using the Ngai search method as a data collection method were published (8, 10, 12). One of these studies showed it underestimated stampede events by approximately 18% (10).

Between 1980 and 2007 this search method identified 215 stampede events worldwide; and 350 events between 1980 and 2012 (10). By studying events with available deaths and injuries information between 1980 and 2007, 7069 deaths and 14078 injuries were identified (12); and between 1980 and 2012, 10,243 deaths and 22,445 injuries (10).

Most events occur during daytime and indoors and in sports events (12). Unidirectional mechanism increased fatality rate by 3.46 times, believed to be due to the confluence of forces in one same direction (12).

Women, children and older people are believed to be more affected, probably because they are less capable to defend themselves from other peoples' weight (16, 36) .

One study showed that the ratio of fatalities between women and men after a stampede in Shanghai was 3:2 (53).

India is the country with the highest number of reported events (12). A study using two different data collection methods identified a total of 40 human stampedes in India between 2001 and 2010 (10). Another study that collected data from the National Crime Records Bureau identified 34 human stampedes in the country between 1954 and 2012, with a total of 1823 reported dead (4). Most events (58.8% according to Ngai and 79% according to Illiyas) are religiously related. Most of the stampede events occurred in the northern half of the country (4).

- **Clinical Aspects**

The extremely overcrowded situations and external compression limit thorax expansion, leading to traumatic asphyxia, the major cause of mortality. Some deaths are caused by trampling and internal organ injuries, but little evidence exists (8, 54).

Classic clinical signs of traumatic asphyxia are cervico-facial congestion and cyanosis, and conjunctival and facial petechiae (8). Resuscitation efforts such as chest compression and ventilation cause injuries very similar to signs of traumatic asphyxia, which can influence legal medicine reports (55).

Crush injuries may lead to rhabdomyolysis and precipitate the need of kidney replacement therapy (56). Other types of severe injuries such as traumatic brain injuries, haemothoraces, and femur fractures are also described (36, 54).

Psychological and psychiatric sequels include depressive and anxiety disorders, phobic disorders, and post-traumatic stress disorder (PTSD) (8, 13). One study with children victims of a school stampede showed PTSD was not the most common psychiatric disorder, suggesting it should not be overemphasized and that other disturbances merited due attention (13).

b) Prevention

Strategies to improve crowd movement and avoid congestions have been formulated, but their effectiveness in reducing the occurrence and severity of stampedes still has not been tested (4, 8).

Reducing the size of the crowd attending an event is an obvious measure but difficult to implement. Big crowds are usually favored by many stakeholders, including the visitors themselves who attend such events to meet people with the same interests and tastes (38, 57).

Crowd management is considered a preventive approach, starting before the beginning of an event. Crowd control occurs during the event and reacts to the needs and behavior of the crowd. Some actions of crowd control fall within the scope of response, depending on the timing of their implementation (58).

- **Design**

The infrastructure of the venue should be designed and operated in a way that avoids bottlenecks, counter flows, intersecting flows, or even merging flows. Obstacles, including people in the way, should be removed. Some ways should be reserved for emergency operations and protected from public access (39).

The following architectural solutions have been proposed (38, 59):

- With segmentation, the crowd is divided in smaller groups and easier to manage. It also prevents propagation of an incident from one group reaching others. Sometimes people with similar characteristics are put together, like gender or age group.
- The principle of the “nested doll” means to have a structure inside another building, like an emergency exit beneath a building. This provides more space to the pedestrians and some are led into a less crowded area. However, costs and space limitations may limit the expansion of such structures.
- Expanding the surface does not have to be done horizontally but can be achieved by adding another dimension, such as higher floors.
- Shaping the area near the exits like a funnel, thus preventing clogging.
- Zig-zag shapes also prevent congestion during panic but cause some discomfort in normal situations.

Before an event, simulation is advised in order to identify critical locations where possible congestion and clogging may occur (17, 39, 48, 50). Knowing the layout of a venue is of great importance before an event takes place (11).

Combining optimal designs in extreme situations that are acceptable in normal situations has been discussed and acknowledged as challenging (59-61).

- **Crowd monitoring:**

Crowd monitoring means to examine the condition, movement and behavior of the crowd (50). Critical areas must be monitored during highly congested time periods, and valuable information displayed in the surveillance system, such as density and crowd pressure (39). Crowd monitoring exclusively done by crowd control staff has proved to be inefficient (60). Other means to monitor the crowd include video recording, Global Positioning System (GPS) , Assisted GPS, Bluetooth, Infrared (IR), Radio frequency Identification (RFID), broadband satellite network, Wireless Local Area Network (WLAN) (50, 62). It has also been suggested that the use of mobile phones could improve accuracy of stampede detection, crowd force estimation, and stampede prediction (63).

- **Crowd management:**

Ensuring that the venue is not overcrowded, and hence a safe capacity, is fundamental. The maximum capacity has been proposed to be calculated by: maximum number of visitors $< \text{Area in m}^2 \times 10$; where 10 is an extreme crowd density. A safety margin of 30% has been suggested (31, 39).

Improving the flow of people can be achieved by avoiding bidirectional flows and restricting entry until the maximum capacity is reached (29). Increasing a bottleneck space is only a temporary solution. Minimizing pedestrian speeds at specific locations may reduce the risk of crowd disaster (60).

Some ways to manage the inflow of visitors have been suggested (31, 64):

- Plan for a long event where people can arrive at different times without reaching critical densities;
- Pre-registration and ticket system;
- Entrance fee;
- Entertainment so the crowd does not get impatient while in the queue;

- Apply a scheduling program, a plan regulating the timing and routing of groups of people. Compliance to these programs should be monitored and if it is not respecting the schedule, apply counter-actions like fines;
- Entry restrictions and limiting group sizes;
- Limiting facilities inside the venue, such as restaurants, toilets, or internet spots.

The banning of festival seating, which means visitors do not have reserved seats in the venue and may even stand, is considered a very effective measure, although many times ignored due to industry pressure (58). In rural settings, and mainly for religious pilgrimages, separating visitors on-foot from others in different tracks has also been suggested (31).

c) Preparedness

Planning an event should be done as early as possible after the decision to hold it, in order to ensure good coordination between organizers, police forces, community leaders, health care services, and to implement risk reduction measures (4, 17). A short period of time for planning and preparation can result in insufficient measures and aggravate a disaster. It is commonly pointed out that scenario based and detailed contingency plans should exist, and these should be worked out and exercised (17, 33, 39, 65).

Emergency ingress and egress should always be planned for and free access ensured during the whole event (16).

Absence of onsite medical resources in an already fragile local healthcare system show how poor resources magnify the consequences of human stampedes (16). Referral hospitals should also be prepared for a stampede or mass casualty incidents (MCI) when mass gatherings occur. A drill in South Africa showed that the biggest preparedness flaws were in risk communication and public relations, safety, supplies, and security (66). Therefore, preparedness should include ensuring proper communication channels (16). The implementation of protocols for record keeping has also been suggested (54, 55).

In schools, where several stampedes have been reported (13, 33), it is recommended that evacuation drills should be conducted regularly and evacuation routes should be tested, in order to detect flaws in design and instructions. Involving the entire class or

even the full school community is also advised, with dissemination of information through appropriate means of communication (33).

d) Response

As stated earlier, some crowd control actions may be seen as part of the prevention or response to stampedes, depending on their time of implementation.

During the event:

It has been suggested that crowd control or counter measures should start as early as stop-and-go waves set in (39). The implementation of early emergency measures reduces the time of exposure to high crowd density or dangerous movements and it increases the recovery rate (41). Late evacuation of the Love Parade venue, at least 6 minutes after crowd turbulence started, is one of the reasons for the death toll of 21 during this incident in Germany (17).

It still remains unclear how real-time crowd control should be undertaken (67). How these measures change the immediate behavior of the crowd has not been assessed (29, 41). Authorities and crowd control staff sometimes use water cannons and tear gas as means to disperse the crowds but this can actually increase confusion and be a trigger for stampede (16, 34).

Lack of coordination between various actors delays an appropriate response and many times leads to ineffective or even prejudicial actions (9).

In the immediate aftermath:

A commonly referred flaw in the immediate response to stampedes is the communication between different services (34). It is believed that vertical communication between the event organizer, the crowd tracking personnel and the crowd control force is better, faster and more effective than the communication just between the members of a crowd control force, such as the police (30).

Reports from stadium stampedes reveal that many times on-site triage is poorly done, with too many people reaching the nearest hospital by their own means or even by ambulance. Overtriage also increases the influx of patients reaching the emergency department.

It has also been reported that the emergency departments were not warned of a mass casualty incident and could not be prepared to receive such influx of patients, and also did not request staff who were not on call. Media like TV and Radio were not used to inform people in an effective way. No psychological support was given to the victims and the staff was not debriefed (34, 54).

On-site medical teams are useful for discharging patients who do not need medical attention, referring those in need of higher level of care, and in giving life-saving support like cardio pulmonary resuscitation (CPR) (42, 55). It is believed that a poor on-site medical care increases the number of fatalities, as many people suffering from traumatic asphyxia do not die immediately and their lives can still be saved (42). Access for emergency medical teams to the disaster site may be compromised due to the crowd (35). However, there are no descriptions of what type of medical care is usually needed and provided on site, how many deaths occur on site and in the hospital (34, 54, 55).

Immediate referral to medical facilities is warranted for some critical patients but it is difficult in rural and low resource settings (4).

Publications mention that many on site assessed patients that were referred to hospitals or for autopsy lacked medical records, which delayed many decisions and treatments (34, 54, 55).

It has been highlighted that on-site care or even peripheral centers lack simple but lifesaving treatments such as intravenous fluid therapy (56).

After the event:

The response deployed and the actors involved also depend on the community's context and the existing health system. In the case of a disrupted country, like in Iraq in 2005, the response has to involve international organizations since the coping capacities are very limited. Supplies like oxygen and ambulances are provided to local hospitals. Families and injured should also be included in this response since the existing systems may not be able to provide any assistance. (68-70).

A common reaction of event organizers is to immediately blame the crowd for causing the stampedes due to an "uncontrolled and animal behavior" (17, 25, 42, 57). This image is also spread through the media (43). However, many studies concluded that response by organizers and other actors was poor. A report by the British Health and Safety Executive (HSE) on the Hillsborough Stadium stampede showed that emergency services failed to activate the major incident plan and the Emergency

Medical Service staff in the stadium was delayed in recognizing the situation as a crisis. They also failed to triage the casualties and in coordination with the different actors (42). It is believed that people suffering from asphyxia did not die immediately and could have been saved had a better response been implemented. Communication problems and changes in police shifts also delayed response in the Love parade disaster. The triage procedure in this disaster did not provide aid to many people in critical health conditions.

An issue presented by Cocking in his work is that the response is highly influenced by misperceptions of panic and danger. This also has consequences in the receptivity of the crowd to information given (71).

Discussion

The research gaps outlined in this study reflect the complexity and multifactorial nature of human stampedes.

Despite a growth in publications in regard to human stampedes, inconsistencies in terms used and the lack of a standard definition still exist. The definitions identified in the literature show a lack of agreement between authors and fields of expertise. Some authors still define stampedes as a consequence of an irrational behavior of the crowd, although this has been already counter-argued in scientific papers, the first one published in 1987 (25). This discrepancy in definitions is very likely related to the fact that the mechanism of stampedes remains poorly understood. It is also possible that cultural beliefs influence how this phenomenon is perceived by the authors. This lack of definition has several implications. First, it hampers research because there is no operational definition that can be used systematically in the reporting of such events. This means it can be an underlying cause for the lack of independent epidemiological monitoring of stampedes. Additionally, as shown in our results, it is unclear whether some measures taken, such as crowd control, are part of the prevention or already of the response. This can have consequences, for instance in how they are managed and when they should be implemented. As previously reported in the literature, research on stampede is scarce, but to my knowledge the lack of a standard definition has not been discussed or highlighted (8, 12).

Most of the documents retrieved were originally from high-income countries like the USA, the UK, Germany, and Australia. High-profile events, such as the Love Parade or the Hillsborough stadium stampede, were the most thoroughly studied in the literature. The asymmetry between research and the occurrence of stampedes, which is much more frequent in low and middle-income countries, has already been described (8, 12). Events in low resource settings do not mobilize the same level of organization, infrastructure, and technology, meaning important registries and recordings do not exist for later analysis, similar to what is done in contexts with more resources available (17, 39, 41, 45, 48). In this context reliable data are even more difficult to obtain, which challenges research and can possibly explain this asymmetry. This means that findings and simulations of crowd behavior that were tested in these high-profile events may not be reproducible in other settings. Because knowledge seems to be based on a specific

group of stampedes, which only accounts for a minority of all the stampedes, it is probably biased and conclusions cannot be generalized.

It has been suggested that human stampedes are a consequence of a complex chain of events and do not arise from a single cause. Sudden noises or perceptions of threat may represent a trigger for stampedes but these are unlikely to happen if the surrounding conditions are ideal: low crowd densities, well-designed venue, unobstructed exits, good communication with the crowd, absence of bidirectional flows, to only name a few. More than a result of an irrational behavior by the crowd, stampedes seem to be a consequence of a succession of failures in the planning and organization of an event. It seems that after some point in this combination of events, the process cannot be stopped and the outcome is inevitable. This multidimensional causality of stampedes has been recently described by scientific studies (17, 42), but also put in evidence in the media after the longest trial to reach a verdict in the UK exculpated the victims of the Hillsborough stadium stampede and blamed different flaws in the organization (72).

- **Study limitations**

This study included several unusual sources of information, such as organization reports and expert opinions. Although they do not account for original research, such documents were valuable for this review by providing key definitions and highlighting important research gaps.

The definition of stampede used in the search could have influenced the selection process. Because it was aiming to be broad and comprehensive, some specificity may have been lost in order to gather as much information as possible.

Many of the included documents focused on specific events. Although some of the findings relate to other papers, it is difficult to extrapolate and make generalizations.

A big effort was made to include as many documents as possible, but not all potentially relevant papers were retrievable through the used databases and thus were not included in this review. Also, it is possible that research and other works were written in other languages than the contemplated in this thesis. However, available literature in this topic is believed to be quite limited and hence the possibility of selection bias is small.

Time constraints did not allow for reference screening and consulting with experts, but these steps are optional according to the scoping review framework used in this thesis.

The decision-making during the selection process and the subsequent literature analysis also had limitations because this study only had one reviewer. However, the selection process was very thorough because, at the abstract skimming round, documents were double-checked before they were excluded. A PRISMA protocol was not applied due to time constraints and the fact that the reviewer was not used to work with this different range of search engines. The reasons for inclusion and exclusion were all recorded individually, but a thorough calculation of all the categories would be extremely time consuming. The PRISMA protocol is advised in the Scoping Review framework but it is not mandatory, and this review tried to be as systematic as possible in the selection process and followed the approaches used in the benchmark articles.

This work did not go into depth in the analysis of mathematics and physics models studied in many documents, because that type of analysis is outside the scope of this thesis.

Lastly, this type of study design does not assess the quality of the included literature, which may influence the perception of existing knowledge. The information gathered may be based on fragile methodology and hence research gaps may actually be much wider than presented in this work.

- **Recommendations for future work**

Human stampedes are a complex type of disaster that needs to be addressed by different perspectives.

The recent 2015 Hajj stampede that killed over 2,000 pilgrims was the deadliest ever recorded. It struck many by surprise as the Hajj management had been considered an example of good practice, especially since the building of the new Jamarat bridge in 2007 (32, 35). This unfortunate event served as a reminder that human stampedes are not fully understood and thus keep recurring, and only an integrative approach will fill this gap.

There is an urgent need to reach a commonly agreed definition of stampedes, as this gap has deep theoretical and practical implications. It is strongly advised that experts from different fields work together in order to overcome this challenge and propose a

holistic, comprehensive, but specific definition. This will also allow for clarification of related concepts such as “trampling”, “crushing”, and “crowd disasters” and will potentiate future research by allowing more systematic and accurate studies, strengthening current knowledge.

The mechanisms of stampedes have been analyzed in the literature, but it hasn't been explained when crowd densities become “critical” or “dangerous”, and how transitions between different patterns of movement occur. Complex behaviors, like one person stopping to help another, probably influence the movement of a crowd, but this has not yet been assessed. Also, outcome differences between static and moving crowds have not been studied.

It is striking to know that, despite multiple and successive calls for inclusion in international databases, no progress has been made in independent reporting of human stampedes (73). Efforts must be made in order to achieve this, but understanding why these events are not included in such databases would help addressing this core know-do gap. This is of uttermost importance because only with such monitoring can important questions be answered, such as mortality and injury rates, differences between sex and age groups, and factors associated with the occurrence and severity of a stampede. With such information the effectiveness of preventive strategies will also be easier to assess.

Finally, understanding the full mechanism and chain of events that lead to a stampede will allow for formulation of adequate strategies to prevent them. Differences in mechanisms and causes according to type of crowd, country and event should be assessed as well in order to find the most appropriate measures to each situation. Attention should be given to mass gatherings occurring in low resource settings since these are hosts to more stampede events but very scarcely studied in the aftermath. By improving this knowledge, it will be possible to address stampede management at a strategic level, elaborate guidelines, formulate regulations and laws, and reach fairer court rulings in liability complaints.

Conclusions

- Human stampedes are a complex and multifactorial event.
- To better understand such events, and to improve prevention, preparedness and response, a multisector approach is needed.
- There is no commonly agreed definition of human stampedes.
- No improvement has been made in the independent reporting of human stampedes.

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Appendixes

Appendix 1:Dataset

CODE NUMBER	code number to guide and organize insertion of a new data point. Ranges from 1 to infinity
DOCUMENT TITLE	Document title as available in the document
SOURCE	Where that document was found: One of the mentioned databases (specify which one)
AUTHORS	Author of the document: Name: F. Surname Name of organization Government of XXX
DATE OF PUBLICATION	Date of publication or public availability presented in Year and month if possible. If not published or made available, date of writing (eg for academic works) If such info is not present, write NO DATA Available
COUNTRY OF ORIGIN	Country where the article was originally written
LANGUAGE	Language in which the document was written
TYPE OF LITERATURE	What generic type of document: Grey Literature Published Article
SUBTYPE OF LITERATURE	IF Grey Literature: Government Report, Guideline, Academic Work, Organizational report, etc. IF published Article: peer-reviewed, expert opinion, letter to the editor.
TARGET POPULATION	What population was studied: Worldwide, national (specify), specific to an event (specify).
PURPOSE OF THE DOCUMENT	For peer reviewed: aim of the study Others: purpose as stated
RESULTS	Key findings, in text. Divided into: <ul style="list-style-type: none"> - Stampedes - Prevention - Preparedness - Response
RESEARCH GAPS	Research Gaps and directions mentioned by the author