COMPREHENSIVE REVIEW

Human Stampedes: An Updated Review of Current Literature

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Abbreviations:
PTSD: posttraumatic stress disorder
UK: United Kingdom
WHOLIS: World Health Organization Library Database

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Abstract

Human stampedes are a major cause of mortality in mass gatherings, but they have received limited scientific attention. While the number of publications has increased, there is no recent review of new study results. This study compiles and reviews available literature on stampedes, their prevention, preparedness, and response.

A search for peer-reviewed and grey literature in PubMed (National Center for Biotechnology Information, National Institutes of Health; Bethesda, Maryland USA), Google Scholar (Google Inc.; Mountain View, California USA), Web of Science (Thomson Reuters; New York, New York USA), the World Health Organization Library Database (WHOLIS; World Health Organization; Geneva, Switzerland), and ReliefWeb (UN Office for the Coordination of Humanitarian Affairs; Geneva, Switzerland) was conducted, and papers were selected according to pre-defined eligibility criteria. Included items were read and results were compiled and summarized. A total of 64 publications were included, of which, 34 were published between 2013-2016. The most studied events were Germany's Love Parade stampede in 2010 (Duisburg, Germany; n = 6) and the United Kingdom (UK) Hillsborough Stadium stampede in 1989 (Sheffield, England; n = 4). Conflicting definitions of human stampedes were found. The common belief that they result from an irrational and panicking crowd has progressively been replaced by studies suggesting that successive systemic failures are main underlying causes. There is a lack of systematic reporting, making news reports often the only source available. Prevention measures are mainly related to crowd management and venue design, but their effectiveness has not been studied. Drills are recommended in the preparedness phase to improve coordination and communication. Delay in decisions, poor triage, or loss of medical records are common problems in the response, which may worsen the outcome.

Stampedes are complex phenomenon that remain incompletely understood, hampering formulation of evidence-based strategies for their prevention and management. Documentation comes mostly from high-profile events and findings are difficult to extrapolate to other settings. More research from different disciplines is warranted to address these gaps in order to prevent and mitigate future events. A start would be to decide on a common definition of stampedes.

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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 and a constant increase of human travels, mass gatherings are becoming more frequent and attract more and more participants.[2] Mass gatherings are either spontaneous, such as at train stations during rush hour,[2] or are planned, such as at sport, cultural, religious, or political events.[1] The Hajj pilgrimage in Saudi Arabia and the Kumbh Mela in India are the biggest regular mass gatherings world-wide, bringing millions of pilgrims together.[3,4]

Mass gatherings may affect health in different ways.[2] Communicable diseases, in particular gastrointestinal and respiratory diseases, are of major concern due to the potential for transmission in large concentrations of people.[1,2,5] Environmental threats include extreme temperatures and weather events.[1] Finally, "crowd disasters" may occur, including the

collapse of infrastructures, fire incidents, terrorist attacks, violence riots, and human stampedes.[1,6,7] Stampedes are often described as the "disruption of the orderly movement of crowds…leading to injuries and fatalities,"[4] often "in response to a perceived danger, loss of physical space," or "a will to attain something seen as gratifying."[4,8,9] They carry high mortality rates and are, besides heat-related illnesses, the most common cause of mortality in mass gatherings.[5,7]

A review of peer-reviewed journals in 2008 only identified 20 relevant articles about human stampedes since 1970, with only eight events described.[8] A later study, which incorporated non-traditional sources like news reports to document the epidemiological characteristics of stampedes, found that a majority of events occurred after 2000, and mainly in low-income countries where they had a 7.75-times higher fatality rate compared to stampedes in other settings. Stampede fatalities were up to 40-times higher in mass gatherings that were unplanned.[10]

In recent years, more research has been published regarding human stampedes in a wide range of scientific fields.[11–13] However, human stampedes still receive scarce scientific attention, and they keep recurring, although being presumably preventable, which suggests that their current understanding is limited.[14–16] An updated review of what is currently known about stampedes was found to be needed. The aim of this study was to identify major themes and to synthesize the literature for stampedes.

Methodology

A search for English, peer-reviewed publications, organization reports, and academic works was undertaken in PubMed (National Center for Biotechnology Information, National Institutes of Health; Bethesda, Maryland USA), Google Scholar (Google Inc.; Mountain View, California USA), Web of Science (Thomson Reuters; New York, New York USA), the World Health Organization Library Database (WHOLIS; World Health Organization; Geneva, Switzerland), and ReliefWeb (UN Office for the Coordination of Humanitarian Affairs; Geneva, Switzerland) with the search terms "stampede*" OR "trampling*" OR "crowd disaster" OR "mass gathering." Papers available until June 2016 and specifically referring to human stampedes, considered a "disruption of the orderly movement of crowds" that could "lead to injuries and fatalities,"[4] were included. Papers regarding crowd evacuation models or crowd behavior not related to stampedes, as well as events related to fire disasters and terrorist attacks, were excluded. Abstracts and newspaper reports were also excluded from this review. Titles were at first screened for relevance and duplicates were removed. In a second round, abstracts and summaries were read and their inclusion was decided based on the eligibility criteria. Full-texts were read if there were any uncertainties. The diagram presented in Figure 1 shows the flow of literature search and selection that led to the final number of included records. Distribution of the literature by type, chronology, and geography was described. Key findings were organized and synthesized according to pre-defined and emerging themes. Pre-defined themes were agreed upon by both authors, whereas major emerging themes were first identified by the first author and posteriorly validated by the co-author.

Results

The initial search of all databases resulted in a total of 20,787 citations. After removing duplicates and screening titles, the abstracts of 729 items were screened for eligibility and full-texts were read in case of uncertainty. Finally, 64 documents were included in this review: 22 from Google Scholar, 14 from PubMed, 10 from ReliefWeb, 18 from Web of Science, and none from the WHOLIS.[4,8–13,15–71] Peer-reviewed scientific papers accounted for 75% (n = 48) of all papers included. The oldest paper retrieved was from 1987,[25] and more than one-half (n = 34) were published between 2013 and 2016. All papers were in English, mostly from India (n = 13), the United States of America (USA; n = 13), China (n = 8), the United Kingdom (UK; n = 5), Germany (n = 5), and Australia (n = 4). The most frequent event reported was Germany's Love Parade stampede from 2010 (Duisburg, Germany) in six different papers. The 1989 Hillsborough Stadium stampede in the UK (Sheffield, England) was reported in four different papers.

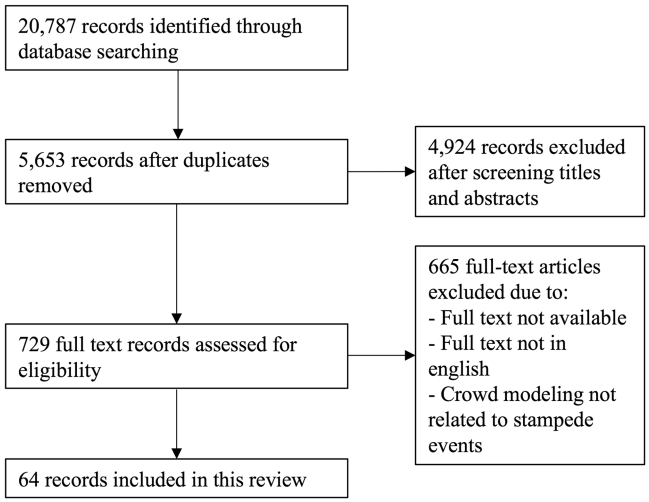

Figure 1. PRISMA Diagram of Literature Search and Selection.

Definition and Classification of Stampedes

The authors found several definitions for stampede, some of them conflicting (Table 1). Several expressions such as "crowd disasters," "trampling," and "crushing," as well as "mass-crowded stampede-trampling accident" and "crowd quakes," were often used with the same meaning.[48,65] Helbing, et al in 2012 suggested that stampede precedes crowd disaster, and that the term "crushing" relates to a crowd pushing towards a bottleneck, whereas "trampling" means people walking carelessly over others.[16]

Ngai, et al proposed a stampede magnitude classification based on reported deaths (Table 2). Other authors argued that a classification should consider number of injuries or fatality and injury rates.[8,10,28]

Causes of Stampedes

Stampedes were often described as a complex chain of events.[16,64] Frequent triggers included rumors of a threat, sudden loud sounds, or the sudden notice of something desirable or urgent, such as the distribution of free tickets or the change of platforms at a train station.[4,21,30,50]

Overcrowding was a major factor for the occurrence of a stampede. Crowd density reportedly influenced the outcome more than the absolute number of attendees.[54] Even if the global density of a mass gathering was low, the local density in specific locations could be very high, as the crowd was not distributed evenly

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Author	Definition
Illiyas, et al 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"
Ngai, et al 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"
Hsieh, et al 2009[10]	"(…) either trampling or asphyxiating crushes with mass casualties"
Burkle 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"
Helbing, et al 2000[68]	"(…) induced by panic, often leading to fatalities as people are crushed or trampled. Sometimes this behavior 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"
Wieringa 2015[60]	"(…) 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."
Sindhu Kolli 2014[29]	"(…) 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.
Prasun 2015[33]	"(…) 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 rumors, which starts at highly dense crowded area (10 people in a square meter area) and like a wave, humans run to escape in a disorderly way."
Salamati, Rahimi-Movaghar 2016[31]	"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"
Bolia 2015[18]	"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)
Khana, et al 2014[26]	"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."

Table 1. Stampede Definitions in Identified Literature

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 1,000 deaths
Class V	Catastrophic	More than 1,000 deaths

Table 2. Stampede Classification by Ngai, et al[8]

throughout the venue.[43,51,65] The capacity of the venue and the density of the crowd depended on the body sizes and culture, and was therefore specific to each event.[43]

Closing entrances or exits, congestion at bottlenecks, and deficiencies in safety barriers, potentiated by a lack of coordination with local authorities, were often described as underlying causes.[9,15,53] When the event took place in isolated, rural, or low-resource settings, there was an increased risk due to narrow lanes, ambulant sellers, steep and muddy floors, or dead ends.[4,30]

Initially, stampedes were described as the result of an irrational crowd behavior caused by panic.[16,25,53,66] An attempt to describe this "escape panic" was made in 2000. First, people try to move faster than normal and start pushing with physical interactions. Moving and passing bottlenecks becomes uncoordinated, with arching and clogging 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.[40,45,49,67,68] However, more recent research counter-argued the description of this behavior as "irrational" and "dangerous." Qualitative studies on victims from different stampedes suggested that, in critical times, the crowd was actually cooperative and behaving rationally.[24,53,66] Even with the perception of a risk, a crowd may feel safe and reduce the risk of a stampede through self-organization and psychological unity.[69] Specific types of crowds, like football

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fans, were often linked to violence, alcohol, and drugs intake, and these behaviors were instinctively blamed when stampedes occurred.[66] This has, however, been counter-argued by the fact that post-mortem blood tests on the Hillsborough Stadium stampede victims did not show elevated levels of drugs and alcohol.[53]

Mechanism

The literature showed different reports on what happens in different crowd densities.

Video analyses from the 2006 Mina crowd disaster (Mecca, Saudi Arabia) showed that even at crowd densities of 10 people/m2, individual speed never reached zero.[43] Different crowd density thresholds were mentioned in the literature. Sindhu Kolli, for example, defined a stampede as an event occurring at a density above 5.26 persons/m2.[27] Another author, Ibrahim, suggested metrics to characterize the crowd: "loose crowd" was one person/m2; "dense crowd" was two persons/m2; and "very dense crowd" was four persons/m2.[70] Experts argued that crowd pressure, a product between the density and the variance of the densities, gave better information about critical areas and timings.[43,46]

A pattern of the mechanism leading to stampedes was described:[43,48] in normal situations, the crowd moves in a free or laminar flow. When density increases, the flow changes 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 around them fall due to sudden forces imbalance. To avoid falling, trampling, which is the act of standing or walking on someone else, may occur. People at the bottom of the crowd eventually die of traumatic asphyxia.[16]

Stampedes reportedly occurred in uni-directional or turbulent flow (random movements in different directions). Uni-directional flows were usually caused by the sudden increase or decrease in force, such as a congested bottleneck or exit, or the collapse of a security barrier, respectively.[8]

A study on an escalator group trample showed that the severity of the situation was influenced by the initial location of the trample, the time at which counter-measures were taken, the pedestrian 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 influenced the outcome.[65]

Epidemiology

Systematic data collection on human stampedes was mostly based on news reports, as formal reporting was lacking. Two search methods were described in the literature. The Ngai method consists of a LexisNexis (LexisNexis Group; New York, New York USA) search with a secondary hand-search of important news agencies. The Roy method searches data from major Indian newspapers, and is only applicable to India.[11] Although more often used, the Ngai method is believed to under-estimate stampede events by approximately 18%.[11]

Between 1980 and 2007, the Ngai method identified 215 stampede events world-wide, and 350 events between 1980 and 2012.[11] Between 1980 and 2007, 7,069 deaths and 14,078 injuries were caused by stampedes,[10] increasing to 10,243 deaths and 22,445 injuries between 1980 and 2012.[11] Most stampedes occurred indoors, during daytime hours, and in sports events.[10] Uni-directional mechanism increased fatality rate by 3.46-times, believed to be due to the confluence of forces in one same direction.[10] Women, children, and older people were reportedly more affected because they were less capable to defend themselves from external weight pressure.[15,21] One study showed that the ratio of fatalities between women and men after a stampede in Shanghai was 3:2.[60]

According to the Ngai method, India was the country with the highest number of stampedes.[10] A combination of Roy and Ngai methods identified a total of 40 human stampedes in India between 2001 and 2010.[11] Another study using data from the National Crime Records Bureau (New Delhi, India) identified 34 human stampedes in the country between 1954 and 2012, with a total of 1,823 reported dead.[4] Between 59% and 79% of the events were religiously-related, and most occurred in the northern-half of the country.[4,10]

Clinical Aspects

In reported stampede events, extreme overcrowding caused external compression, which limits thorax expansion, leading to traumatic asphyxia, the major cause of mortality. A smaller proportion of deaths was caused by trampling and consequent internal organ injuries.[8,19] Classic clinical signs of traumatic asphyxia are cervico-facial congestion and cyanosis, and conjunctival and facial petechiae.[8] Resuscitation efforts, such as chest compression, caused injuries similar to signs of traumatic asphyxia, complicating legal medicine diagnoses.[20] Crush injuries may lead to rhabdomyolysis and precipitate the need for kidney replacement therapy.[33] Other possible physical consequences of stampedes were traumatic brain injuries, hemothoraces, and femur fractures.[19,21] Psychological and psychiatric sequels included depressive and anxiety disorders, phobic disorders, and posttraumatic stress disorder (PTSD).[8,12] A study on school stampede victims showed PTSD was not the most common psychiatric disorder, suggesting that other disturbances merit attention.[12]

Prevention

The most consensual measure was to reduce the size of the crowd and avoid overcrowding. Nevertheless, this remains difficult to implement, as big crowds are usually preferred in mass gatherings by organizers and visitors themselves.[39,54] Crowd management is a preventive approach that starts before the event, whereas crowd control reacts to the behavior of a crowd.[39,52]

A proposed maximum capacity calculation was that the number of visitors should be inferior to seven-times the area in m2.[30,43] Strategies to manage visitor inflow included dispersing arrivals, pre-registration and ticket systems, regulating the timing and routing of groups, or limiting group sizes.[30,42] Festival seating, the lack of reserved seats in the venue, was widely appreciated among visitors and organizers, but its banning was described as an effective measure to decrease risk for stampedes.[52]

A challenge commonly reported was the conception of venue designs that are optimal in case of emergencies, but also practical in normal situations.[38,47,57] Avoiding bottlenecks and intersection or merging flows was widely recommended, as well as removing obstacles and protecting emergency lanes.[43] Several architectural solutions were proposed in the literature. Segmentation divides a crowd into smaller groups that are easier to manage, and it also prevents propagation of an incident between them. The "nested doll" inserts a structure in the venue, like an emergency exit beneath a building. Expanding the surface can be achieved by adding another dimension, such as higher floors.[43] Zig-zag shapes

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prevent congestion during panic, but they are unpractical in normal situations.[54,57] Increasing a bottleneck space is only a temporary solution, whereas minimizing pedestrian speeds at specific locations may reduce the risk of a crowd disaster.[47]

Crowd monitoring examines the condition, movement, and behavior of a crowd,[70] and it was recommended to monitor critical areas during highly congested time periods.[43] Some crowd monitoring systems included video recording, Global Positioning System (GPS), Bluetooth, Infrared (IR), Radio frequency Identification (RFID), broadband satellite network, and Wireless Local Area Network (WLAN).[70,71] Recent research suggested that the use of mobile phones could improve accuracy of stampede detection, prediction, and crowd force estimation.[56]

Preparedness

Planning a mass-gathering event should start as early as possible and ensure a good coordination between organizers, police forces, community leaders, and health care services.[4,16] Detailed contingency plans were strongly recommended, and they should be worked out and exercised.[16,26,37,43] Emergency ingress and egress should always be planned for and access ensured during the whole event.[15] During mass gatherings, referral hospitals should be prepared for various types of mass-casualty incidents. A drill in South Africa highlighted that important flaws in preparedness were related to risk communication and public relations, staff and patient safety, supplies, and security.[34]

Response

Experts believed crowd control and response should start as early as when stop-and-go waves set in, to reduce the time of exposure to high crowd density or dangerous movements.[43,65] Late evacuation of the Love Parade venue, about six minutes after crowd turbulence started, was considered one of the reasons for the outcome of 21 deaths.[16] It remains unclear how real-time crowd control should be undertaken, and how it changes the immediate behavior of the crowd, but water cannons and tear gas can worsen the situation.[15,28,41] Vertical communication between the event organizer, the crowd tracking personnel, and the crowd control force was presumably more effective than horizontal communication between members of a crowd control force, such as the police.[27]

Reports from stadium stampedes revealed that on-site triage and referral was often poorly done. Frequently, injured arrived at the nearest hospital by their own means. Lack of prompt communication to emergency departments, poor use of media to inform people effectively, and lack of psychosocial support to the victims were commonly reported.[19,28]

On-site medical teams were useful for discharging patients who did not need medical attention, referring those in need of a higher level of care, and giving immediate life-saving support like cardio pulmonary resuscitation (CPR).[20,53] Poor on-site medical triage and care could miss persons with traumatic asphyxia likely to be saved should they have received appropriate medical attention.[53] Access for emergency medical teams was vital, but was often a problem in the dense crowd.[64] Immediate referral for critical patients was of extreme importance, but this was problematic in rural and low-resource settings.[4] Loss of medical records during transportation was a common flaw that delayed hospital treatment and hindered legal medicine reports.[19,20,28]

A report by the British Health and Safety Executive (HSE; Bootle, UK) on the Hillsborough Stadium stampede showed that emergency services failed to activate the major incident plan, and the Emergency Medical Services were delayed in recognizing the situation as a crisis.[53] Response could be highly influenced by misperceptions of panic and danger, which had consequences in the receptivity of the crowd to information given.[63]

The health system and community context where the stampede took place also determined the level and quality of the response. In more deprived or unstable settings, health facilities often need external provision of basic supplies and additional assistance to the victims and their families.[64–66]

Discussion

Publications and reports on human stampedes have increased in recent years, as more than one-half of the material included in this study dates from between 2013 and 2016. This study showed that the definition used by researchers and operational organizations varied significantly. Moreover, some of the definitions used were conflicting and based on the now outdated belief that stampedes result from an irrational or even "animal" behavior of the crowd. This lack of systematic wording and definition has not been highlighted elsewhere in the literature.

While stampedes mainly occur in low-income countries, this search retrieved publications mostly from high-income countries, and most frequently including high-profile events, such as the Love Parade or the Hillsborough Stadium. The imbalance between occurrence or risk of stampedes and number of publications does not come as a surprise. Events in low-resource settings do not mobilize the same level of organization or infrastructure, and reliable data are scarce.[16,40,43,44,65] Current knowledge thus seems to base itself on a minority of all stampede events, and as a consequence, it is biased and does not picture nor explain this global and increasing phenomenon.

This review highlights the complex and multifactorial causes of stampedes. Indeed, most studies have shown that they are in fact a complex chain of events, coming from flaws in the organization of mass gatherings, crowd mismanagement, miscommunication, and inadequate planning and preparedness. The multidimensional causality of stampedes has recently been described in scientific studies.[16,53] Attributing the responsibility of stampedes to an irrational crowd may represent a communication strategy for the event organizers, but it is seldom true. Indeed, this has been demonstrated in the longest trial to reach a verdict in the UK, related to the Hillsborough Stadium stampede, as the event organizers were found guilty due to planning and management deficiencies, despite their long accusing of the victims for their violent behavior.[72]

Despite multiple and successive calls for improvement, no progress has been made in systematic reporting of human stampedes. A lack of definition can be an explanation for this know-do gap. Without such detailed data, it will be difficult to gain better insight on mortality and injury rates, differences between sex and age groups, and factors associated with the occurrence and severity of a stampede.

The recent 2015 Hajj stampede that killed over 2,000 pilgrims was the deadliest ever recorded, an unfortunate crowd disaster in a country known for its crowd management strategies that include the specifically constructed, stampede preventing, Jamarat bridge.[31,64] This event served as a reminder that human stampedes are not fully understood.

Limitations

Despite a thorough and comprehensive search of the literature, it is possible that important reports were missed. The definition of stampede used in this search strategy may have influenced the selection process. Because this review aimed to be broad and comprehensive, some specificity may have been lost.

It must also be noted that 16 (25%) of the papers included were not peer-reviewed. These were mainly organization reports on stampede events and management plans. This does not allow to generalize findings or to be extremely accurate in the results. However, this exercise has allowed researchers to understand current practices, used definitions, and highlight important research gaps.

Conclusions

Despite an increasing awareness to human stampedes, this event still occurs frequently and causes a considerable number of fatalities. Current knowledge remains mostly based on a small sample of high-profile events in high-income countries. The authors suggest to commence systematic reporting, and to include low-profile stampedes from lower-resource settings, in order to provide evidence to tackle this complex and multifactorial event. A first step is to decide on a standard and operational definition of human stampedes.

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