Individual Behaviour in Emergency Evacuations of Campus Buildings: An Empirical Analysis Based on Field Experiments

By

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Abstract

Individual differences in evacuation behaviour are influenced by multiple factors. There is an ongoing debate regarding the extent to which herd behaviour affects evacuation decisions. These contrasting perspectives highlight the complexity of herd behaviour and its dual role as a potential facilitator and hindrance during evacuation. To address these challenges, this study first investigated the triggering mechanisms of herding behaviour through questionnaires and video recordings. Second, it further explored the impact of herding behaviour on evacuation paths and decision-making using questionnaires and text mining. Finally, it conducts a cognitive analysis of evacuation decisions made by individuals exhibiting herding behaviour using eye trackers, uniquely capturing attention patterns and cognitive processes at the micro-level. This study analyzed the factors influencing individual behaviour during emergency evacuations in public buildings, focusing on the triggers of herd behaviour and its impact on evacuation decision-making. Using a combination of real evacuation drills and advanced data collection methods, typical evacuation behaviours were observed to identify the key patterns. Data was gathered through video recordings, questionnaires, and interviews to explore underlying behavioural mechanisms, while eye-tracking technology monitored attention distribution during evacuations. The results indicate that herd behaviour is especially prominent at higher-floor intersections, where individuals seek more evacuation information and tend to follow the path of the majority. Their cognitive sequence involves observing the surrounding walls, followers within their field of vision, and, finally, the ground. This suggests that individuals first scan their environment to gather information. When the environment is unclear, such as in low visibility, they focus more on the surrounding groups. Further statistical analysis and text mining indicated that personality traits significantly influenced the likelihood of herd behaviour. For example, extraverted individuals are more prone to following others in such situations. However, this herding tendency can lead to suboptimal decision-making, such as overlooking direct evacuation routes clearly marked by signage. Moreover, this study highlights the unique role of female leaders with strong directional awareness in facilitating orderly evacuations, thereby demonstrating the value of leadership dynamics during crises. These findings provide both theoretical and practical insights. On a theoretical level, this study contributes to a deeper understanding of the behavioral mechanisms underlying emergency evacuations. Practically, it offers recommendations for optimizing building design and emergency management strategies, thereby enhancing public safety during evacuations.

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Contents

List of Publications

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[2] Ni, M., Xia, L., Wang, X., Wei, Y., Han, X. & Pan, S. Psychological influences and implications for household disaster preparedness: A systematic review**.** *Frontiers in public health* (Accepted)

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Chapter 1 - Introduction

1.1 Research background

As global urbanization accelerates, the number and complexity of public buildings has increased significantly. With more people concentrated in urban areas, the functionalities of public spaces have become more sophisticated and occupancy density has also increased. According to a United Nations report (2019), 68% of the world's population is expected to live in cities by 2050, highlighting the need for more effective evacuation strategies in public spaces. In this context, understanding human behaviour during emergency evacuations is crucial to ensure public safety. According to past statistical data, losses caused by building fires alone amount to hundreds of billions of dollars globally, accounting for approximately 1% of the global GDP annually (Agbola & Falola, 2021). Globally, incidents such as fires and crowd crushes emphasize the urgent need for evacuation research in such scenarios. For example, the 2017 Grenfell Tower fire in London claimed 72 lives and exposed the inefficiencies of high-rise building evacuations (BBC, 2018). Similarly, the 2015 Mecca stampede resulted in over 700 deaths, illustrating how poor crowd management can lead to catastrophic outcomes at large-scale gatherings. In China, the risks associated with fires and crowd congestion are increasing because of rapid urbanization. According to the China Fire Yearbook 2022, over 130,000 fire incidents occurred nationwide, many of which occurred in public buildings such as hospitals, shopping malls, and schools (Ministry of Emergency Management, 2023). These incidents underscore the need for scientific research on evacuation behaviour to improve safety measures in public facilities. The population in urban public buildings is diverse and dense, with increased interactions between people or between people and their environment, leading to higher safety risks (Mostafavi et al., 2021). In emergencies such as fires or riots, the movement of large crowds is often restricted to limited spaces, making it easy for congestion or even stampedes to occur, which can lead to safety issues. Crowd dynamics can be unpredictable, and factors such as panic, poor visibility, and inadequate signage can exacerbate the situation and complicate evacuation efforts. This highlights the importance of the safe operation and management of public buildings. Effective crowd management strategies, including the design of exit routes and training of staff in emergency protocols, play vital roles in minimizing risks. In emergencies, evacuating people to safe areas is crucial, as it relates to the safety of lives and property (Gagliardi et al., 2023). Research indicates that the speed and efficiency of evacuation can significantly reduce injury rates and fatalities (Ronchi & Righini, 2016). Thus, understanding crowd behaviour and implementing systematic evacuation plans are essential for ensuring public safety.

The evacuation process can be complex because of the large number of people involved and varied decision-making behaviours. During emergency evacuations, people's actions are influenced by multiple factors, including personal characteristics, social interactions, environmental conditions, and information dissemination (Arias et al., 2022; Fu et al., 2024; Kinateder & Warren, 2021). Among these, psychological and emotional responses, such as panic, anxiety, and stress, play critical roles in shaping how individuals make rapid decisions under pressure. Studies have shown that high-stress situations often lead to cognitive overload, which can impair judgment and cause individuals to rely more on instinctual responses rather than rational decision making (Drury et al., 2009). These instinctual responses may include “fight-or-flight” reactions, which can vary widely depending on a person’s temperament and prior experience with emergencies. Social dynamics, such as herd behaviour and social influence, are pivotal in evacuation scenarios. Individuals often look to those around them for cues on how to behave, especially in uncertain or high-stress situations. This tendency can lead to a phenomenon known as "herding." where individuals may conform to the behaviours of those around them, leading to a herd mentality that hinders effective decision making. This behaviour is particularly evident in high-stress environments, where the spread of emotional states such as fear or panic can rapidly influence group behaviour through a phenomenon known as "emotional contagion" (Barsade, 2002; Schwarz & Clore, 2003). When one individual exhibits signs of panic, others nearby may quickly pick up on these cues, leading to a chain reaction that amplifies the group's fear. Such emotional contagion can intensify herd behaviour, as individuals may abandon their evacuation plans to follow others in the hope of achieving safety. Herding behaviour is a double-edged sword: while it can foster coordinated movement towards exits, it can also result in bottlenecks and delays if the group path is inefficient. Additionally, social ties can influence whether people choose to stay with friends and family or prioritize safety. For example, studies have indicated that individuals are more likely to wait for close friends or family members during evacuations, even if it increases their personal risk (Templeton et al., 2015). This "group cohesion effect" suggests that people may prioritize social bonds over individual survival, adding another layer of complexity to crowd behaviour during emergencies. The main challenges are as follows:

1) Understanding people's psychological activities and decision-making processes

Existing research employs a range of methods to gain deeper insight into the mechanisms that influence people's evacuation decisions and route choices, utilising techniques such as simulation modelling, evacuation drills, and surveys. For example, evacuation drills have revealed common behaviours such as herding and overtaking in various settings, including hospitals, schools, and shopping malls (Drury et al., 2009). These drills provide practical insights and allow researchers to observe the interaction between individuals and their environment during stress-induced scenarios. While most simulation methods focus on the impact of environmental and individual factors, such as the physical structure of buildings and people's physiological conditions, these approaches often overlook other important elements, such as the unique psychological states of individuals within buildings and the social dynamics of groups. Surveys, on the other hand, aim to explore decision-making processes and the psychological factors that guide people's route planning during evacuations (Launder & Perry, 2014). However, they are often subject to biases, as responses may reflect subjective perceptions rather than actual behaviours. A key challenge in this field remains understanding how individual behaviours are triggered in real-world scenarios and how psychological characteristics, such as fear, stress, or group affiliation, influence both evacuation decisions and route planning in realistic and dynamic evacuation environments.

2) The complexity of group interactions in emergency evacuations

In public buildings, where spaces are often enclosed and narrow, groups are particularly vulnerable to heightened panic and anxiety during evacuations. Many individuals in these settings share social relationships, which can lead to behaviours such as following, clustering, and herding, all of which can influence the command and control of emergency evacuations (Haghani et al., 2019). These social connections can create both positive and negative dynamics; for instance, individuals may feel compelled to assist others, but this can also lead to delays if they prioritize group cohesion over personal safety and well-being. Herding behaviour is a complex phenomenon that raises questions about what triggers an individual's instinct to follow the crowd. Research findings on this issue are mixed, with some studies suggesting that herding can accelerate evacuation by promoting coordinated movement (Pan et al., 2007), whereas others argue that it can hinder efficiency by causing crowd congestion and confusion (Templeton et al., 2015). This dual nature of herding behaviour highlights the necessity of tailored evacuation strategies that consider the specific context of an emergency and the characteristics of the crowd. This inconsistency highlights the broader challenge of understanding how group dynamics and social interactions affect the outcomes of evacuations. Factors such as pre-existing group hierarchies, the presence of leaders within the crowd, and the level of communication among individuals can significantly affect the overall evacuation process in a fire. The role of these interactions in emergency scenarios remains a critical area of study for improving the effectiveness of evacuation protocols.

1.2 Research objectives and questions

The evacuation process inside buildings is relatively complex, and individual evacuation decisions and route planning may change owing to the surrounding environment and group interaction. To effectively use individual behaviour patterns to guide evacuation design and emergency management strategies, the following issues need to be addressed:

1. Physiological and psychological reactions of individuals during public building evacuations

During evacuations, public buildings, enclosed spaces, and dense crowds can impact individuals' physiological and psychological states. These environments can trigger various stress responses. It is important to explore physiological and psychological reactions throughout the evacuation process, such as signs of tension, anxiety, and panic, and to understand the causes of these psychological responses and their changes. Factors such as crowd density and the clarity of evacuation instructions can exacerbate feelings of anxiety and panic, making it crucial to identify these triggers.

2. Behavioural patterns of individuals during emergency evacuations in public buildings

Due to external environmental factors, such as visibility, individuals may exhibit different behaviour patterns during evacuation, such as transcendence and herding behaviour. For behaviours such as herding, it is crucial to identify the conditions that trigger such behaviours and the factors that influence their intensity. When individuals need to make critical decisions during an evacuation, it is important to examine whether psychological changes occur and how these changes influence their evacuation decisions throughout the process.

3. Decision-making process of individuals during evacuations

During evacuations, especially at critical junctions such as intersections, individuals face the need to decide on their evacuation routes. The decision-making process includes micro-level attention and behaviours. To understand this process, the following key issues need to be studied: (1) factors influencing decision-making, such as how personal traits, such as personality, social relationships, and past experiences, affect individual decisions. (2) Decision-making process: This involves exploring an individual's focus points, psychological changes, and thought patterns during the decision-making process.

The primary aim of this study was to explore the patterns of individual behaviour during emergency evacuations in public buildings, with a particular focus on herding behaviour and its impact on evacuation decisions. Understanding these patterns is crucial for developing effective evacuation strategies that can save lives and reduce injuries. The specific objectives were as follows.

1) Mechanism of herding behaviour**:** Through experiments and data analysis, this study seeks to determine common behavioural patterns, such as herding behaviour and route selection. Investigated how individual traits (e.g., personality and cognitive level) and environmental factors (e.g., building layout and visibility of evacuation signs) affect herding behaviour. Using a real-world drill, this study aimed to capture a comprehensive view of how people react under stress.
2) Evaluate the impact of herding behaviour on evacuation decisions: use evacuation drills to verify how herding behaviour either facilitates or hinders evacuation efficiency under different scenarios.
3) Provide recommendations for optimizing building design and management: Based on the findings, suggestions are offered to improve the design of public buildings and emergency management strategies, aiming to enhance evacuation efficiency and safety. Recommendations include improving signage, increasing the number of exits, and implementing training programs for building occupants to better prepare them for emergencies.

This study aims to address the challenges of emergency evacuations in public buildings using new technologies and methods. By leveraging advancements in data collection and analysis, this study seeks to fill gaps in our understanding of evacuation dynamics. For example, evacuation drills can be used to collect and analyze basic evacuation data from specific groups of people. These drills will simulate real-life scenarios, allowing researchers to observe behaviour in a controlled environment while ensuring participant safety. By combining data from cameras and surveys, quantitative research on herding behaviour during evacuation can be performed. This integration of qualitative and quantitative data enables a more comprehensive analysis of how group dynamics influence individual choice. Eye-tracking devices will be used to investigate the individual decision-making process. By capturing where individuals focus their attention during an evacuation, researchers can identify critical information that influences their choices, such as exit signs and crowd movement. Understanding pedestrian movement patterns during evacuation can guide the planning and design of buildings, aid evacuees in making more effective evacuation decisions, and improve guidance systems.

1.3 Research significance

This study makes significant contributions to the theoretical and practical domains of emergency evacuation management. Its primary practical value lies in generating actionable strategies to enhance public safety in real-world built environments.

1) Optimizing public building design and management

Based on the experimental results, this study offers practical recommendations for improving evacuation design and management strategies in public buildings. These recommendations are informed by empirical data on individual and group behaviours observed during emergency simulations, ensuring that they are rooted in real-world applications. For example, it suggests how to set clearer evacuation signs, optimize corridor design to avoid overcrowding, and enhance individuals' sense of direction and decision-making abilities during emergency evacuations through training.

2) Developing emergency management

The results enable the development of targeted training programs for public facilities. Specifically, the leadership training framework prioritizes female staff with a strong sense of direction to guide evacuations. By simulating a group-triggered drill scene (e.g., low visibility and complex layout), emergency preparedness can be improved.

3) Highlighting theoretical significance

This study deepens the understanding of the mechanisms of emergency evacuation behaviour. Specifically, this study first verifies the dominance of informational herding in emergency evacuation through real evacuation experiments and constructs a cognitive framework of "environmental information—social clues—decision output," which fills the gap in the research on the decision-making processing mechanism in evacuation behaviour.

1.4 Research content

To address the issues mentioned above, this study plans to adopt a combination of evacuation drills, questionnaires, interviews, and eye-tracking to conduct an in-depth study on individual behavioural patterns during emergency evacuations in public buildings. This multifaceted approach allows for a comprehensive analysis that captures both qualitative and quantitative data, ensuring a robust understanding of evacuation dynamics. This research will utilize new technologies and methods, such as cameras, eye-tracking devices, and text mining, integrating factors such as psychology, physiology, and social relationships, to further analyze individual behaviours during emergency evacuations. By employing eye-tracking technology, this study aims to uncover specific visual focus areas that influence decision-making, while text mining can help analyze qualitative data from interviews to identify common themes and patterns in the participants' experiences. This study focuses on herd behaviour during the evacuation process. Understanding the triggers and effects of herd behaviour is essential for designing effective intervention strategies to facilitate safe evacuation. In addition, this study examined individual decision-making behaviour at evacuation nodes and micro-level attention behaviours. This comprehensive analysis aims to provide actionable insights that can enhance evacuation protocols and inform building design, ultimately leading to improved safety and efficiency during emergencies.

(1) Collect baseline data on the emergency evacuation of individuals.

(2) Study the factors influencing individual herd tendencies and behaviours as well as the impact of herd behaviour on the choice of evacuation route.

(3) Investigate individual micro-behaviours, such as decision-making at evacuation nodes, and use eye-tracking technology to explore attention behaviours at stairways and intersections.

To comprehensively achieve these objectives, the main research approach is outlined in Fig. 1.

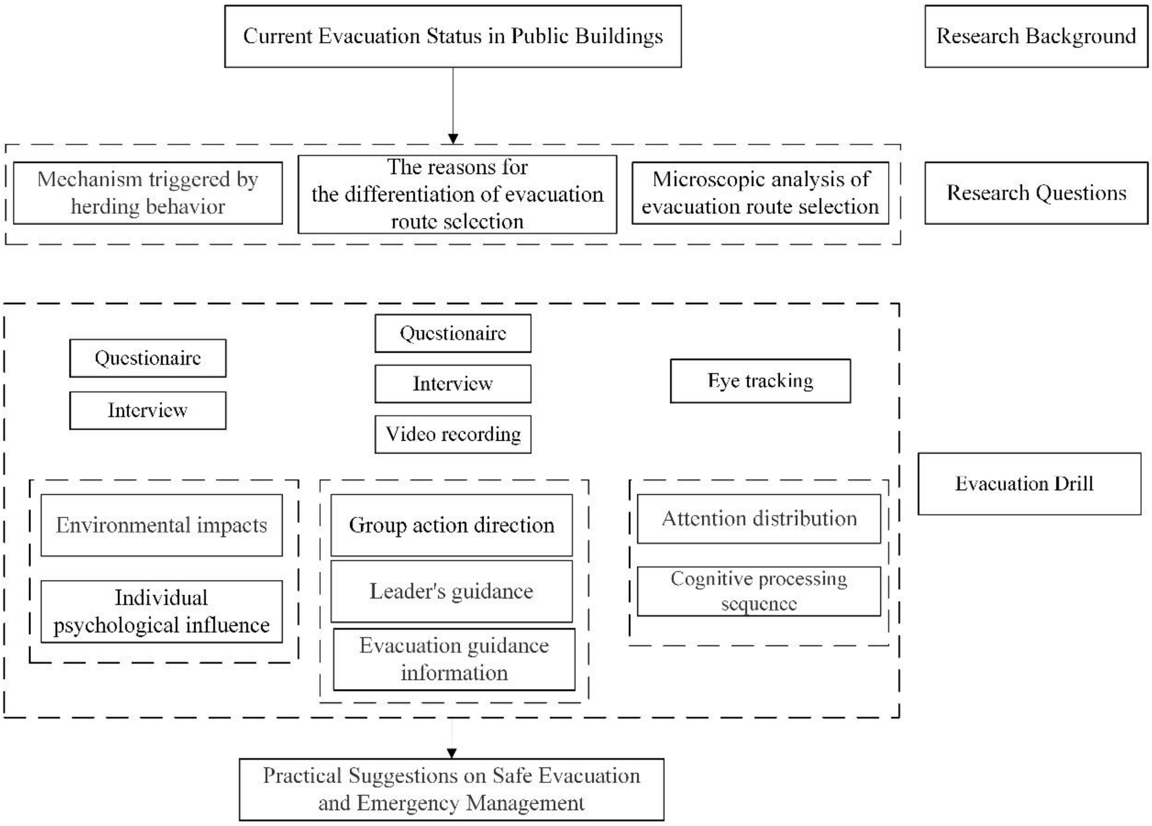


Fig. 1. Framework diagram of the thesis.

The main research content of each chapter is introduced as follows:

Chapter 1 introduces the background and significance of research on evacuation behaviour in buildings, highlighting the complexity of emergency evacuations in public buildings during urbanization. As cities grow and public spaces become increasingly crowded, the challenges associated with effectively evacuating these environments become more significant and complex. It identifies unresolved issues in public building evacuations and outlines the main research content and approach of this study.

Chapter 2 explains the current state and challenges of emergency evacuation in public buildings. It classifies and summarizes relevant literature based on different research methodologies and provides an overview of domestic and international studies on individual evacuation behaviour in buildings. Based on the gaps in the existing research, this chapter sets forth the research objectives and highlights the contributions of this study.

Chapter 3 focuses on the evacuation drill experiments conducted over three months, consisting of 11 groups under different conditions. It covers the basic details of the experimental plans and procedures, as well as the data collection and analysis tools used during the evacuation drills. These tools included questionnaires, semi-structured interviews, and eye tracking equipment. The main behaviours studied include herd, route choice, and overtaking behaviours. The key findings of this study were derived from a comprehensive analysis of the individual evacuation behaviour data collected during the drills.

Chapter 4 presents the findings from video recordings and questionnaire data analysis regarding evacuation behaviours, particularly the influence of herd behaviour on evacuation decision-making and path selection. The video footage revealed common behaviours, such as aggregation, transcendence, and herding behaviour. Questionnaires were used to explore the internal characteristics of individuals exhibiting herd behaviour and how this behaviour influenced their evacuation decisions and route planning. The findings suggest that, in addition to herding tendencies, various factors influence individuals' evacuation decisions.

Chapter 5 describes the methodology and findings of the interviews conducted with participants to understand individual evacuation behaviours and decision-making influences. A text mining approach, specifically Latent Dirichlet Allocation (LDA), was used to analyze the interview content, identifying four main topics related to evacuation decision-making. This analysis provided a structured understanding of the factors that drive evacuation decisions

Chapter 6 investigates individual micro-behaviours during emergency evacuations in public buildings, focusing on the role of eye-tracking technology in analyzing visual attention during emergency evacuations. This chapter compares the differences between individuals displaying herding behaviour and those who do not, particularly in route selection at intersections. Using sequential analysis, this study clarifies the cognitive processing differences at decision points between the two groups. These findings emphasize the influence of visual attention on decision-making during evacuations and provide insights into enhancing public building safety measures by optimizing the evacuation signage and spatial design.

Chapter 7 offers recommendations and future research directions for improving evacuation systems based on the study findings. Key suggestions include optimizing building design and evacuation signage to enhance the efficiency of emergency evacuations. Visual guidance, such as luminous signs, is added to evacuation routes to alleviate congestion caused by herd behaviour in high-rise buildings during fire emergencies, particularly in high-rise structures. Future research should further explore the impact of various signs and layout configurations on evacuation efficiency and utilize dynamic monitoring systems to optimize evacuation pathways for varying crowd densities.

Chapter 8 summarizes the experimental results and conclusions of the study, highlighting the innovative aspects of this research and providing an outlook on future research work.

Chapter 2 - Literature review

2.1 Current status of public building evacuation

Public buildings are non-residential structures designed for public social activities, characterized by their social service nature and open spaces. They are categorized by function, such as education (kindergartens, schools), transportation (airports, metro stations), and cultural/recreational (museums, theaters) (Fageha & Aibinu, 2014). Because they must accommodate large crowds, fire protection designs must strictly adhere to national codes to ensure efficient evacuation and structural fire safety. Key Chinese standards include the Code for Fire Protection Design of Buildings (GB 50016-2014) and specialized regulations, such as the national standard for safety signage (GB/T 2893.1-2013) (Chen et al., 2019).

Current studies on personnel evacuation have identified several issues, such as low evacuation efficiency and unpredictability of human behaviour (Joo et al., 2013; Kuligowski, 2013; Wang et al., 2023). These challenges are particularly evident in emergencies where quick decisions are critical, and human reactions can significantly affect the overall effectiveness of evacuation efforts. The uniqueness of public buildings stems not only from their complex structures and functions but also from the diverse and unpredictable behaviours exhibited by occupants during emergencies. First, the characteristics of public buildings, such as the number of floors and corridor width, can affect evacuation behaviour and its efficiency. In public buildings with fewer than six floors, the evacuation speed can minimize the possibility of squeezing and stampedes (Ronchi & Nilsson, 2013). Group behaviours, such as herding, are intensified in constrained spaces. Corridor widths of <1.8m (as measured in the experimental building) increased the propensity by 60% (Zheng et al., 2021). In addition, interactions among occupants influenced by their personal experiences and social dynamics can further complicate these scenarios. These spaces often feature intricate layouts, multiple floors, narrow corridors, and various entry and exit points, all of which can confuse evacuees and hinder evacuation speed (Fahy & Proulx, 2001; Li et al. 2023). Furthermore, the high population density typical of public buildings increases the risk of congestion, overcrowding, and panic, thereby placing greater demands on evacuation efficiency and safety. Crowd behaviour, often unpredictable during crises, can lead to bottlenecks that further impede movement toward exits. Human behaviour during evacuations can be influenced by factors such as anxiety, confusion, and herding instincts, leading to deviations from planned evacuation routes and strategies (Pan et al., 2007; Xu et al., 2023). Understanding these psychological responses is crucial for developing effective evacuation protocols that can adapt to the real-time conditions of the environment. Additionally, the presence of vulnerable groups, such as children, the elderly, and individuals with disabilities, further complicates evacuation processes, requiring specially tailored plans to ensure their safety. These plans must consider the specific needs of these groups, including assistance requirements and alternative evacuation routes for them.

To address these challenges, improving evacuation efficiency involves not only optimizing the physical space but also understanding and anticipating human behaviour in high-stress situations. This dual focus allows for a more comprehensive approach to emergency management, enhancing both building design and the strategies employed during evacuations. This necessitates the integration of advanced evacuation models that consider psychological, social, and environmental factors, along with regular evacuation drills to prepare the occupants. These drills should be realistic and incorporate feedback mechanisms to improve evacuation strategies continuously. Although technologies such as real-time monitoring systems and simulation tools have enhanced evacuation strategies, the unpredictable nature of human behaviour continues to pose significant challenges in dynamic environments. Therefore, ongoing research and innovation are essential for adapting to the evolving complexities of public safety during emergencies.

When addressing the challenges of public building evacuations, researchers and relevant authorities face many difficulties, particularly the unpredictability of individual behaviour and the complex influences of environmental factors (Cuesta et al., 2016). These challenges are further compounded by the diverse characteristics of building occupants, including age, physical ability, and prior experience with emergencies, all of which can affect their behavioural responses. In emergency situations, individuals can exhibit highly diverse behavioural patterns; some remain calm and adhere to planned evacuation routes, whereas others may act irrationally, driven by fear or confusion. This variability highlights the need for flexible evacuation plans that can accommodate different behavioural responses. This variability makes it difficult to predict how people will respond in real time and complicates the process of developing effective evacuation strategies (Guo et al., 2024; Pelechano & Malkawi, 2008).

The irrationality and unpredictability of human behaviour are often magnified in high-stress scenarios, such as fires or other life-threatening emergencies, where people may deviate from expected behaviours because of heightened emotional states. Factors such as the presence of smoke, limited visibility, and chaotic environments can exacerbate emotional responses, leading to disorientation and panic.

Psychological factors, such as panic, fear, and anxiety, significantly influence decision-making during evacuations (Pan et al., 2007). These emotions can lead to rushed or impulsive behaviours, such as crowding certain exits or disregarding safety protocols, which can create bottlenecks and slow the overall evacuation process. For example, individuals may gravitate toward the nearest exit without assessing whether it is safe or accessible, potentially leading to dangerous situations such as stampedes. In particular, panic can impair an individual's ability to process information clearly, leading to poor decision-making regarding route selection, as individuals may follow others without fully considering the safety or efficiency of the path they choose (Proulx, 2001; Ternero et al., 2023). The cumulative effect of these psychological states not only reduces evacuation efficiency but also increases the risk of injury or death during emergencies. In extreme cases, mass panic can result in trampling or other severe consequences, highlighting the urgent need for strategies to mitigate such reactions. Therefore, understanding the psychological dynamics at play during evacuations and accounting for the unpredictable nature of human behaviour remain critical challenges for researchers and policymakers working to improve public building safety. Ongoing research efforts must focus on developing interventions that can effectively manage human behaviour during emergencies, ensuring that safety measures are practical and responsive to real-world complexities.

2.2 Evacuation behaviours and factors affecting evacuation behaviours

To address the challenges mentioned above, researchers need to analyze the unique evacuation behaviour characteristics of public buildings and the factors influencing them. By reviewing and summarizing the literature on evacuation behaviour in buildings, evacuation behaviours can be divided into individual and group behaviours based on the number of people involved.

An individual serves as the fundamental unit within a crowd, and their personal behaviours significantly shape the overall dynamics of an evacuation. These behaviours encompass a range of actions, including information-seeking, where individuals actively gather data to better understand the emergency situation (Wang et al., 2021), which can be crucial in enabling individuals to make informed decisions about their next steps, potentially improving evacuation outcomes. These behaviours include: helping others, such as providing assistance to those who are vulnerable or in need during the evacuation (Ding et al., 2021; Lin et al., 2020); route selection, where individuals make decisions about which path to follow based on factors such as familiarity, perceived safety, or crowd movement (Ding et al., 2021); hesitation, which can arise from uncertainty, fear, or a lack of clear information (Şahin et al., 2019; Wang et al., 2021); and herd behaviour, where individuals mimic the actions of others around them, often following the crowd rather than making independent decisions (Ding et al., 2021; Liu & Mao, 2022; Mao et al., 2019). While individual psychological and behavioural differences are evident during evacuations, these distinctions tend to blur as the number of evacuees increases and crowd density increases. As density increases, noise and visual stimuli from the crowd can overwhelm individual decision-making processes, leading to a reliance on social cues. Certain behaviours become more standardized and reflective of group dynamics, with individuals conforming to the collective patterns of action. For example, in dense crowds, herding becomes more pronounced as people tend to follow those ahead of them without assessing alternative routes or options. This reliance on herd behaviour can create feedback loops in which the actions of a few individuals influence the majority, sometimes leading to inefficient evacuations. This shift from individualistic behaviour to more group-oriented actions highlights the influence of crowd dynamics on the evacuation process.

Current research has focused on several key group behaviours, including aggregation, competition, and cooperation (Carter et al., 2020; Lu et al., 2017). Aggregation behaviour refers to the tendency of individuals to cluster in groups, often seeking safety in numbers or responding to the actions of others in proximity. This behaviour can either facilitate or hinder evacuation, depending on how effectively a group navigates towards the exits. This behaviour can manifest as individuals moving toward familiar faces or established groups, which can either facilitate or hinder evacuation depending on how effectively the group navigates towards the exits. On the other hand, competitive behaviours may emerge in more urgent or panic-driven scenarios, where individuals prioritize their own safety over others, leading to pushing, shoving, or bottlenecks at exits. In these cases, the instinct for self-preservation can overshadow social considerations, resulting in a chaotic evacuation environment. Conversely, cooperative behaviours involve individuals working together, helping one another, and facilitating smoother movement towards safety. Such cooperation can be vital in overcoming physical barriers and maintaining a steady flow of evacuees during a disaster. These group behaviours are critical in determining the overall efficiency and safety of evacuations. Understanding the interplay between individual actions and collective behaviours is essential for developing effective evacuation strategies that consider the complexities of human behaviour in emergencies.

Evacuation behaviour inside a building is influenced by many factors, mainly the building environment, such as wayfinding design (Kuligowski, 2017; Zhu et al., 2020a). Individual characteristics include physiology (Lämmel et al., 2010), psychological state (Kuligowski & Kuligowski, 2008; Wang et al., 2021), and knowledge and experience (Kuligowski & Kuligowski, 2008). Physiological factors, including physical fitness and mobility, influence the speed at which an individual can respond and move during an emergency. Individuals with higher fitness levels may navigate obstacles more effectively, whereas those with mobility impairments may require additional support or alternative routes. Simultaneously, an individual's psychological state, such as panic and anxiety, and the interaction between individuals and others, such as emotional contagion and herding (Barsade, 2002; Schwarz & Clore, 2003), affect the evacuation plan and path selection. The interaction between individuals plays a crucial role, with phenomena such as emotional contagion, where panic spreads through a crowd, and herding behaviour, where individuals follow others without independent judgment, further complicating evacuation dynamics. These social influences can lead to rapid shifts in crowd behaviour, often resulting in inefficient evacuations if they are not managed effectively. Furthermore, an individual's prior knowledge and experience with evacuation procedures, or familiarity with the building layout, can greatly enhance their ability to make effective choices during an emergency. Those who have participated in evacuation drills or have a clear mental map of the building are typically more adept at navigating towards safety, as they can quickly assess their options and act accordingly.

Among the building environmental factors, it mainly pay attention to the influence of the sign system (Liu et al., 2011; Shi et al., 2022; Yuan et al., 2018) and the layout of entrances and exits (Lee et al., 2021; Zhao et al., 2017) on evacuation behaviour. Signage systems are critical for guiding evacuees toward safe exits, particularly in unfamiliar or complex environments. Effective signage not only directs movement but also helps alleviate panic by providing clear instructions on the safest routes. Studies have shown that clear and strategically placed signage can significantly reduce evacuation times and minimize confusion (Liu et al., 2011; Shi et al., 2022; Yuan et al., 2018). In terms of building layout and design, the layout of entrances and exits is another crucial factor; the number, size, and location of these points directly affect the flow of people during evacuation. Research indicates that optimizing these elements can lead to more efficient crowd movement, reducing the likelihood of bottlenecks and overcrowding. Relevant research has taken typical public buildings, such as subways, schools, and shopping malls, as research sites (Lee et al., 2021; Wang et al., 2022) and provided guidance and suggestions for safe evacuation by changing the location and number of exits and the location of obstacles (Ma et al., 2021). Efforts to improve signage systems have primarily focused on the effectiveness of evacuation signs and the role that different types of evacuation systems play in guiding people (Zhu et al., 2020b). Studies have explored how changes in the location, size, and colour of evacuation signs can impact evacuation efficiency. For instance, placing signs in more visible locations and using high-contrast colours have been shown to enhance the speed and accuracy of evacuee movements (Zhu et al., 2021).

2.3 Progress and research methods of evacuation behaviours in building

2.3.1 Research progress of evacuation behaviours in buildings

Building evacuation has become an important research area in emergency management and behaviour analysis (Ding et al., 2021). Over the past several decades, this area of research has evolved to form a systematic theory and methodology that continues to shape and advance evacuation strategies and safety design. This evolution reflects the growing recognition of the complexities involved in human behaviour during crises and the necessity for comprehensive approaches that integrate psychological, environmental, and social factors. This progression has been driven by the need to understand how individuals and groups behave during emergencies and to apply that knowledge to improve the effectiveness of evacuation protocols in public spaces.

The early stages of research in this field can be traced to the 1950s. The first phase, spanning 1950 to 1970, primarily focused on studying human behaviour in emergency scenarios, such as fires (Canter, 1980). During this period, researchers aimed to identify and document basic human behaviour patterns in fire incidents, relying heavily on case studies and post-incident reviews to analyze human responses to them (Bryan, 2002). Research during this period largely relied on case studies and post-incident reviews of fire accidents, such as the analysis of records of past fire events. Researchers collected detailed accounts from survivors and emergency responders to understand the sequence of actions taken during the evacuations. One study, for example, summarized the behaviours of over 2,000 individuals in 952 fire incidents (Reeves et al., 2006), providing a foundational dataset that reveals common patterns of movement and decision-making. This data highlights key issues, such as the time taken to respond to alarms and the factors influencing route selection during evacuations.

As research progressed into the 1970s and beyond, the focus began to shift toward the quantification of individual behavioural characteristics during evacuations (Helbing et al., 2006; Helbing et al., 2007). This new direction emphasizes the development of evacuation models that seek to quantify not only the physical movement of individuals during an evacuation but also their psychological responses. This marked a significant advancement in understanding the dynamics of crowd behaviour, as researchers began to recognize the importance of psychological factors in shaping evacuation outcomes. By incorporating factors such as panic and fear, researchers have begun to create more sophisticated models that can simulate how individuals might react in different emergency scenarios (Proulx, 1993). These models allow for the exploration of various variables, including crowd density, exit configurations, and the presence of obstacles, all of which can impact the efficiency of an evacuation. Moreover, the use of computer simulations has become increasingly prevalent, enabling researchers to conduct "what-if" analyses to predict evacuation outcomes under various conditions. Although there are certain patterns in evacuation behaviour, the factors influencing them require further investigation. As researchers continue to refine these models, there is a growing emphasis on the need to include real-time data and behavioural observations to enhance the accuracy of simulations. Understanding the nuances of human behaviour in emergencies is essential for developing effective evacuation strategies that can adapt to the complexities of real-world scenarios.

Evacuation behaviour research has entered a developmental stage to further refine the understanding of human behavioural characteristics. This phase began to explore how individual differences, psychological states, and other factors led to diverse impacts on evacuation behaviour (Ali et al., 2013; Kohata et al., 2005).

Researchers have recognized that traits such as age, gender, and prior experience with emergencies can significantly influence decision-making processes during evacuations. Experiments and surveys were conducted to gather more data on individual and group evacuation decisions, and computer simulations were used to predict and analyze evacuation behaviour. Sime (1985), through experimental data, highlighted the critical role of psychological factors in evacuation, particularly the tendency of individuals to seek out familiar environments and people during emergencies, such as fires. This finding emphasizes the importance of understanding psychological responses, such as fear and panic, and how these emotions influence decisions under stress. Gwynne and Kuligowski (2001) investigated the effects of group behaviour and evacuation cues on evacuation decisions through detailed experiments and surveys. Research during this phase deepened the understanding of evacuation behaviour and provided insights into emergency evacuation guidance and building design. Despite these advancements, real emergency situations are influenced by a myriad of unpredictable factors, many of which are difficult to fully capture or quantify in controlled studies or simulations (Kuligowski, 2016). For instance, unanticipated reactions from individuals in crisis situations can lead to rapid changes in group dynamics, complicating the established evacuation plans. Variables such as the unique psychological states of evacuees, spatial constraints, and group dynamics under extreme stress present ongoing challenges for researchers and emergency planners. This highlights the need for adaptive strategies that can account for variability and unpredictability in human behaviour during actual emergencies, ensuring that safety measures are flexible and effective.

Based on the findings of previous studies, advanced simulation techniques, such as machine learning, have been increasingly introduced into evacuation studies to enhance predictive accuracy and optimize strategies. These techniques allow for the analysis of complex data patterns, enabling researchers to develop sophisticated models that can adapt to varying conditions during emergencies. Current research extensively uses computational models and simulation technologies combined with large-scale data analysis to predict and refine evacuation behaviour under various emergency conditions. By integrating sensing technologies and the Internet of Things (IoT), it is now possible to achieve real-time evacuation monitoring and provide dynamic guidance during emergencies (Horii, 2020; Nguyen et al., 2016; Osorio et al., 2022). This integration allows the collection of real-time data on crowd movement, environmental conditions, and individual behaviour, which can inform immediate response strategies and enhance overall safety. Researchers have also developed evacuation models tailored to different types of emergencies, including fires, earthquakes, and other critical situations. These models aim to better incorporate human behaviour and social dynamics, recognizing that such factors significantly influence the success of evacuation efforts (Yoo & Choi, 2022). The inclusion of behavioural data enhances the predictive accuracy of models, making them more effective for planning diverse real-world scenarios. Furthermore, recent studies have considered specific risks in indoor evacuation scenarios, such as radiation exposure, toxic gas leaks, and other hazards that may arise during an emergency (Chen et al., 2021). By addressing these specific threats, researchers can develop specialized protocols and safety measures that are critical for ensuring occupant safety in various emergency situations.

To make evacuation scenarios as accurate as possible, certain factors, such as human interactions and individuals' psychological responses, need to be considered (Chang et al., 2024; Deng et al., 2024). Neglecting these elements can result in inaccurate predictions and flawed evacuation strategies, as human behaviour is often unpredictable and influenced by both social dynamics and psychological factors under stress. Emotional contagion, where panic and anxiety spread quickly through a crowd, leads to irrational actions such as rushing to crowded exits, which can create dangerous bottlenecks (Drury et al., 2009). This phenomenon underscores the importance of effective communication and guidance during emergencies, as clear information can mitigate the spread of panic. Additionally, hesitation and delay are common, as individuals may hesitate because of uncertainty or disbelief about the severity of the situation, which can lead to critical delays in fast-developing emergencies, such as fires (Aguirre et al., 2011). Lastly, herding behaviour is commonly observed, where individuals follow the actions of others, often without independent judgment, which can either streamline or hinder evacuation depending on the crowd’s movement and decision making (Bellomo et al., 2016).

2.3.2 Research methods for individuals’ behaviour in building evacuation

To date, various methods have been employed to study human movement patterns and evacuation behaviour, focusing on understanding the complex factors that influence decision-making and actions during emergencies. These include incident analysis (Sime, 1985), behavioural experiments (Huo et al., 2014; Peacock et al., 2012; Xudong et al., 2009), evacuation drills (Chen et al., 2020), and simulation modeling (Hughes, 2002; Zhang & Han, 2011).First, incident analysis refers to the examination of past cases, often using qualitative methods such as surveys and interviews. This approach provides deeper insights into the psychological and social interactions that occur during an evacuation. For example, Galea et al. (2010) collected data on decision-making processes and dynamic psychological changes during the evacuation of real-life events, such as the WTC 9/11 incident. Similarly, Shields et al. (2009) conducted a questionnaire survey after a building fire and identified evacuation delays, noting that the number of floors on which residents lived affected their escape route planning and choices. Behavioural data collected from qualitative investigations of real incidents are authentic and reflect the actual characteristics and patterns of evacuation behaviour in emergencies. Common evacuation phenomena such as delays, gathering, and backtracking have been observed (Johnson, 2005). Common phenomena observed during evacuations include delays, where individuals hesitate before evacuating; gathering, where evacuees tend to cluster together, often for safety or reassurance; and backtracking, where individuals return to retrieve belongings or reunite with family members (Kobes et al., 2010). Such behaviours are critical for understanding inefficiencies in evacuation processes and are often revealed through incident analysis. However, video analysis has limitations. The video analysis of real incidents is often hindered by environmental factors such as smoke. Additionally, qualitative analysis focuses on subjective experiences during the evacuation process, relying heavily on participants' perceptions, which may not always align with actual situations. For example, individuals might overestimate or underestimate their reaction times or fail to recall certain key actions accurately because of the stress of the situation (Proulx, 2001). Therefore, the alignment between perceived and actual behaviour remains uncertain in many cases.

To address the limitations of the aforementioned research methods and better collect physical data, such as the impact of flow direction and exit distribution on evacuation efficiency, behavioural experiments have been introduced. These experiments utilized observations, statistical methods, and video analysis to record precise behavioural data. Often, large public buildings are chosen as study sites, or researchers create simpler controlled environments, such as temporary spaces, to conduct non-emergency experiments in which variables can be closely monitored and manipulated (Haghani & Sarvi, 2019; Xie et al., 2020). The primary focus of these studies is on non-emergency behaviours, which allows researchers to systematically explore factors such as visibility, signage direction, and the number of followers, all of which influence group behaviour and evacuation route selection. It would be beneficial to discuss the criteria for selecting specific study sites and how these choices may impact on the generalizability of the findings. By creating controlled scenarios and manipulating various external factors, researchers have studied how people respond to different environmental cues and how these factors affect evacuation decisions. For instance, experiments have examined the role of signage visibility in guiding people toward the safest exits and how the presence of others (e.g., the size of a following group) affects an individual's decision to choose a particular route. Further elaboration on the types of environmental cues tested and their specific impacts on behaviour could enhance our understanding of these dynamics. By comparing evacuation times and behaviours under different experimental conditions, these studies have identified the physical conditions necessary for safe evacuations and assessed how behavioural characteristics influence decision-making during evacuations. Although these behavioural experiments provide valuable data with high repeatability and controllability, they also have limitations. The outcomes are often influenced by experimental design and specific objectives set by researchers. For example, by focusing on non-emergency scenarios, these experiments typically fail to capture the urgency and psychological stress that characterize real-world emergency evacuations. A discussion on how researchers might adapt their methods to simulate real emergency conditions, such as incorporating time constraints or stress-inducing elements, could provide insights into improving experimental validity. While these studies help clarify how people behave in controlled settings, they may not fully represent the unpredictable dynamics of actual crisis situations.

Evacuation drills are crucial for understanding human behaviour during emergencies as they closely mimic how individuals respond to real-life crisis situations. Consequently, these drills have emerged as effective methods for replicating the evacuation process under conditions that closely resemble actual emergencies. In recent years, the utilization of evacuation drills as a research instrument has notably increased, both nationally and internationally. Typically, these drills take place in various public environments, such as educational institutions, residential complexes, and other large facilities, where the complexities of evacuation can be particularly pronounced. Various techniques are employed to ensure that drills accurately simulate genuine emergency scenarios. Alarm systems were activated, and non-toxic smoke was introduced to create a sense of urgency. Additionally, other environmental stressors may be integrated to heighten the realism of the experience, thereby encouraging participants to react as they would if they faced a real crisis (Kagawa et al., 1986). The entire evacuation process is meticulously documented using strategically placed cameras that capture the unfolding events for later analysis (Xudong et al., 2009; Yazdan & Haghani, 2023). Because evacuation drills closely reflect people's behaviour in emergency situations, they are an effective method for replicating the evacuation process under near-real conditions. In recent years, evacuation drills have become widely used research tools both domestically and internationally. These drills are typically conducted in public settings, including teaching buildings, residential buildings, and other large facilities where evacuations are complex. To simulate real emergency scenarios as accurately as possible, alarm systems, non-toxic smoke, and other environmental stressors were employed to create a sense of urgency, encouraging participants to respond as they might in an actual crisis (Kagawa et al., 1986).Cameras were set up to record the entire evacuation process (Xudong et al., 2009).Researchers have increasingly used these drills to gather behavioural data from a wide range of participants, including those with different cultural backgrounds, physical characteristics, and varying levels of familiarity with the building layout. By studying participants under these controlled yet realistic conditions, researchers can gain valuable insights into how different factors influence evacuation behaviours. For example, studies have found that variables such as the initial location of evacuees, visibility of exit signs, and presence of obstacles play significant roles in shaping individual and group decision-making during evacuations (Härkänen et al., 2019; Zhu et al., 2021).

Although evacuation drills differ to some extent from actual emergency scenarios, they succeed in capturing many key aspects of human behaviour during real evacuations, providing valuable and reliable data for research on evacuation dynamics. These drills offer an opportunity to observe how individuals respond to stress, the routes they choose, and their interactions with the environment, all of which contribute to our understanding of evacuation behaviour in emergencies. These drills offer an opportunity to observe how individuals respond to stress, the routes they choose, and their interactions with the environment, all of which contribute to our understanding of evacuation behaviour in emergencies. The current objectives of evacuation drills are as follows: First, they aim to verify the existence of common evacuation behaviours, such as delays in initiating movement, herding tendencies, and preferences for familiar routes. Second, they sought to explore the factors influencing evacuation, with a particular focus on how building layout and individual characteristics, such as physical condition or prior knowledge, impact evacuation decisions and outcomes. These drills have contributed significantly to improving building safety design and emergency protocols by identifying how factors such as exit visibility, signage placement, and the number of available exits affect evacuation efficiency.

However, one area that has received less attention is the impact of social interactions between individuals and their surrounding groups during an evacuation. Evacuation drill protocols and plans need to be further refined to better address these aspects. Owing to the diversity and complexity of building types, it is essential to investigate and predict evacuation scenarios to prevent adverse outcomes such as stampedes. Based on behavioural data from real incidents and evacuation drills, simulation modeling can be used to replicate and compare evacuation scenarios across different conditions (Cui et al., 2005; Song et al., 2019).For instance, Zou & Fernandes (2021) conducted a comparative study in a prototype subway station under both normal and emergency conditions, focusing on key parameters such as the number of passengers, the presence of trains, and the distribution of exits. Their results showed that these parameters significantly influenced evacuation times, providing actionable insights for optimizing subway station safety during emergencies. Similarly, Jiang & Zhang (2014) investigated evacuation behaviour in large hospital buildings, highlighting that factors such as exit width, and the availability of efficient evacuation instructions are critical to ensuring successful and timely evacuations. Han & Liu (2021) modeled evacuation scenarios in shopping malls, analyzing bottlenecks in evacuation flow and identifying the critical points where crowd density could lead to delays. Their research provided recommendations on how to overcome these bottlenecks, offering strategies for achieving the best alignment between the flow of people and the capacity of emergency passageways. The findings of these studies demonstrate that evacuation simulations rely heavily on parameters derived from classical dynamic models. Evacuation models consider individuals as particles and fluids and are divided into macroscopic and microscopic models. Macroscopic models mainly study pedestrian movement phenomena, such as bottleneck problems and cluster phenomena. The model focuses on the overall group movement behaviour, which saves computation to a certain extent, but ignores some details, such as the interaction process between people. The microscopic model considers individuals as units and explores how human characteristics influence evacuation behaviours by setting parameters such as individual evacuation speed and interpersonal distance (Hu et al., 2018; Varas et al., 2007; Zheng et al., 2011). However, the psychological state of individuals during evacuation is unstable and can be influenced by the external environment and surrounding crowds, which may lead to changes in decision making (Zheng et al., 2009). Therefore, considering individual psychological traits is crucial for building evacuation simulation models. Currently, most simulations focus on quantifying external environmental factors and individuals' physical characteristics, which creates discrepancies between simulation results and actual evacuation situations.

The decision-making process and cognitive differences among individuals during evacuation cannot be ignored (Kinsey et al., 2019). Both external factors, such as time constraints, and internal factors, such as social influence and individual traits, contribute to the formation of cognitive biases during emergencies. For example, in emergencies, individuals may be influenced by the reactions of those around them, leading them to disregard their own judgment and choose to follow the actions of others. These biases result in variations in how people perceive their environment and make decisions, leading to divergent evacuation paths chosen by different individuals (Gao et al., 2022; Nguyen et al., 2018). Common cognitive biases include confirmation bias and the availability heuristic, which may cause individuals to rely too heavily on recent experiences or the reactions of others rather than comprehensively assessing the situation. However, exploring the cognitive mechanisms that influence these decisions is particularly challenging because decisions made by individuals in emergency situations are often instantaneous and dynamic. Unlike planned or reflective decision-making, evacuations require quick responses, often under conditions of high stress and uncertainty. In such high-pressure environments, individuals may struggle to process information effectively, leading to misjudgments that affect their decisions. This makes it difficult to fully understand the underlying cognitive processes using traditional research methods, such as surveys or post-incident interviews, which rely on delayed self-reporting and may not capture real-time decision-making dynamics. Therefore, future research should adopt a mechanism that can effectively analyze the decision-making process or decision-making changes to better understand the complexity of these rapid decisions.

To solve the above challenges, technologies such as eye-tracking devices have been employed in other fields, such as educational science and market research, to record individuals' cognitive preferences and processing patterns (Muñoz Leiva et al., 2022). Eye-tracking allows researchers to measure where and how long a person focuses on stimuli, offering insights into how individuals prioritize information and make decisions. The application of such advanced research tools in the field of evacuation studies could significantly enhance our understanding of the individual decision-making processes. Using eye-tracking and similar technologies, researchers can gather more precise data on how individuals perceive and react to visual cues, signage, exits, and the actions of others in real time, thus addressing a major gap in current evacuation research. The adoption of these technologies and methodologies would help improve the analysis of cognitive mechanisms during evacuations. By tracking the visual attention and decision-making patterns of individuals under stress, researchers can refine existing models of evacuation behaviour, making them more reflective of real-world scenarios. Moreover, these insights would allow for the better design of evacuation systems and building layouts, as well as the development of more effective emergency protocols that consider the cognitive limitations and biases of individuals in crises.

2.4 Literature overview and research gaps

Current research on public building evacuations encompasses a variety of models and methods, focusing on the dynamic changes in individual and group behaviours and their impact on evacuation behaviour and efficiency. Numerous studies have employed simulation models, behavioural experiments, evacuation drills, and surveys to investigate human behavioural patterns during evacuations in public buildings. Individual behaviours, such as path selection and information seeking, exhibit significant variability during evacuations, especially under conditions of high crowd density, where group characteristics become more pronounced. Group behaviours, including gathering, competition, and cooperation, also demonstrate different dynamic features under varying evacuation conditions. Based on these studies, researchers have proposed various methods to improve evacuation efficiency, particularly by optimising exit locations and signage system designs.

By summarising and analysing the literature on typical behaviours during building evacuations, a large number of findings have been obtained. Domestic and international studies indicate that scholars have systematically explained the mechanisms of individual evacuation behaviour in buildings during emergencies and explored the factors influencing individual behaviour and decision-making in such situations. However, gaps still exist in the current literature regarding the understanding and prediction of individual behavioural patterns in emergencies.

(1) In existing studies on evacuation, attention has been paid to typical evacuation behaviours such as overtaking and gathering. However, the conclusions regarding the influence of herd behaviour on the evacuation process are inconsistent. The impact of herd behaviour can be obstructive, facilitative, or neutral. The factors influencing herd behaviour and the conditions under which it occur are unknown.

(2) In the analysis of factors influencing individual behaviour during evacuation,

extensive research has been conducted on how environmental factors and building structures affect evacuation behaviour; however, the influence of individuals' internal traits on evacuation behaviour has been overlooked.

(3) Previous studies have primarily focused on evacuation simulations and path optimization. Improvements in building layouts, exit design, and flow control have enhanced evacuation efficiency. However, evacuation efficiency is unstable owing to the influence of individual and group decision-making. Individual decisions can affect the group's evacuation path. Therefore, it is crucial to explore the decision-making process of individuals during evacuations and the factors that influence them. This aspect has been overlooked in previous studies.

This study aims to address these gaps by collecting real data on individual behaviour through the integration of on-site evacuation drills and advanced data collection technologies such as text mining and eye-tracking. It delves into the decision-making variations and cognitive differences of individuals during evacuation processes within buildings. Using this data, this study conducted both qualitative analysis and quantitative modelling to explore the multiple factors influencing individual evacuation decisions and behaviours. This approach not only enhances the understanding of individual behaviour patterns in emergency evacuations but also provides practical guidance for the safe design and emergency preparedness of public buildings, offering significant theoretical and practical value.

Chapter 3 - Methodology

This study adopts a mixed-methods research strategy, integrating both quantitative and qualitative data collection and analysis methods to comprehensively explore individual behaviour patterns during emergency evacuations in public buildings (See Fig. 2). Initially, fire evacuation drills were conducted in a laboratory building using cameras and eye-tracking devices to collect real-time data. Simultaneously, surveys and in-depth interviews were conducted to collect participants' perceptions and behavioural feedback. The sample selection focused on students who were unfamiliar with the layout of the teaching building. Data analysis will combine quantitative statistical methods with qualitative analysis. Special attention was given to ethical approval in this study, ensuring comprehensive protection of all participants' privacy and data confidentiality. This study aims to provide empirical support for enhancing evacuation efficiency and safety in public buildings, offering scientific evidence for emergency management practices and policy formulation.

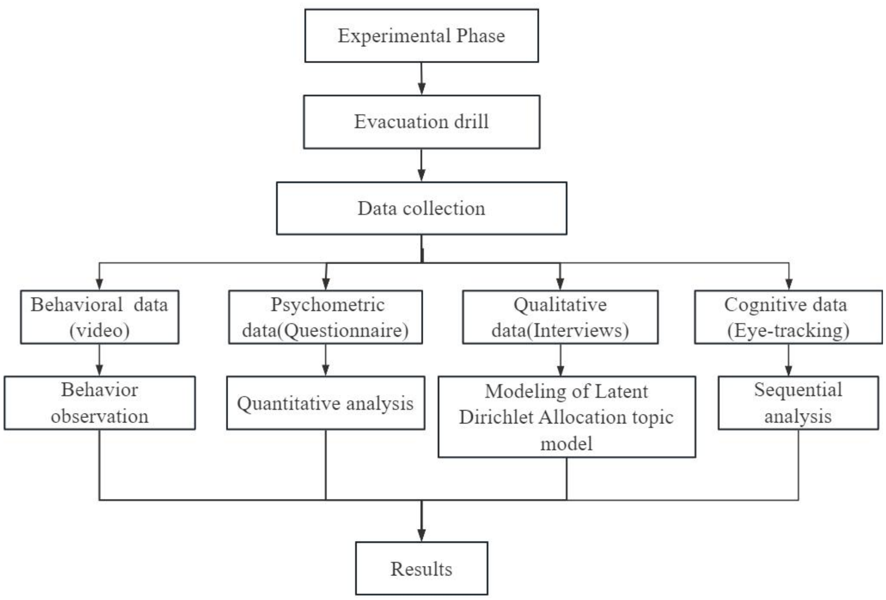


Fig. 2. Framework diagram of methodology.

3.1 Experimental design and data collection

3.1.1 Experiment set-up

The experiment was conducted in October 2022 at a teaching building in China, a three-story laboratory building, with each floor of the experimental building having an area of 1521.14 m^2. The building complies with the Code for Fire Protection Design of Buildings (GB 50016-2014, 2018). All corridor widths exceed 1.4 m, and no clutter is stored in the hallways to avoid obstructing safe evacuation. Evacuation signs, designed to guide people to safety exits, are made of luminous materials and are intact to ensure visibility during a fire. The placement, color, and other requirements of safety signs also comply with the Guidelines for Safety Signs and Their Use (GB/T 2893.1-2013). The building had four available safety exits, except for a fire exit on the second floor. All other exits were situated on the first floor (See Fig. 3). Based on meeting construction standards, building selection was driven by its complex spatial layout, featuring multiple intersections, long corridors, and various emergency exits, which collectively provide a challenging environment for observing natural evacuation behaviour in public spaces. Additionally, the laboratory building is stocked with large quantities of chemicals, which pose safety risks. In the case of chemical leaks or explosions, the safety of personnel could be endangered. Therefore, this building was selected for regular evacuation drills.

In this experiment, several cameras were set up to record the participants' behaviour during evacuation. A total of 20 cameras were deployed at the scene, with 6, 7, and 7 cameras placed on the first, second, and third floors, respectively, to monitor evacuation behaviour comprehensively (See Fig. 5.). Fig. 4 shows a video screenshot of the evacuation. The multi-camera setup was specifically chosen to minimise blind spots and ensure accurate tracking of participant movements throughout the evacuation. The camera placement was strategically designed to cover critical decision-making points, such as stairwells and intersections, where individuals are most likely to encounter directional choices and decide whether to follow others. This setup was intended to capture detailed, unobstructed footage that would enable the subsequent analysis of path selection, hesitation points, and crowd clustering behaviour.

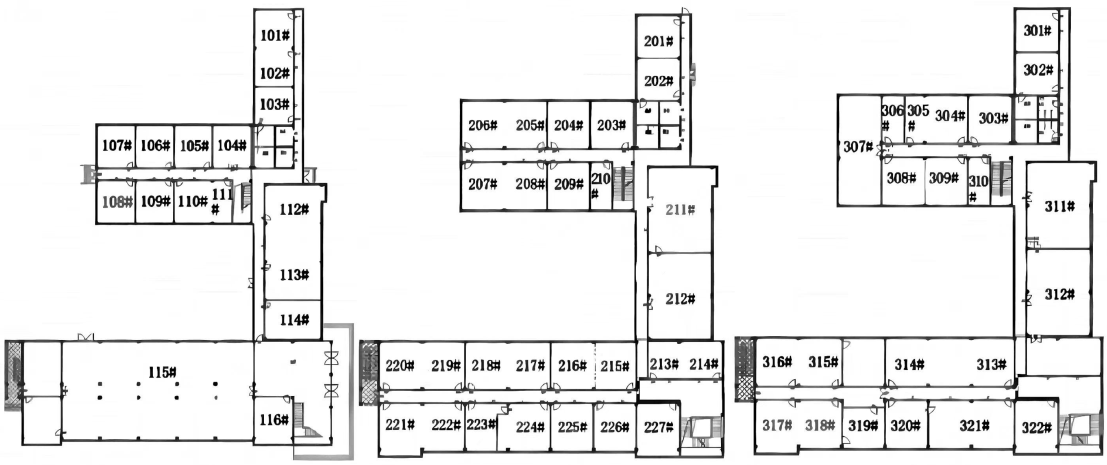


Fig. 3. Floor plan of the experimental building.

A total of 11 experiments were conducted in the building, each lasting 20 min. To avoid learning effects, each participant was involved in only one drill session. Learning effects were mitigated by limiting each participant to one drill, preventing route familiarity and memory effects from influencing natural decision-making. This randomization enhanced the generalizability of the findings by reducing the potential biases introduced by repeated exposure to similar conditions. Furthermore, the selection of participants (primarily unfamiliar with the building layout) ensured that the observed behaviours accurately reflected instinctual responses under emergency conditions rather than rehearsed actions. In addition to the participants, seven staff members contributed to the experiment. Of these staff members, four were chosen to record evacuees at the four exits, respectively: one for monitoring the safety of individuals participating in the evacuation process in the central control room, one for briefly introducing the experiment to participants, and one for igniting the smoke cake and initiating the experiment.

Fig.4. Records of personnel escaping in evacuation drills.

The objective of this study was to investigate the emergence of herding behaviour within a building and the factors influencing its occurrence. The experiment incorporated three primary design dimensions: story (2 levels), hazard source (2 levels), and leaders' designated route (2 levels). These variables were set to study the influence of different environmental factors on individual decision-making and group behaviour. Specifically, the choice of two different building story levels (second and third floors) aims to simulate varying levels of accessibility to exits, as higher floors often increase evacuation difficulty and induce greater stress, potentially enhancing herding behaviours (Chen et al., 2020). By comparing behaviours on different floors, the experiment can capture how environmental height impacts individuals' urgency and decision-making processes.

The use of hazard sources, such as smoke cakes, was designed to simulate the visual and olfactory limitations caused by fire-related emergencies. This variable was included not only to emulate real-life emergency conditions but also to examine how restricted visibility affects individuals' reliance on surrounding group members for guidance. Smoke cakes were selected because of their low toxicity and rapid smoke release, which allows for a realistic yet safe replication of fire conditions. The smoke is designed to selectively block optimal escape routes, compelling participants to choose between following a familiar yet obstructed route or an unfamiliar but clear path, thus testing the tendency to follow the leader or group under restricted visibility (Kuo et al., 2020).

The detailed experimental conditions are presented in Table 1.

Table 1 Drill conditions for 11 groups

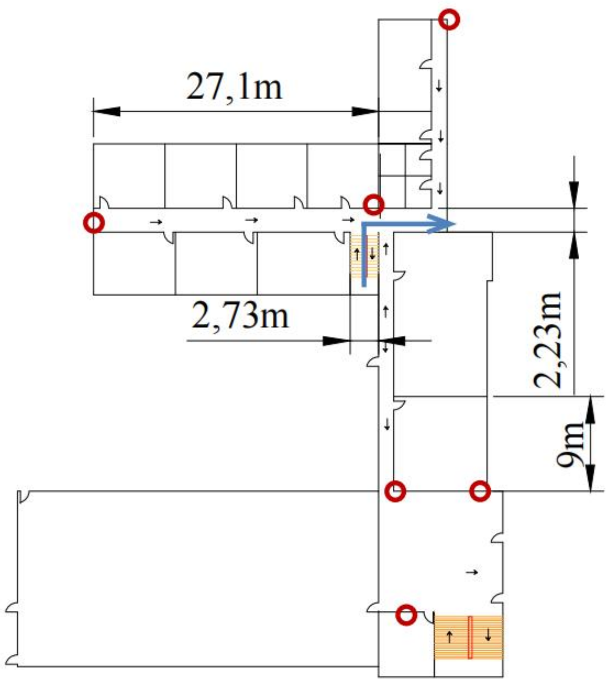
Drill No.	Participants	Story	Leaders' designated route
1	28	Third floor	B
2	30	Third floor	B
3	30	Second floor	A
4	30	Second floor	A
5	28	Second floor	A
6	29	Second floor	A
7	27	Third floor	B

8	30	Third floor	B
9	26	Third floor	B
10	29	Second floor	A
11	27	Second floor	A

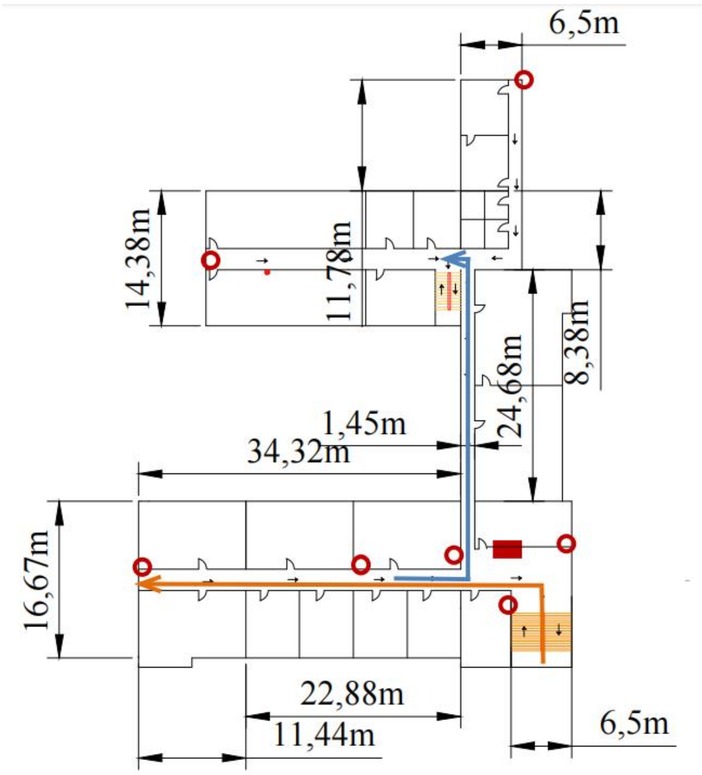
(1) Leaders’ designated routes

A class monitor was selected as the leader for each class in the experiment. Each class participated in the experiment, questionnaire, and interviews only once to prevent participants’ memories from influencing the evacuation. The purpose of setting up leaders is 1) to investigate leaders' influence on herding behaviour. In other decision-making domains, leaders typically serve as authoritative guides. This experiment established class monitors as leaders to observe their guidance effects on group behaviour during evacuation processes. 2) To reduce path familiarity interference and accurately identify herding behaviour. The experiment required leaders to select unfamiliar and inefficient routes for the group (e.g., Routes A and B). This design eliminates interference from individual "route familiarity" choices, thereby distinguishing herding behaviour from habitual route-selection patterns.

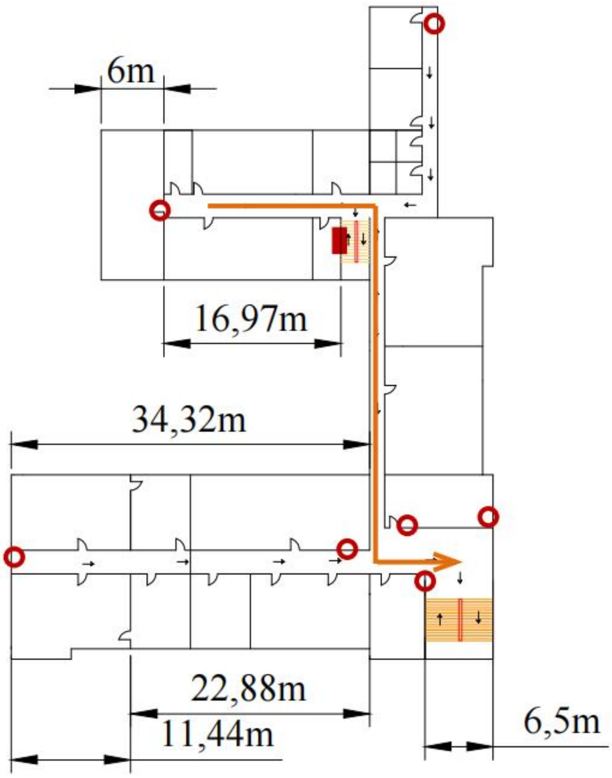
These leaders were randomly assigned to the two evacuation routes (Routes A and B on the second and third floors, respectively, as shown in Table 1). Route A starts from room 215 on the second floor and ends at the safety exit on the first floor, whereas Route B starts from room 308 on the third floor and ends at the safety exit on the second floor (See Fig. 3). When designing evacuation routes for a teaching building, the distance from any point within the building to a safety exit must not exceed a maximum evacuation distance of 30 m, as specified in the Code for Fire Protection Design of Buildings. Therefore, the designated routes in this study had a maximum evacuation distance of 30 m to the nearest safety exit, meeting the requirements. The rationale for configuring these alternate routes was to evaluate whether participants, particularly those in herding roles, would demonstrate herding behaviour when confronted with longer and less efficient route options. Cameras were placed in the building to monitor the evacuation processes.



1st floor



2nd floor



3rd floor

Fig. 5. Designated evacuation routes, the locations of the cameras in, and the layout of the building.

(2) Story

In this experiment, both three- and two-story scenarios were considered. Higher floors were more likely to induce herding behaviours (Chen et al., 2020), and proximity to a safe exit influenced the strength of herding tendencies. As individuals moved farther from their safety destination, their fear levels escalated, resulting in maladaptive behaviours.

(3) Hazard sources

In this experiment, smoke cakes were used to replicate the actual conditions of smoke encountered during emergencies. The effects of the cigarette cake combustion are shown in Fig. 6. Smoke cakes released dense smoke that mimicked the smoke produced during real fires, allowing the simulation of limited visibility. The choice of smoke cakes was based on their low toxicity and rapid smoke release, which can effectively replicate fire conditions without compromising the safety of the participants. The smoke ingredients include potassium nitrate, gum, ammonium chloride and sulfur (Kuo et al., 2020). Smoke cakes were placed at the path intersections. At these crossing points, people typically have multiple evacuation route options. The released smoke obscured the clearest escape route, prompting participants to consider alternative paths under stressful evacuation conditions.

Fig. 6. Schematic diagram of smoke cake combustion.

The average duration of this process, from ignition to smoke dispersion, was approximately 50 seconds. In this experiment, hazards were placed in two locations

(See Fig. 5) to maximize the differentiation between individuals who exhibited herding behaviour and those who relied on their independent judgment. Placing hazard sources on the optimal or shortest route impeded individuals from gathering information from their surroundings and made them more susceptible to the influence of other moving individuals. Participants relinquished the familiar optimal route to choose the leader’s less efficient path, which was classified as herding behaviour.

3.1.2 Participants

A total of 317 undergraduates from 11 classes in this building participated in this experiment. These subjects were all first-year students, and their familiarity with the information of the building selected in this study, including the layout of the building and the optional evacuation routes, was limited. The participants in this study were all aged between 18 and 20 years old. To mitigate potential repetition effects, each participant was tested only once. To ensure that the rights and interests of participants were respected and conformed to ethical standards, all participants were informed about the purpose and safety precautions of the experiment, and ethical approval from the UNNC Committee was obtained (See **Appendix**). Specifically, the research purpose, experimental process, potential risks, anonymous data storage, security protection measures, participants' rights, and their freedom to withdraw from the experiment are displayed. Informed consent should ensure that participants fully understand the experiments they participate in and how their personal information is used. For example, participants need to know that their actions will be recorded and that the data will be used for academic research. The university where the subjects were located did not require ethical approval.

The 11 classes of students were grouped into 11 experimental groups based on their respective classes. The goal of this study was to investigate the emergence of herding behaviour within a building and the factors influencing its occurrence. Owing to the limited number of instruments, only one subject's data could be collected in each experiment. Eleven participants were selected to wear eye-tracking devices, and they were screened from 11 groups, with one set of eye-tracking data collected per experiment. The selection criteria for these 11 participants were: 1) good vision without wearing glasses, and 2) proximity to the leader before the drill. The leader is usually the key reference point in emergency evacuation, and the above criteria are used to test how the leader's behaviour affects the herding behaviour and evacuation decision of the surrounding participants. Each participant took part in the experiment only once. Before using the eye-tracking device for testing, each user needed to undergo calibration at 0.8m to 1.2m from the calibration card to minimise errors. A single circular calibration board was used to align the gaze and pupil positions for each participant. In addition, adaptation training was completed to ensure the comfort of the evacuation process. We documented any discomfort experienced during these sessions. If the participants reported discomfort, the staff used adjustable nose pads to fit different face shapes and personal comfort preferences.

3.1.3. The experimental procedure

In addition to the participants, seven staff members contributed to the experiment. Of these staff members, four were chosen to record evacuees at the four exits, respectively: one for monitoring the safety of individuals participating in the evacuation process in the central control room, one for briefly introducing the experiment to participants, and one for igniting the smoke cake and initiating the experiment.

Before commencing the experiment, each participant was instructed to fill out a pre-evacuation questionnaire (refer to **Appendix**) and was assigned an experimental number. The purpose of assigning numbers was twofold: 1) to simplify the identification of individuals' herding behaviour in experimental videos, and 2) to investigate correspondences and disparities between participants' subjective questionnaire responses and their actual behaviours during the experiment. Each participant was assigned a unique numerical label. The designated leaders were escorted to the front of the group. The selected subjects were calibrated with an eye tracker and arranged near the leader after no discomfort was reported. Two routes were selected that required participants to take longer and more indirect paths to the exits, which enabled the researchers to observe whether individuals prioritized efficiency over conformity in high-stress scenarios. By instructing class monitors to follow specific routes, the study examined how leaders influence evacuation behaviour, particularly in inducing following behaviour among participants with limited visibility or spatial awareness. This setup allows researchers to quantify the extent of herding behaviour and identify the conditions that may amplify this tendency.

The three experimental procedures are described as follows:

(1) The experimental commander briefed the participants on the experiment, stating, "No specific exit has been designated for this evacuation exercise. During the exercise, participants were instructed to prioritise their safety, avoiding pushing or crowding." All participants were aware of the scheduled evacuation drill in advance

but were unaware of its precise timing.

(2) The experimental assistant ignited the smoke cake to initiate the exercise. A signal (alarm) was dispatched from the central control room of the building, prompting all participants to evacuate. The experimenter, stationed in the central control room, continuously monitored the safety of the participants throughout the evacuation drill. The experiment ended when all the participants arrived at the safe area.

(3) Subsequently, all participants were directed to a tranquil open area to rest and were instructed to complete the post-evacuation questionnaire.

Following the experiment, data from 11 eye tracker wearers were recorded and saved. Following the experiment, based on the evacuation experiment video and the questionnaire survey results, 50 participants engaged in face-to-face semi-structured interviews within a tranquil classroom setting, adhering to the principle of voluntary participation. The entire experiment lasted for 15–20 min. Staff members conducted individual interviews with the participants, with prior consent and assurance that interview recordings would be retained for research purposes.

3.2 Measurements

3.2.1 Questionnaire

The questionnaire was designed based on established scales and previous research findings. For example, psychological traits such as directional anxiety, leadership tendency, and herding tendency were measured using validated Likert scales adapted from existing evacuation studies (Helbing et al., 2000; Haghani & Sarvi, 2019). Additionally, the questionnaire items were pre-tested on a smaller group before the main experiment to identify and resolve any ambiguities, ensuring that questions effectively captured the intended psychological and behavioural constructs. Questions were carefully designed, repeated topics were set, leading or suggestive wording was avoided, and participants were ensured to provide fair answers. The aim was to analyse the responses and identify differences in pedestrian behavioural patterns and psychological states in regular and emergency situations. Distinct questionnaires were prepared for use before and after the evacuation. Class monitors disseminated and collected the pre-evacuation questionnaires one day before the experiment began. Following the evacuation, the participating students were assembled by the staff in a classroom where they promptly administered the post-evacuation questionnaire, completed it on-site, and submitted it immediately. A questionnaire was omitted if the answers to similar questions were inconsistent or if the answers to all questions were intentionally the same. This resulted in 307 valid questionnaires being used, of which 10 were discarded.

Drawing from previous research on the evacuation process (Helbing et al., 2000; Haghani & Sarvi, 2019), the variables influencing herding behaviour and evacuation decisions were considered. Based on a comprehensive understanding of the relationship between herding behaviour and evacuation decision making, especially to explore the influence of herding behaviour on evacuation decision making, pre- and post-evacuation questionnaires were developed for this study. The effects of leaders' characteristics on their herding behaviour were investigated. Leader traits such as expertise and experience, gender, and personality played important roles in group decision-making and behaviour (Colbert et al., 2012; Kwon et al., 2016; Van Vugt & Spisak, 2008). Leaders' collective consciousness describes their ability to set and communicate common team goals, promote cooperation within the team, and is related to group conformity (Arnold et al., 2000; Kim et al., 2020; Toendepi, 2021). Personality influences the decisions she/he makes. Personality constructs are measurable indicators derived from common features shared by individuals to describe and assess different personality types (Teglasi et al., 2007). The personality constructs included introverted, extroverted, willful, rational, and emotional (Bain, 1860; Jung & Beebe, 2016). By comparing the pre-and post-evacuation questionnaire results, the behavioural change of groups, that is, whether people were influenced by the behaviour of others and changed their decisions and behaviour, was determined.

1) Pre-evacuation questionnaire

This questionnaire comprised 30 questions categorized into three sections: basic information, psychological traits, and evacuation response behaviour assessment. Basic information encompassed demographic details and previous evacuation drill experiences, providing insights into the participants' profiles and cognitive levels. Psychological traits, including personality (Bain, 1860; Jung & Beebe, 2016), directional anxiety (Kozlowski & Bryant, 1977), sense of direction (Kozlowski & Bryant, 1977), collective consciousness (Kim et al., 2020) and leadership (Judge et al., 2022), and herding behaviour, were evaluated using a 5-point Likert scale ranging from −2 to 2, where "−2" signifies Strongly Disagree, "−1" denotes Disagree, "0" represents Neutral, "1" indicates Agree, and "2" corresponds to Strongly Agree. Evacuation response behaviours include pre-evacuation performance, evacuation routes, exit choices, and responses to behavioural differences throughout the evacuation process.

2) Post-evacuation questionnaire

The complete content is provided in the **Appendix**. There are 9 questions primarily divided into two categories: first, the basis for selecting safety exits and evacuation routes, considering the behaviours and decision-making of individuals in unique evacuation situations, such as choices made at fork intersections. These questions were in a multiple-choice format and assigned scores of 1, 2, 3, and 4, following the available options. Second, factors influencing evacuation decision-making during the evacuation process, such as the impact of the majority's flow direction on participants' directional choices, were assessed using a five-point Likert scale ranging from −2 to 2. In this scale, "−2" denotes strong disagreement, "−1" represents disagreement, "0" signifies neutrality, "1" stands for agreement, and "2" corresponds to strong agreement.

3.2.2 Interviews

Interviews are robust tools for capturing individuals' subjective perceptions and experiences (Karaçar & Demirkıran, 2023). Open-ended and non-leading interview questions were used to gather participants' opinions, past experiences, insights, and interpretations of the situation. This approach was intended to gain insight into the current state of evacuation and gather the participants' subjective views. The open-ended format of the interviews allowed participants to freely discuss their thought processes, while the semi-structured format ensured that key areas relevant to herding behaviour and individual decision-making were covered.

Based on the mainstream definition of herding behaviour (Asch, 1961), herding behaviour in this study is defined as an individual's tendency to change their decisions and imitate the behaviour of the majority. Therefore, if a participant indicates a change in their decision-making and chooses the option regarding routes that follow the crowd's direction in the post-evacuation questionnaire, and the participant's actual path choice is confirmed through video recording, then the participant is considered to have a herding tendency. To delve deeper into the different manifestations of herding behaviour and its underlying motivations (Conrad & Tucker, 2019), purposive sampling was conducted on participants who met these criteria. Fifty target subjects volunteered to participate in the interview. The semi-structured interviews comprised three sections: (1) narratives of experiences related to the exercise, (2) elucidations and justifications for changes in decision-making, and (3) factors influencing the selection of evacuation routes and safe exits. The questions used in the interview are shown in the **Appendix**. Each interview lasted between 15 and 20 minutes. After presenting the study's objectives and procedures to all subjects, the staff confirmed the subjects' voluntary participation and confidentiality. All interviews were recorded with participants' consent, allowing for accurate transcription and detailed analysis. During the interview, the order of the questions was adjusted based on the communication between the interviewer and interviewee. However, the interviewees were required to answer all questions.

3.2.3 Eye-Tracking

This study aimed to explore the attention distribution and cognitive processing of individuals during evacuation. Subjects' behavioural decisions during escape reflect the decision-making process among multiple alternatives (Punde et al., 2017). Characteristics such as attention allocation and cognitive processing need to be measured during the decision-making process (Benedek & Kaernbach, 2010).

Eye-tracking is mostly used to explore the individual decision-making process. It combines camera, infrared, and computer technology to track eye movements and record critical data, such as fixation duration and gaze duration (Edwards, 1954). Based on the need for real-world testing, which requires portability, ease of assembly, and user-friendly analysis software, the Tobii Pro Glasses 2 eye tracker was selected for this study (Raptis et al., 2018; Configural & Hamilton, 2019). Tobii Pro Glasses 2, the mobile eye tracker used for this study, allows its users to wear an eye tracker without significantly influencing the user's mobility. Using a wearable eye-tracking device, Tobii Pro Glasses 2 allows the recording of eye metrics and subconscious behaviours. The Tobii Pro Glasses 2 eye-tracker consists of a wearable module (the glasses) and a recording module, as shown in Fig. 7. The wearable module includes a scene camera, eye tracker, and inertial measurement unit. Compared with a standard eye tracking device that is fixed at a certain location, a user can wear eye tracking glasses and walk around to observe the surroundings (Schulte-Mecklenbeck et al.,2017). The recording device can log eye-tracking data and save it to the accompanying eye-tracking data processing software. The recording module was compact, allowing the participants to move freely without any burden or restrictions. Tobii Studio software (version 1.79) was used for the calibration and recording of eye metrics. A single circular calibration board was used to align the gaze and pupil positions for each participant.

Fig. 7. Schematic diagram of the Tobii Pro Glass 2 eye tracker.

3.2.4 Video camera

The effectiveness of video recording can clearly capture the specific reactions of individuals in an emergency, such as whether to change the original route, whether to rely on other people's behaviour, and whether to produce collective follow-up behaviour. These data can support subsequent behavioural pattern recognition.

The camera can capture real-time behaviour in the current environment (Philpot et al., 2019). In this experiment, cameras were used to explore individuals' behaviours and evacuation routes in emergency situations. The camera covers important decision-making points such as stairs, corridors and exits, and can record key data such as participants' moving path, assembly behaviour and path selection in real time. The placement of the cameras is shown in figure 8. The cameras were always turned on. The aspect ratio was 16:9 and the video resolution was 1280 × 720 pixels (0.9 MP). The detailed movement process of each participant in the evacuation process was obtained from the camera.

Fig. 8. Real camera shooting in experimental scene.

3.3 Data analysis method

3.3.1 Questionnaires

This study explored the factors influencing herding behaviour during the evacuation process and the impact of herding behaviour on evacuation route choice. Data were analysed using SPSS 26.0 software. The questionnaire data were analysed using descriptive statistics, nonparametric tests, correlation analysis, one-way ANOVA, and multiple logistic regression. Descriptive statistics were used to analyse basic demographic information and behavioural changes in the sample before and after the drill. Non-parametric tests, Spearman rank correlation, and one-way ANOVA were employed to identify factors influencing herding behaviour. Finally, multiple logistic regression analysis was used to explore the impact of herding behaviour on the choice of evacuation routes.

To ensure the robustness of the findings, descriptive statistics were first employed to provide an overview of participants' demographic information, including age, gender, and familiarity with building layout. This step allowed the identification of basic trends and patterns in the data, serving as a foundation for more complex analyses. Descriptive statistics is a statistical method that organises, simplifies, and summarises data using charts or mathematical techniques to clearly convey the basic information of a dataset. This type of analysis typically includes a range of statistical tools, such as mean, median, mode, variance, standard deviation, and quantiles. These tools help researchers understand the central tendency, dispersion, and distribution patterns of the data, providing a foundation for an initial understanding and further in-depth analysis (Alabi & Bukola, 2023).

To further investigate the impact of leaders' gender and evacuation experience on herding behaviour, the Mann-Whitney U test was conducted. The Mann-Whitney

U test is suitable for non-normally distributed data and is used to compare two independent samples (McKnight & Najab, 2010). For instance, this approach was applied to compare decision-making tendencies between individuals with prior emergency experience and those without, enabling a clearer understanding of how familiarity with emergencies might influence evacuation behaviour. Since the study involved 11 groups of leader-related data that did not follow a normal distribution, the Mann-Whitney U test was chosen. The Kruskal-Wallis test, an extension of the Mann-Whitney U test, is a non-parametric test used to determine if three or more groups come from the same distribution, applicable in multi-group data comparisons (Ostertagova et al., 2014).The Kruskal-Wallis test was conducted to examine the effects of personality traits on herding behaviour.

Correlation analysis and one-way ANOVA were then conducted to examine the relationships between specific psychological traits (e.g., directional anxiety and leadership tendencies) and herding behaviour. By identifying statistically significant correlations, this study pinpointed the individual traits that were most likely to influence evacuation decisions, thus enhancing the theoretical understanding of herding mechanisms in high-stress environments.

Correlation analysis is used to explore the degree of association between two continuous variables, measuring whether changes in the two variables are synchronised (Bishara & Hittner, 2012). This analysis focuses on the correlation between variables but does not consider causation. The result of a correlation analysis is typically expressed by a correlation coefficient (r), which ranges from -1 to 1 and reflects the strength and direction of the association between the two variables. The closer the coefficient is to 1 or -1, the stronger is the linear relationship. This is because Spearman's correlation analysis does not require data to follow a normal distribution. Therefore, Spearman's rank correlation coefficient was used to test the relationship between collective consciousness and herding behaviour.

One-way Analysis of Variance (ANOVA) is a statistical method used to determine whether there are significant differences in the means among three or more groups. One-way analysis of variance (ANOVA) is a parametric method. It is specifically designed to analyse the effect of different levels of a single independent variable (factor) on a dependent variable. (Kim, 2017). One-way ANOVA is suitable when the independent variable is categorical with multiple levels, and the dependent variable is continuous data. In this study, personality was treated as a categorical variable in the questionnaire. Thus, a one-way ANOVA was adopted to explore how individual personality traits affect herding behaviour.

Logistic regression analysis was employed to examine the impact of multiple independent variables on the likelihood of herding behaviour, allowing for the control of confounding variables, such as age and gender. This multivariate approach provides insights into how various factors interact to influence individual decisions, offering a more nuanced view of the evacuation process. For instance, it helped clarify whether environmental factors (such as visibility) or social influences (such as herding tendency) played a more significant role in participants' evacuation route choices. Since Y (the options) in this study is unordered with multiple levels, an unordered multinomial logistic regression model was used for analysis. The unordered multinomial logistic regression model is a multivariate statistical analysis method used to examine the relationship between an unordered categorical dependent variable (or outcome variable) and independent variables (or predictor variables)

(El-Habil, 2012). Typically, it assumes that the dependent variable Y has m levels, with the i (i ∈ (1, 2, ⋯, n)) level selected as the reference level, let π_i be the conditional probability when the level is j ((j ∈ (1, 2, ⋯, i-1, i+1, ⋯,n)), then, the multinomial logistic regression model is defined as follows:

$$ln(\frac{\pi_j}{\pi_i}) = \ln\frac{P((y=j|x))}{P((y=i|x))} = \alpha_j+\beta_{j1}x_1+\beta_{j2}x_2+\cdots\beta_{jn}x_k=\alpha_j+\sum_{k=1}^{n}\beta_{jk}x_k,\ j\in (1,2,\cdots i-1, i+1,\cdots,n) \quad (1)$$

In the equation (1):

x_k represents the independent variable in the model; k stands for the number of independent variables; α_j and β_{jk} represents the independent variable regression coefficient vector. $\ln\frac{P((y=j|x))}{P((y=i|x))}$, it represents the ratio of selecting j (selection group) and i events (reference group) (usually, i is set to m or 1, meaning the reference level is either the first or the last category, referred to as the odds ratio). Simultaneously, the following conditions must be satisfied:

$$\sum_{j\in 1,2,\cdots i-1,i+1,\cdots,n}\pi_j+\pi_i = 1 \quad (2)$$

In this study, based on research design, Y (i.e., evacuation path choice) was set as the dependent variable, whereas other factors, including herding tendency, were considered as influencing factors or independent variables. SPSS 22.0 is used to perform a forward stepwise multinomial logistic regression analysis on the relevant independent and dependent variables.

3.3.2 Interviews

All audio recordings of interviews were transformed into textual data, and a text-mining method was utilized to extract relevant information. This strategy enabled us to explore the subtleties of the subjects' responses and extract valuable insights. Given the substantial textual data from the 50 subjects in this study and considering diverse themes due to individual variations, the Latent Dirichlet Allocation (LDA) topic model was applied to identify potential vital topics (Blei et al., 2003). Specific steps are illustrated in Fig. 9.

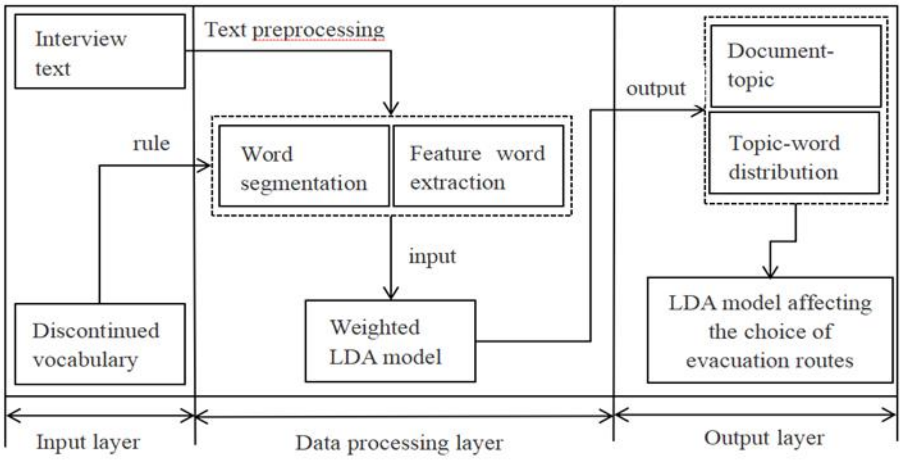


Fig. 9. Topic Extraction Framework for Evacuation Route Selection Based on LDA.

During the text pre-processing phase, the collected data were meticulously refined. The study eliminated duplicate segments, incomplete data, deactivated words, and redundant spaces to ensure that our dataset was optimized for precise and meaningful analysis. Subsequently, the cleaned data were organized, and the experimental corpus was subdivided and processed using the Gensim library in Python, a word segmentation tool, to create the lexical database.

LDA topic modeling is a technique used in text mining to discover potential topics from a collection of documents. LDA is a generative model that assumes each document is a mixture of multiple topics, and each topic is composed of multiple words. Semi-structured interviews were conducted using open-ended questions, resulting in substantial unstructured text data. Through the LDA model, research can identify the main topics in the document and the keywords in each topic, thus organising and classifying a large amount of text data.

Determining the optimal number of topics in the LDA topic model is essential. Calculating the degree of *perplexity* and *internal consistency* is a method for evaluating the optimal number of topics in the model, ensuring a good prediction ability and isolation between topics (Gan & Qi, 2021). The following calculations are used to calculate model *perplexity* (Gan & Qi, 2021) and *internal consistency* (Röder et al., 2015):

$$Perplexity(D) = \exp\left(\frac{-\sum_{d=1}^{M}\log P(W_d)}{\sum_{d=1}^{M} N_d}\right) \tag{3}$$

$$C_{\text{UMass}} = \frac{2}{N(N-1)}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\log\frac{p(wi,wj)+\epsilon}{p(wj)} \tag{4}$$

In Eq. (3), *Perplexity* measures the model's ability to predict unseen documents, with lower values of perplexity implying better predictive performance of the model, where *M* denotes the number of documents in the text set *D*, N_d is the number of words contained in document *d*, $\sum_{d=1}^{M} N_d$ is the sum of the number of words in the document set *D*, $P(W_d)$ is the probability of a word being produced in document *d*.

Internal consistency measures the semantic similarity between words within a topic. Higher consistency values usually mean that the words in a topic are more semantically related. Therefore, themes are more accessible for interpretation. In this study, the summation of *UMass coherence* accounts for ordering among the top words of a topic. In Eq. (4), *N* denotes the number of words in the topic, *wi* and *wj are* the words in the topic. p (*wi, wj*) is the probability of two simultaneous occurrences computed from the current set of documents, and *p*(*wj*) is the probability of occurrence of the word *wj*, ϵ is added to avoid a logarithm of zero.

The evaluation metrics were subsequently examined to identify the topics associated with the model that exhibited the lowest perplexity and highest internal consistency score. This determination is essential for further ascertaining the word distribution within each topic. Initially, each word within the document was randomly assigned to a topic. Subsequently, the following steps are executed for each word in the document. For the present word, assuming that the topic assignments for all other words are accurate, the topic is reassigned to the current word based on the following probabilities (Griffiths & Steyvers, 2004):

$$p(topic_k|current_{word}) \propto \left(n_{k,word} + \beta\right) \times \frac{n_{k,doc} + \alpha}{n_k + V \times \beta} \qquad (5)$$

Where $n_{k,word}$ represents the number of times the word occurs in topic k, $n_{k,doc}$ is the number of words assigned to topic *k* in a single document, n_k is the number of total words assigned to topic k, *V* represents the number of vocabulary lists, α and β are parameters of the Dirichlet distribution. After several iterations, the converged result is as follows (Heinrich, 2005):

$$p(word|topic_k) = \frac{n_{k,word} + \beta}{\sum word^{(n_{k,word}+\beta}} \qquad (6)$$

The distribution of topics for each document and the distribution probabilities of words for each topic can be obtained.

3.3.3 Eye-Tracking

The purpose of this study was to explore how individuals make evacuation paths, that is, their gaze preference for visual clues and the cognitive processing process of the surrounding environment. Eye tracking indicators were set, and these eye-tracking metrics were used to understand why certain cues were prioritized over others during evacuation. This integration allowed for an in-depth analysis of cognitive processing and attention distribution in real-time evacuation scenarios. The eye movement data collected during the experiment were analyzed using **Tobii Pro Lab Analyzer** software, which enables quantitative visualization of the results or extraction of statistical indicators of eye tracking. The analysis interface is shown in Fig. 10.

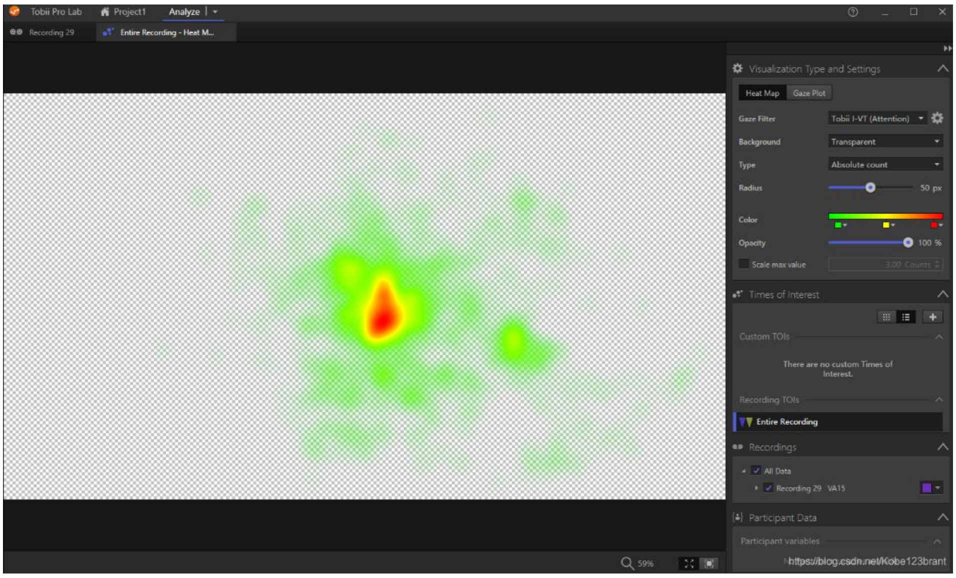


Fig. 10. Data analysis software interface.

This section includes several key factors, including basic information and eye metrics, as listed in Table 2. Eye tracking metrics, such as fixation duration and gaze points, provided quantitative data on where participants directed their attention, particularly at critical junctions and exits. These metrics offered insights into decision-making cues, such as whether participants focused more on exit signs or the movement of others, thus reflecting their reliance on environmental versus social cues. Welch's t-test was used to evaluate and compare the attention distribution and visual changes of different participants. A correlation analysis was used to explore the relationship between an individual's basic characteristics and attention distribution. Through sequence analysis, differences in the cognitive order and ways of different individuals at decision-making nodes were further explored.

The purpose of this study was to compare gaze preferences in evacuation path selection among different individuals and analyze participants' cognitive processing at decision nodes. Before extracting eye metrics, dynamic areas of interest (AOIs) were identified and set. In various eye tracking studies, researchers can manually delineate the areas of key elements based on the research question and experimental design. These delineated areas are referred to as areas of interest (AOIs) (Eraslan et al., 2020). Five commonly observed objects during the experiment were designated as AOIs: the ground, the following people, corridor walls, and safety exits, as well as other objects such as stairs. Welch's t-test is used to evaluate and compare the attention distribution and visual changes across these five AOIs among different participants. Correlation analysis was conducted to explore the factors that influence individual attention distribution, and sequence analysis was employed to further investigate differences in cognitive sequences and patterns among individuals at decision nodes. The quantification of the attention distribution and preferences mentioned above was achieved through eye-tracking metrics, with the individual basic information and eye-tracking metrics included in the correlation analysis presented in Table 2.

Table 2 Basic information and eye tracking metrics

Factors	Variables	Source
Background information	Familiarity with the layout of the building; Sense of direction; Directional anxiety	Pre-experiment Questionnaire
Eye metrics	Fixation count, Mean fixation duration and Visual attention index	Eye-tracking device

Eye metrics within predefined AOIs were measured and recorded at regular time intervals. The eye metrics used in this study are defined as follows:

Dwelling time (DT): The total time (ms) that participants spent fixating on a specific AOI. A longer dwelling time indicated that participants allocated a significant amount of visual attention to a certain object.

$$DT_j = \sum_{i=1}^{n} (ET_{ij}\ ST_{ij}) \quad (7)$$

where DT_j denotes the dwell time of the jth AOI, and ET_{ij} and ST_{ij} represent the ending and starting times of the ith fixation of the jth AOI, respectively.

Fixation counts (FC): The total number of recorded gaze points within a defined AOI. The greater the number of fixations counts, the more important the AOI is.

Mean fixation duration (MFD): The average value of the fixation duration (ms), calculated by dividing the total dwell time by the number of fixation counts.

$$MFD = \frac{DT}{FC} \quad (8)$$

Visual attention index (VAI): This index is defined as the proportion of the total fixation duration relative to the time spent in saccades. A smaller VAI value indicates that participants spent more time engaged in visual searching rather than recognition.

$$VAI_j = \frac{DT_j}{ST_j} \tag{9}$$

Where VAI_j denotes the visual attention index for jth AOI and ST_j is time (ms) spent in saccades.

Sequence analysis refers to the encoding and analysis of gaze sequence in eye movement trajectory to identify fixed paths or rules between gaze points. Through encoding sequence, the research can systematically compare the paths of different observers in visual tasks or compare the paths of the same observer in different tasks (Brandt & Stark, 1997; Foulsham & Underwood, 2008). In sequence analysis, gaze paths are typically broken down into sequences that are represented by symbols. For example, if areas of interest in an evacuation scenario are labeled as ground (g), safety exit (e), and following people (p), then the observer's gaze order in this scene might form a sequence such as "gpeg". Sequence analysis can reveal which areas of interest are prioritised by observers, and which sequence of focus on these areas may be critical to task completion.

Sequence analysis was used to further analyze the cognitive processing of the subjects at the key nodes in the evacuation process. This study examined the difference between the herding individuals and the non-herd individuals in choosing the evacuation path by dynamically tracking their gaze (Bahil et al., 1975), the analysis method was transition probability analysis. In this method, researchers construct a transition probability matrix to quantify the transition frequency between various states in a sequence (such as behaviours and gaze regions). By calculating the probability of each transition and its corresponding Z-score, we can determine whether the transition occurs significantly more often than chance. The specific analysis steps were as follows. First, the transition frequency between each state in the sequence was recorded and a transition matrix was constructed, where each cell represented the frequency of transitions from one state to another. The likelihood of each transition occurring was then determined by normalizing the transition frequencies into probabilities. For each transition, the Z-score was calculated to assess its significance. The higher the Z-score, the more likely the transition was to be significant compared with random chance, suggesting that it may be part of a behavioural pattern rather than a random event. When the Z-score exceeded 1.96, it was typically considered statistically significant ($p < 0.05$), indicating that the transition was a key part of the behavioural pattern. This may indicate that the transitions from one behaviour to another are significant rather than occurring by chance. In complex tasks or dynamic scenes, transition probability can reveal the strategic preferences of observers (Anderson et al., 2015; Cristino et al., 2010).

Chapter 4-Results of video camera and questionnaire

4.1 Video camera

Through the video recording of the evacuation process, typical behaviours, including transcendence behavior and aggregation behaviour, were observed in this study, as shown in Figs. 11a and 11b. The herding tendency in the evacuation process can be understood as the tendency towards mass behaviour (Helbing et al., 2000), Figs. 12(a), 12(b), and 12(c) successively present three stages: leaders' choice of evacuation route, group's analysis and judgment of evacuation route, and group's choice of evacuation route. It can be seen that the participants close to the leader hesitated about the path chosen by the leader, but most people who came later chose another route. Finally, the participants close to the leader chose to follow the evacuation decision of the majority. The video data initially showed the emergence of herding behaviour.

(a) (b)

Fig. 11. Typical behaviour in evacuation process.

Fig. 12. Screenshot of the process of herding tendencies.

4.2 Questionnaires

Careless response patterns, such as straight lining and consistent acquiescence/negative response styles, were screened (Curran et al., 2016). In total, 307 valid questionnaires were completed. Basic information on the participants is shown in Table 3. It can be seen that 93.4% of the participants have experience in emergencies and 6.6% have no such experience.

Table 3 Demographic characteristics of survey participants.

Demographic characteristics	Classification	Frequency	Percentage
Age	18 or below	203	66.30%
	19-22	104	33.70%
Gender	Male	231	75.20%
	Female	76	24.80%
Experience in evacuation drills	Yes	232	75.50%
	No	75	24.50%

Experience in emergency	Yes	287	93.40%
	No	20	6.6%

4.2.1. Individuals' difference in evacuation route choice and exits

The comparison results between the pre- and post-evacuation questionnaires revealed a shift in evacuation decision-making (See Table 4). Initially, most participants (70.1%) were inclined to formulate a rational evacuation plan. However, after participating in the evacuation drill, some participants changed to opt for the path that was taken in the drill, resulting in an increase in the proportion of participants choosing to follow the majority of the group, reaching 16.6%. Simultaneously, there was a decline in the percentage of people relying on signs during evacuation to 46.2%. These numerical shifts signify that in addition to the emergence of herding tendencies, other potential factors can also diversify evacuation routes.

Table 4 Comparison of evacuation route choices before and after evacuation drill.

Evacuation route options	Pre-evacuation (percentage)	Post-evacuation (percentage)
Follow the crowds	24 (7.8%)	51 (16.6%)
Familiar routes	38 (12.3%)	83 (27.0%)
Low-traffic routes	29 (9.4%)	32 (19.4%)
Follow the route indicated by evacuation signs	216 (70.1%)	142 (46.2%)

Total	307 (100%)	307 (100%)

4.2.2. Individual differences in factors influencing herding behaviour

The research first investigated the impact of leaders' traits on herding behaviour, such as gender, personality traits, and collective consciousness, on the herding behaviour of other participants. The herding probability was defined as the proportion of participants who followed the majority in the experiment to the total number of participants. Considering the small sample size of the 11 leaders, The Mann-Whitney U test was conducted to examine the effects of a leader's gender and evacuation experience on herding behaviour, whereas the Kruskal-Wallis test was conducted to examine the effects of personality traits on herding behaviour. Spearman's rank correlation coefficient was conducted to test the relationship between collective consciousness and people's herding behaviour. The results showed that gender significantly affected herd behaviour (Z=1.978; P=0.048*), with female leaders eliciting higher herding than male leaders. The correlation between collective consciousness and the herding behaviour was insignificant (r=0.15, P=0.659). Evacuation experience and personality traits did not have a significant impact on herding behaviour (Z=1.327; P=0.185; Z = 4.08, P= 0.395>0.05).

Owing to the limited impact of leaders, other factors in the questionnaire were explored to determine their impact on participants' herding behaviour. These factors included personality, sense of direction, directional anxiety, familiarity with the environment, and visibility. Except for the nominal personality variables, the remaining variables were continuous variables. One-way ANOVA was used, and the corresponding results showed significant differences in herding behaviour among personality types (F (5, 300) =3.191; P=0.008<0.05; η^2=0.050). Specifically, introverted participants exhibited a herding tendency (M=−0.61, SD=0.84) compared to extroverted participants (M=−0.17, SD=0.67) and emotional participants (M=−0.03, SD=0.68). Introverted individuals preferred to adhere to their plans and judgments when devising evacuation routes, displaying reduced susceptibility to the influence of the surrounding environment and others. In contrast, extroverted individuals tended to engage with the external environment during evacuation, remaining susceptible to the opinions of the surrounding group, potentially leading to changes in their decisions to align with the majority for escape.

For variables such as sense of direction, directional anxiety, leadership, familiarity with the environment, and visibility, Pearson's correlation analysis was used to describe the connection between these variables and herding behaviour. As evident from the results of the Pearson correlation analysis, as shown in Fig. 13, visibility exhibited a significant positive correlation (r=0.176, P<0.05) with herding behaviour, signifying that participants were inclined to follow the crowd in situations characterised by high visibility. Other factors, such as familiarity with the environment and directional anxiety, showed no significant correlations with herding behaviour, which is consistent with the findings of previous studies (Haghani & Sarvi, 2019; Xie et al., 2020). This outcome may stem from the fact that the subjects had heightened familiarity with the building's layout and preferred to devise the evacuation route instead of following the crowds in the evacuation.

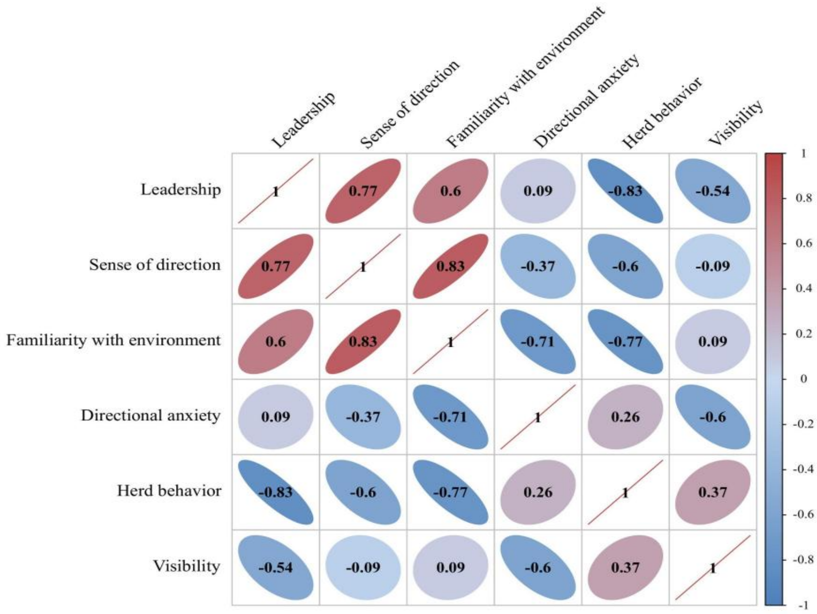


Fig. 13. Correlational Analysis of Sense of Direction, Direction Anxiety, Leadership, Environmental Familiarity, Visibility and Herding Behaviour.

4.2.3. Factors affecting evacuation route selection

Multinomial Logistic Regression was employed to assess the influence of various factors on the choice of evacuation routes, which are category variables, and to discern the preferences and patterns in selecting evacuation routes during evacuations. The input variables included herding behaviour, leadership, directional anxiety, sense of direction, emergency experience, evacuation drill experience, familiarity with evacuation sites, personality, age group, and gender, with the output variable being evacuation route selection. Four evacuation routes can be selected: following the stream of people, a familiar evacuation route, an evacuation route to avoid people flow, and an evacuation route guided by evacuation signs. The route of following the stream of people was selected as a reference.

As the first step of Multinomial Logistic Regression, the likelihood ratio chi-square test was performed, and the results indicated the model's validity, with statistical significance ($\chi^2(30)=68.755$, *P*=0.000). To further understand how these factors affect the choice of evacuation routes, the Maximum Likelihood Method was used to estimate the parameters. The results are shown in Table 5. Herding behaviour had a significant negative impact on participants choosing the route guided by evacuation signs ($\beta = -0.816$, *P*=0.014, 95%CI=[0.231, 0.846]) compared to choosing the route following the stream of people. Specifically, compared with the likelihood of participants following a stream of people, herding behaviour was more likely to inhibit the likelihood of participants following evacuation signs ($OR=0.442<1$). Leadership, directional anxiety, and sense of direction exhibited a significant positive correlation with evacuation routes guided by evacuation signs (β=0.682; 0.747; 0.530, *P*=0.011; *P*=0.011; *P*=0.045, 95%CI=[1.169, 3.345]; 95%CI=[1.183, 3.768]; 95%CI=[1.013, 2.851]). These results indicated that high leadership, high directional anxiety, and individuals with a strong sense of direction tended to rely on objective external environmental information, such as evacuation signs, to formulate evacuation routes. The overall prediction accuracy of the results obtained using Multinomial Logistic Regression was 71.66%, thereby demonstrating the reliability of the method.

Table 5 Summary of Multivariate logistic regression analysis results

Evacuation	Variables	β	SE	P	OR	95%CI

routes						
Familiar evacuation route	Herding behaviour	−0.457	0.368	0.215	0.633	[0.308, 1.303]
	Leadership	0.296	0.307	0.335	1.344	[0.737, 2.452]
	Directional anxiety	0.412	0.338	0.224	1.509	[0.778, 2.929]
	Sense of direction	0.199	0.309	0.520	1.22	[0.666, 2.235]
Evacuation route to avoid people flow	Herding behaviour	−0.813	0.412	0.049*	0.444	[0.198, 0.995]
	Leadership	0.674	0.354	0.057	1.962	[0.980, 3.925]
	Directional anxiety	0.366	0.375	0.328	1.443	[0.692, 3.007]
	Sense of direction	0.690	0.338	0.041*	1.994	[1.028, 3.868]
Evacuation route guided by evacuation signs	Herding behaviour	−0.816	0.331	0.014*	0.442	[0.231, 0.846]
	Leadership	0.682	0.268	0.011*	1.977	[1.169, 3.345]
	Directional anxiety	0.747	0.295	0.011*	2.112	[1.183, 3.768]
	Sense of direction	0.530	0.264	0.045*	1.699	[1.013, 2.851]

Note. * $P<0.05$ ** $P<0.01$

Chapter 5 - Results of the interview and text mining

5.1 Basic information about the interviewee

Basic information on the subjects is presented in Table 6. The following conclusions can be drawn from the content of the statements:

1) 96% of the interview participants participated in evacuation drills, with 59% participating in fire drills, 24% in fire and earthquake drills, 10% in earthquake drills, and only one in flood drills. Exercises for fires and earthquakes are commonly performed, whereas other emergency drills are rarely formulated and implemented.

2) All interview subjects acknowledged alterations in their decision-making during evacuation for different reasons. There, 26% of the subjects modified their initial evacuation route due to external environmental factors like visibility. 33% of the subjects have a normative herding style; to meet the expectations of the people around them, they choose to follow the rules of the vast majority. 41% of the subjects aligned with the informational herding style, which endorsed the conclusions of herding style elucidated by Toelch (2015), leaning towards accepting evacuation information from others, believing that it can aid in devising an improved evacuation path. The interview included four additional subjects who reported that their decisions did not change in the questionnaire survey. They explained why the decision was not changed, the selected evacuation route, and the reasons for choosing a specific evacuation route. Based on the interview results of the participants. The reason for their unchanged decision-making was related to the information reserve for self-cognition. They believed that they had more information or were more reliable than those around them, leading them to choose not to follow the crowd. Comparing

these results with those of the herding participants, more evidence was found that the initiation of herding behaviour may stem from an individual's expectation of obtaining information from others.

3) Regarding the pivotal factors influencing safe and optimal evacuation, evacuation drill experience was deemed the most critical factor (32%), followed by familiarity with the building' s layout (28%) and the direction of people' s movement (22%).

Table 6 Characteristics of interviewees and factors affecting safety evacuation.

Subject No.	Gender	Evacuation drill experience	Herding style	Selection of exits	Factors for making the fastest evacuation choices and escaping
Q1	Male	Fire drills	/	Uncrowded exits	Location of exits, type of emergencies
Q2	Male	Fire drills	/	Uncrowded exits	Sign, familiarity with building layout
Q3	Male	Fire drills; Flood drill	Informative	The exit that most people choose	Evacuation drill experience, crowd orientation, types of emergencies
Q4	Female	Fire drills	Normative	The exit that most people choose	Flow direction; familiarity with building layout
Q5	Female	Fire drills	Normative	The exit that most people choose	Evacuation drill experience; Sign
Q6	Male	Fire drills	Normative	The exit that most people choose	Location of exits

Q7	Female	Fire drills; Flood drill	/	Uncrowded exits	Evacuation instruction
Q8，Q19	Male	Fire drills	Informative	The exit that most people choose	Familiarity with building layout
Q9	Female	Fire drills	Informative	The exit that most people choose	Flow direction
Q10	Female	Fire drills	Informative	The exit that most people choose	Evacuation instruction
Q11	Male	Earthquake drills	Informative	The exit that most people choose	Flow direction; Evacuation drill experience
Q12,Q17, Q20	Male	Earthquake drills	Normative	The exit that most people choose	Evacuation drill experience
Q13	Female	Fire drills	Informative	The exit that most people choose	Flow direction; Evacuation drill experience

Q14	Male	Fire drills	Normative	The exit that most people choose	Sign
Q15,Q18, Q28	Male	Fire drills. Earthquake drills	Informative	The exit that most people choose	Flow direction
Q16	Male	Fire drills	/	Uncrowded exits	Familiarity with building layout
Q21	Male	Fire drills	Informative	The exit that most people choose	Sign; Evacuation drill experience
Q22	Male	Fire drills	Normative	The exit that most people choose	Flow direction; Evacuation instruction
Q23	Male	Fire drills	Normative	The exit that most people choose	Flow direction; Location of exits
Q24	Male	Fire drills. Earthquake drills	/	Uncrowded exits	Evacuation instruction
Q25, Q27	Male	/	Informative	The exit that most people choose	Familiarity with building layout

Q26	Male	Fire drills	/	The exit that most people choose	Familiarity with building layout; visibility
Q29, Q32	Male	Fire drills	Informative	The exit that most people choose	Evacuation drill experience
Q30	Female	Fire drills. Earthquake drills	Informative	The exit that most people choose	Sign; Familiarity with building layout
Q31, Q34	Female	Earthquake drills	/	Uncrowded exits	Evacuation drill experience
Q33	Male	Fire drills	/	Uncrowded exits	Visibility
Q35	Female	Fire drills. Earthquake drills	Informative	The exit that most people choose	Evacuation drill experience; Flow direction
Q36	Male	Fire drills	Normative	The exit that most people choose	Evacuation drill experience
Q37	Male	Fire drills; Earthquake drills	Informative	The exit that most people choose	Evacuation drill experience

Q38	Female	Earthquake drills	Normative	The exit that most people choose	Evacuation drill experience; Familiarity with building layout
Q39， Q49	Male	Fire drills; Earthquake drills	Normative	The exit that most people choose	Familiarity with building layout
Q40,Q42, Q47	Male	Fire drills; Earthquake drills	Informative	The exit that most people choose	Evacuation instruction
Q41	Male	Fire drills	/	Uncrowded exits	Sign
Q43	Female	Fire drills; Earthquake drills	Normative	The exit that most people choose	Sign
Q44	Female	Fire drills; Earthquake drills	Normative	The exit that most people choose	Location of exits
Q45	Male	Fire drills		Uncrowded exits	Familiarity with building layout
Q46	Male	Fire drills	Informative	The exit that most people choose	Leader

Q48	Female	Fire drills; Earthquake drills	/	Uncrowded exits	Familiarity with building layout
Q50	Male	Fire drills	/	Uncrowded exits	Sign; Location of exits

5.2. High-frequency word nephogram

A word cloud was created (Fig. 13) to visualize the most frequently used terms in our interview texts. In this visualization, terms with larger fonts indicated a higher frequency of appearance in the interviews, highlighting their significance in the context of building evacuation. From Fig. 14, it can be concluded that individuals are primarily concerned with devising safe exit strategies and evacuation routes, and certain factors such as visibility, herding, and prominent familiarity influence the evacuation process. It is not reasonable to rely on word frequency alone to construct a topic matrix because some commonly used words may have a high word frequency; however, it does not reflect the importance and uniqueness of a word. In this study, the Latent Dirichlet Allocation (LDA) topic model was introduced to identify potential topics for building evacuation.

Fig. 14. Cloud map of evacuation words.

5.3. Evaluation of LDA topic model and determination of topic numbers

Based on the initial analysis of the interview text, text mining was utilised in this study to further extract the themes of the personnel evacuation process and the related evacuation elements within each hot topic. To do this, using the LDA method, the perplexity and internal consistency was firstly obtained, and the relevant results are shown in Fig. 15.

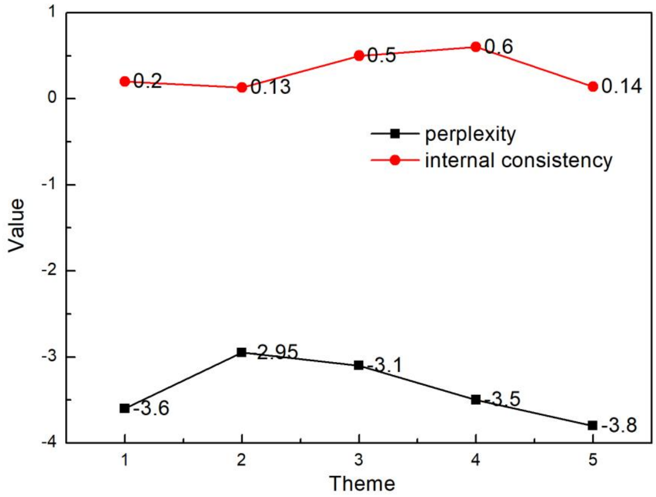


Fig. 15. Trends in perplexity and internal consistency with Changes in the Number of Themes.

From Fig. 15, it is evident that the lowest perplexity and the highest internal consistency were achieved when the number of topics was 5 and 4, respectively. With high internal consistency, the topics extracted from text mining can be regarded having the most significant influence on the evacuation process. Therefore, the total number of topics were set as 4. After the total number of topics was identified, Python's Gensim library was employed to create a word distribution for each topic (See **Appendix**), ranking the topic words based on their probability. The meanings conveyed by these words were synthesised, and closely related words were condensed into four representative topics of which the names were generated. The results for the four topics, related topic words, and corresponding distribution probabilities are shown in Table 7.

Table 7 Topic-feature word distribution in the field of evacuation

Evacuation decision and route selection (Topic 1)		Drill Evacuation experience (Topic 2)		Evacuation commander (Topic 3)		Mechanism of decision-making change (Topic 4)	
Words	Distribution Probability	Words	Distribution Probability	Words	Distribution Probability	Words	Distribution Probability
Evacuation	0.157	Evacuation alarm	0.09	Evacuation instructions	0.069	Follow	0.075
Routes	0.094	Earthquake	0.045	Leader	0.049	Evacuation	0.065
Sign	0.055	Fire	0.042	Surroundings	0.038	Routes	0.063
Information	0.045	Number of drills	0.039	Smoke	0.031	Junction	0.06
The fastest	0.045	Escape	0.032	Guidance	0.029	Decision-making	0.058
Environmental familiarity	0.039	Vast majority	0.03	Level of emergency	0.028	Visibility	0.05
Safety	0.034	Evacuation	0.024	Crowded	0.026	Change	0.036
Visibility	0.026	Visibility	0.023	Authoritative	0.021	Exits	0.034

Utilizing LDA modeling, four distinct topics were identified. For instance, Topic 1 delved into the factors influencing the planning and selection of evacuation routes. These topics offer structured data comprehension and align with overarching research objectives. Among the 50 subjects in the interview, the approach to planning escape routes relied on external environmental factors such as visibility, evacuation signs, and familiarity with the environment, emphasizing the shortest and safest route carefully designed during evacuation. Topic 2 shed light on the prevalence of evacuation drills, detailing the subjects' experiences and understanding of such drills, with earthquakes and fires being the most common scenarios. Most participants engaged in multiple evacuation drills and had some knowledge of the process and significance of these drills. It was generally agreed that the sounding of the evacuation alarm signaled drill initiation. Topics 3 and 4 were centered on finer aspects of the evacuation process. Topic 3 underscored the significance of having an evacuation leader, as the presence of heavy smoke during evacuation could elevate anxiety and tension, potentially leading to unfavorable outcomes such as crowding. An authoritative and trustworthy leader could provide a safer evacuation plan for the group, especially when subjects believed in their capacity to formulate such a plan based on the severity of the emergency. Conversely, Topic 4 focused on decision points during evacuation, such as intersections, highlighting how subjects' decision-making could shift in response to reduced visibility, aligning with the majority's direction, and ultimately collaborating with the group to reach a safe exit.

Chapter 6 - Results of eye tracking

6.1 Basic information on the subjects

In this study, 11 participants were selected across 11 experiments, with one participant selected based on the experimental conditions. The 11 participants were divided into two groups: herding group and non-herding group. If a subject indicates a change in his/her decision-making and chooses the option regarding routes that follow the crowd's direction in the post-evacuation questionnaire, and the participant's actual path choice is confirmed through video recording, then the subject is considered to have a herding tendency. Table 8 presents the basic information of the 11 participants. Of the participants, 36% had participated in evacuation drills, and only 27% were familiar with the layout of the building. Among these 11 participants, five participants exhibited herding behaviour during the evacuation process.

Table 8 Demographic information of the subjects

No.	Experience of evacuation drills	Familiarity with architectural layout	Herding tendencies
1	no	general	Yes
2	no	general	Yes
3	no	general	Yes
4	no	not very familiar	No
5	yes	be familiar with	No
6	no	be familiar with	Yes
7	yes	general	Yes
8	no	general	No

9	no	general	No
10	yes	be familiar with	No
11	yes	not very familiar	No

6.2 Participants' cognitive differences when viewing different elements

To identify the attention distribution and visual changes of different participants while searching for evacuation routes, eye metrics, including the Visual Attention Index (VAI) and Mean Fixation Duration (MFD), were analysed and presented in Table 9. Given the unequal sample sizes of the herding and non-herding groups, Welch's t-test was used. This test was used to compare eye-tracking metrics (MFD and VAI) between the two groups (herding and non-herding) across two areas of interest (following the crowd and the physical environment). The physical environment AOI refers to the sum of the four areas of interest that describe the surrounding environment, except for the areas of interest of the following people. The results indicated that there were statistically significant differences between the two groups only in the visual attention index (VAI) of the physical environment AOI. This suggests that herding may influence an individual’s attention allocation to physical environments. Specifically, individuals with a tendency to conform allocated more gaze time to following the crowd, whereas those without a herding tendency distributed their attention equally across all areas of interest.

The results showed that there was a statistically significant difference between the two groups only in the Visual Attention Index (VAI) for areas of interest (AOI) in the physical environment. This suggests that herding behaviour may affect how individuals allocate their attention to the physical environment. Specifically, individuals with a tendency to conform exhibit significantly higher visual attention in areas of interest (AOI) within the physical environment than those without such a herding tendency. This indicates that herding individuals spend less time on the cognitive processing of elements in the surrounding environment and focus more on the groups they are following.

Table 9 Differences in individual fixation preferences

AOI	Eye Metrics	t	p
Following people	MFD	0.299	0.783
	VAI	0.506	0.646
Physical environment	MFD	1.336	0.271
	VAI	2.92	0.036

6.3 Factors affecting subjects' fixation preference

This study explored the relationship between participants' familiarity with the building layout, sense of direction, and directional anxiety, as expressed in the questionnaire, and their gaze preferences. In other words, it examines the individual traits that influence participants' gaze preferences. As shown in Table 10, the correlation analysis of factors affecting eye-tracking metrics revealed that participants who were more familiar with the building layout spent less time gazing at windows, railings, and other features at decision points during the evacuation process, with less cognitive processing. They spent less time following the group's gaze, indicating a tendency to plan their own evacuation route rather than relying on group decisions. Owing to their familiarity with their surroundings, their cognitive processing of environmental elements is shallower.

Table 10 Correlation analysis of influencing subjects' gaze preference

	Familiarity with the layout of the building	Sense of direction	Directional anxiety	MFD for following the individuals	VAI for following the individuals	FT for surrounding environment	MFD for surrounding environment	VAI for surrounding environment
Familiarity with the layout of the building	1							
Sense of direction	-0.045	1						
Directional anxiety	-0.17	-0.186	1					
MFD (following the individuals)	-0.710*	-0.195	-0.066	1				
VAI (following the individuals)	-0.384	-0.097	0.07	0.615*	1			
FT (surrounding environment)	0.554	0.053	-0.117	-0.202	-0.055	1		

MFD (surrounding environment)	0.064	-0.613*	0.047	0.385	0.155	0.555	1	
VAI (surrounding environment)	0.618*	0.145	-0.159	-0.22	0.109	0.918**	0.336	1

* p<0.05 ** p<0.01

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6.4 Cognitive processing process of individuals at decision-making nodes

The decision-making process and cognitive differences of participants during evacuation from a building were studied by comparing participants' Eye Movement Sequence Analysis. As shown in Fig. 16, the analysis results indicate a significant cognitive processing difference between these two groups (herding and non-herding groups). In non-herding individuals, the AOI transition sequence, specifically the gaze sequence from other objects (o) to the corridor wall (w) (o→w), was significant (z=2.44>1.96). The results indicate that individuals who follow their own evacuation decisions tend to observe the surrounding environment at decision points rather than focus on the group ahead. For herding individuals, however, their AOI transition sequence shows significant connections from the ground to other objects (o), such as stairs, and then to the following group (p) (z=2.17, 2.20>1.96). These findings suggest that, at decision points, they first observe the surrounding environment and then shift to monitoring the group's movements and reactions. When a visible exit appears within their field of view, their gaze shifts from the corridor wall (w) to the exit (e), rather than continuing to follow the group.

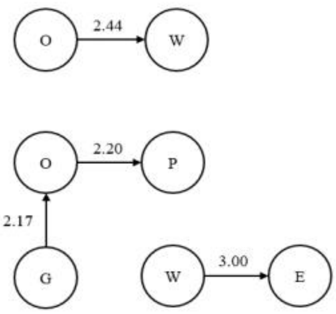

Fig. 16. Differences in gaze sequence between herding individuals and non-herding individuals.

Chapter 7 - Discussion

7.1 Generation and motivation of herding behaviour

This study examined evacuation patterns within buildings using questionnaires, interviews, and eye-tracking to understand the impact of herding behaviour. The results indicate that herding behaviour is prevalent during evacuations, especially at decision points such as intersections. At the decision points, individuals first observe the surrounding environment and then the group's movements and reactions. When a visible exit appears within the field of view, the gaze shifts from the corridor wall to the exit rather than continuing to focus on the group. Individuals tend to follow the crowd because of their limited access to evacuation information, which is influenced by external environmental conditions and individual psychological characteristics. Extroverted personalities increased herding behaviour, whereas low visibility reduced it. Female leaders were more likely to elicit herd behaviour. Herd behaviour hinders people from choosing efficient evacuation routes.

In identifying herd behaviour, the results of this study are consistent with the conclusions drawn by Lin et al. (2020) through virtual reality, confirming herding behaviour during the evacuation, especially at decision points such as intersections. Within the herding group, the primary motivation for most individuals to follow the crowd stems from a lack of personal evacuation information. They believed that cues from those around them could help them plan their escape route rather than feeling the need to adhere to group norms. This conclusion was consistent with the herding style theory developed by Toelch (2015). It is worth mentioning that the herding style theory was validated for the first time through an experimental study, as reported in this paper, highlighting the importance of clear evacuation instructions and comprehensive evacuation information for individual safe evacuation.

7.2 Factors affecting herd behaviour

During the evacuation process, individuals choose their evacuation path based on judgments of the surrounding environment and the direction of movement of people within a normal field of vision. Herding individuals do not decide to follow the crowd right away; instead, they first observe the corridor environment to gather escape information. Owing to the limited visibility of smoke in the corridor, the information that can be obtained is restricted. When a visible exit appears, their gaze shifts from the corridor wall to the exit, rather than continuing to follow the group. This finding highlights the importance of visible exits among the internal environmental elements in buildings. The findings of this study align with those of Vilar et al. (2014), showing that when environmental factors conflict with signage information, factors such as corridor width and brightness can influence route choices. However, as evacuation progresses, people increasingly tend to follow signage. This finding underscores the critical importance of visibility and the design of safety signs, especially exit signs, for evacuation efficiency. Priority often depends on both environmental factors and the effectiveness of the signage itself, suggesting that sign design should integrate behavioural assessments and environmental impacts.

Furthermore, this research comprehensively investigated the factors affecting the tendency to follow the crowd from the perspectives of external environmental conditions, individual psychological factors, and leaders. The results indicated that leader characteristics, such as gender, had a significant influence on herding tendency. Female leaders were more likely to elicit people's herding behaviour, which may be because women are more concerned with team dynamics and cohesion (Paustian-Underdah & Woehr, 2014). Evacuation experience, collective consciousness, and personality traits had a limited impact on herding behaviour. These results differ from those of previous studies. A possible reason is that, besides the leaders, the other participants were not entirely inexperienced (Colbert et al., 2012). Additionally, the weak effect of collective awareness may be because the group has reached a consensus to execute the evacuation drill rather than the leader forming a consensus through collective decision-making or discussion (Arnold et al., 2000). The lack of differences in leaders' personality traits may be due to different selections of personality trait dimensions. The scope of conscientiousness in the Big Five personality traits (Van Vugt & Spisa, 2008) differs from the scope of the extroverts that we adopted (Bain, 1860; Jung & Beebe, 2016). Future research should focus on selecting leader samples and measurement methods. For instance, ensuring the absolute expertise of the leader and considering the impact of other personality trait dimensions, such as the Big Five personality traits, on herd behaviour.

In addition to leaders, external environmental conditions and internal psychological factors play vital roles. Specifically, individual personality traits were key internal psychological factors affecting herding behaviour. This conclusion, obtained from the results of the questionnaires, is reported for the first time. Extroverted participants relied on the external environment for information and guidance and were more likely to follow the ideas of most people. The theories and dimensions of personality types are diverse (Chung, 2017), and it is unknown how personality traits under various theories influence herd behaviour. On the other hand, it was found that low visibility weakens people's herding tendency, based on the results of the questionnaires. However, this conclusion is inconsistent with the findings of previous studies (Shen et al. 2004). This may be because some physical conditions, such as indoor illumination, were not strictly controlled in this experiment; the smoke concentration in the experiment was not high enough to yield intensive herding behaviour.

7.3 Factors affecting evacuation route selection

The participants chose different evacuation routes for various reasons. The tendency to follow a crowd significantly influences an individual's choice of evacuation route. Other factors, such as sense of direction and leadership, also affected the selection and formulation of evacuation routes. Spatial sense, a dimension of spatial ability, affects pathfinding behaviour (Hegarty & Waller, 2004). The results of this study emphasized the role of spatial sense in evacuation from a teaching building, illustrating that vital spatial ability aids in swift route identification, undeterred by disorientation. A novel observation was that individuals with strong leadership independently judged and planned evacuation routes, often relying on reliable cues, such as evacuation signs. However, those with a high tendency for herding depended on their peers' decisions, often opting for more popular routes than the shortest ones indicated by evacuation signs. This finding highlights the harmful effects of herding, which contrasts with other studies (Delen & Crossland, 2008; Lovreglio et al., 2014; Shin & Shim, 2020). These studies emphasize the effective guidance of benign herding in emergency evacuations. This contrast could be caused by differences in experimental conditions, such as group size, familiarity with exits, social culture, and the environment, which were not the same as those in previous relevant studies (Haghani & Sarvi, 2019).

7.4 Comparison of the results of questionnaire survey and interview

An interesting finding of our study was that some interview conclusions diverged from the questionnaire survey results. The questionnaire results showed that individuals with strong leadership could devise relatively safe and swift evacuation routes. They relied more on the guidance of evacuation signs rather than following the majority's judgment. Similarly, the interview results affirmed the positive role of leaders, suggesting that authoritative leaders are convincing. However, some inconsistencies were also observed. The interview results indicated that the critical factors influencing the planning of evacuation routes included herding behaviour, building layout familiarity, and visibility. This diverged from the conclusions of the questionnaire survey, which indicated that familiarity with the building layout had no significant effect on evacuation route choice. These differences may be due to several reasons: 1) Time constraints and memory bias: the questionnaire was administered shortly after the evacuation, earlier than the interview, and respondents' answers may have been affected by memory bias. 2) Evacuation drill experience: Many interviewees who were acquainted with multiple drills and their procedures likely drew from past experiences when responding. 3) Sample variation: Unlike the questionnaire, all 50 interview participants displayed pronounced herding tendencies and exhibited similarities. 4) Social expectation: Social expectations might have led respondents to select options diverging from their true beliefs (Meisters et al., 2020). Based on the above analysis, it is evident that interviews are a solid supplement to questionnaire surveys, especially in studies that identify the influence of psychological factors on evacuation.

Chapter 8 - Conclusions and recommendations for future research

8.1 Conclusions

This study aims to explore behavioural patterns and underlying reasons for individual actions during building evacuation process， this study focuses on herd behaviour, including factors influencing herd behaviour, and its impact on path choices. The cognitive process behind individuals' different evacuation decisions, or path choices, is also examined. The research identifies herd behaviour through evacuation videos and questionnaires, using variance analysis, correlation analysis, and multiple logistic regression analysis to explore the factors affecting herd behaviour and its influence on evacuation route selection. Text mining and the Latent Dirichlet Allocation (LDA) model are used to identify key points and elements that individuals pay attention to during evacuation, supplementing and expanding the questionnaire results. Eye-tracking devices are employed to further investigate the decision-making process of individuals during evacuation process. The main conclusions are:

1. Herd behaviour usually begins at high-rise intersections. The main motivation for this behaviour is that the external environment, such as visibility intervention, leads to insufficient evacuation information, and individuals collect evacuation information from surrounding groups instead of following group norms.

2. Female leaders were more likely to elicit herding tendencies. Internal psychological characteristics, such as personality, and external environmental conditions, such as visibility, also played a role. Specifically, extroverted personalities increased herding behaviour, whereas low visibility reduced it.

3. Herding behaviour prevented individuals from selecting the shortest route,

demonstrating the detrimental effects of herding behaviour. Conversely, high leadership, directional anxiety, and a strong sense of direction encouraged individuals to choose the shortest route indicated by evacuation signs.

4. A micro-level analysis of individuals' cognitive processes during evacuation reveals significant differences in their attention distribution. Compared with other individuals, herding individuals do not keep their focus solely on the crowd ahead. Instead, they observe their surroundings, such as corridors and walls, to gather evacuation information. When external factors such as reduced visibility interfere with available information, individuals shift their attention back to the group's movements. However, when a visible exit appears within their field of view, their gaze shifts to the exit rather than continuing to follow the crowd.

5. Analysis of basic eye-tracking parameters, such as average fixation duration and the visual attention index, shows that non-herding individuals have roughly equal values for these metrics across all areas of interest, indicating a balanced attention distribution. In contrast, herding individuals have the lowest average fixation duration and visual attention index when following the crowd, suggesting a preference for focusing on the group and dedicating more visual attention to it.

6. Correlation analysis between eye-tracking metrics and questionnaire variables reveals that participants more familiar with the building layout spend more time fixating on elements like windows and railings at decision points, engaging in less cognitive processing. Individuals with a stronger sense of direction allocate less attention to processing their surrounding environment.

8.2 Recommendations for future research

8.2.1 Suggestions on the design and management of public buildings

Future research should focus on optimizing building layouts and guidance systems to facilitate safer evacuation during emergencies. The study found that herding behaviour was more pronounced on higher floors and complex layouts, which could impede efficient evacuation. Therefore, future research should investigate the following questions:

1) Optimization of evacuation signage systems and other guidance systems: Enhancing the visibility of evacuation signs is crucial for improving safety and efficiency during emergencies, especially in public buildings with high foot traffic, such as schools and office complexes. This study indicates that individuals relying on crowd actions rather than signage are particularly prevalent during evacuations, especially at key decision points in public buildings, such as intersections and stairwells. Considering the invisibility of signs caused by reduced visibility, the signs need to be clear and obvious, especially at junctions on higher floors, and brightly colored signs are set up at short intervals. Additionally, visual guidance points, such as brightly colored floor arrows or illuminated lines, can serve as intuitive markers that direct people toward the nearest exits. These cues should be positioned in areas where eye-tracking data indicates high attention, aligned with natural visual preferences. Future research could also explore the impact of different types of signage (e.g., size, color, and lighting) on evacuation efficiency under low-visibility conditions. By comparing these variables, studies can identify the most effective signage for various environmental conditions, thereby providing valuable insights and guidance for the interior layout design of different types of public buildings. Other guidance systems such as non-visual navigation systems: can mitigate information loss caused by crowd gathering. This study confirms the positive role of female leaders. Future sound systems such as announcements, alarms, and voice guidance systems that track and report on the movement of people in real time can

capture women's voices.

2) Improvement of architectural layout: The experiment was conducted in a university laboratory building. The widths of the evacuation passages in the building were inconsistent, including several narrow passages. The results indicate that herding behaviour impedes efficient evacuation, likely because of the pressure exerted by the passage widths. Narrower passages may enhance herding effects because individuals are more easily influenced by others' behaviour in confined spaces (Moussaïd et al., 2011). The layout of passages can also influence the flow of people (Heliövaara et al., 2013). For the renovation of existing buildings, a combination of Building Information Modelling (BIM) and intelligent monitoring systems can adjust the width of critical areas by evaluating the usage efficiency of each passageway (Martinez-Aires et al., 2018). Specifically, the three-dimensional model of the building is established through BIM, and the position and width of the adjustable partition wall are marked based on the densely populated area, so as to observe the evacuation situation of the simulated scene. In the application of new buildings, the designer could install interactive information boards at decision nodes (such as stairwells) to display real-time evacuation progress and optimal routes, thereby enhancing individuals' independent decision-making capabilities.

8.2.2 Suggestions on emergency preparedness and response strategies

The study results indicate that female leaders are more likely to prompt herd behaviour, possibly due to their stronger focus on team dynamics and cohesion. Future research could focus on female leaders and explore how training and education might enhance leaders' guidance abilities during emergency evacuations to improve group decision-making. Since this study examined only a limited set of leader traits, such as evacuation experience, collective consciousness, and personality, future studies should emphasize leaders' roles in fostering positive group herding, especially for individuals unfamiliar with building layouts. Further investigation of how leaders with diverse characteristics impact group evacuation could aid in developing more effective management strategies. Additionally, as this study involved participants with some familiarity with the building, future research could compare the visual attention patterns between evacuees with and without emergency drill experience to create more targeted guidance strategies. Special groups, including the elderly and children, also require attention to understand their unique visual behaviours during evacuation, enabling the design of strategies to address their specific needs. One of the findings of the interview was that although most participants had experience in evacuation drills, they only participated in fire drills, while other emergency scenarios such as earthquakes were rarely involved in evacuation drills. It is suggested that evacuation drills involving various emergency situations be conducted regularly to enhance people's ability to cope with different emergencies. In addition, to improve the effectiveness of evacuation training, VR and AR technologies can be used to create a virtual emergency evacuation environment and conduct more realistic emergency drills. This improvement not only allows participants to experience more realistic emergency evacuation scenes but also helps researchers observe the details of individual behaviour and group reactions, thus improving evacuation strategies.

8.2.3 Limitations of research design and improvements

This study is significant in its comprehensive exploration of individual behavioural patterns during the evacuation process in public buildings, focusing specifically on the impact of herding behaviour on evacuation path selection. By integrating multiple methods, including evacuation drills, surveys, interviews, and eye-tracking technology, this study provides a nuanced understanding of how environmental factors, such as visibility, and psychological factors, such as herding tendency, interact to shape individual decisions and path choices in emergencies. These insights reveal that in low-visibility or high-stress scenarios, individuals may rely heavily on group cues rather than signage, underscoring the importance of strategic building design and visible evacuation markers. The findings of this study provide valuable theoretical support and empirical data for optimizing public building layouts, improving emergency response protocols, and developing scientifically based evacuation guidance strategies. Such insights are essential for creating safer environments for schools, offices, and other high-traffic buildings. Despite its contributions, this study acknowledges certain limitations and suggests that future research should address these gaps and propose targeted solutions to enhance the robustness and applicability of evacuation strategies across diverse building types and populations.

First, this study had limitations in terms of both the experimental setting and sample selection. The university teaching building was chosen as the experimental site, and while the evacuation pathways met the minimum width requirement of 1.4 meters, the inconsistent widths of the corridors inside the building may have amplified the negative impact of the herding behaviour. Visual inconsistency in the layout might have influenced the participants' evacuation decisions, thus affecting the results. To address this, future architectural designs should focus on optimizing the width and layout of the evacuation routes to ensure more uniformity. Additionally, the sample selection in this study, which involved participants familiar with the building, may have constrained the degree to which herding behaviour was triggered. To enhance the validity of future research, more stringent experimental designs should be considered, such as by selecting participants who are completely unfamiliar with the environment. In addition, when conducting interviews on herding behaviour, researchers should use random sampling to ensure that the sample is representative and adopt standardized scales to quantify participants' herding tendency. Future studies should delve into individual differences in herding behaviour and explore how varying degrees of herding manifest across different participants and conditions. This would provide a more comprehensive understanding of the factors influencing herding and its effects on behaviour during an evacuation.

Second, there is considerable potential for improvement in both research methods and design. In this study, the dimensions used to measure the personality traits that influence herding behaviour were drawn from Bain (1860) and Jung & Beebe (2016). However, personality theories and dimensions are diverse, and the impact of different personality traits on herding behaviour remains unclear. To address this, future research should consider including a broader range of personality dimensions, such as the "Big Five" personality traits, which could offer deeper insights into how these traits influence individuals' tendencies to conform. By expanding the scope of personality traits studied, researchers could more accurately identify which characteristics are more likely to lead to herd, improving the ability to predict behaviour in group decision-making situations. In addition to refining the research design, advancements can be made in data analysis methods. The current approach primarily focuses on basic eye-tracking metrics, such as fixation and gaze duration, which, while helpful in understanding how visual attention is allocated, provide limited insight into the cognitive processing that occurs in complex environments. Future studies could adopt more sophisticated analytical techniques, such as time-series analysis of dynamic areas of interest (AOIs) and machine learning methods. Time-series analysis could offer a more detailed understanding of how attention shifts over time, especially at critical decision points, and reveal how herding behaviour develops in real time. Moreover, machine learning could be used to predict future behaviours or decisions based on eye-tracking data. By employing regression algorithms or deep learning models, researchers can forecast which areas participants are likely to focus on next, what path they might choose, or what decisions they are likely to make (Bulling & Roggen, 2011). These advancements would not only enhance the understanding of the mechanisms behind herding behaviour, but also contribute to the development of more personalized strategies for evacuation planning and behaviour interventions, offering practical applications in real-world settings.

Eye-tracking data provides valuable insights into how individuals allocate attention and engage in cognitive processing during emergency evacuations. It reveals that people who tend to conform typically first focus on their immediate surroundings, such as walls, corridors, and other environmental features, before shifting their attention to observe the actions of fellow evacuees. This pattern of cognitive processing highlights the importance of environmental awareness in high-pressure situations, where individuals prioritize gathering information about their surroundings before making decisions that are influenced by the group. This behaviour is especially evident in low-visibility conditions, where the ability to assess the environment is compromised, and making group dynamics more influential. Therefore, understanding how individuals can effectively access evacuation information when external cues are limited, particularly in poor visibility situations, becomes a crucial area for further investigation. Considering that this study focuses on the reduction effect of smoke cakes but ignores the intervention of its diffusion degree on the evacuation process, environmental factors, such as wind direction, can significantly affect the range and speed of smoke diffusion. In future studies, simulating smoke diffusion in a VR environment may be a viable approach. By presetting environmental parameters, such as wind speed and temperature, researchers can explore evacuation behaviour under conditions of control and consistent smoke diffusion velocity.

Although eye-tracking technology offers significant advantages in revealing how attention is distributed and cognitive processes unfold during an emergency, it may not fully capture the complexity of an individual's psychological state and decision-making processes. Relying solely on eye-tracking data might overlook other important factors, such as emotional responses and cognitive load, which can also influence behaviour during an evacuation. Therefore, future research should incorporate additional data-collection methods to create a more comprehensive understanding of how people react to stressful situations. For instance, physiological signals like heart rate variability and skin conductance response could be combined with eye-tracking data to provide a more nuanced picture of cognitive and emotional states (Benedek & Kaernbach, 2010). By measuring these physiological indicators, researchers could assess the level of cognitive load and emotional stress individuals experience in real time, leading to a better understanding of their decision-making processes during emergencies. This multidisciplinary approach could help develop more effective strategies for improving evacuation efficiency, ensuring that individuals receive the necessary information to make informed decisions, even under challenging conditions such as low visibility or high stress.

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Appendix

Questionnaire

This questionnaire aims to understand the emergency evacuation behavior of students in the event of an emergency, to improve the emergency plan for safety evacuation in universities. The questionnaire survey is divided into **Pre-Evacuation Questionnaire** and **Post-Evacuation Questionnaire**. **Pre-Evacuation Questionnaire** should be filled before the evacuation drill, and the **Post-Evacuation Questionnaire** should be filled in after the experiment.

This study is an anonymous survey and will only be used for scientific research and will not reveal your personal information. There are no good or bad options to choose from, please fill in the questionnaire with the actual situation, thank you for your cooperation.

Pre-Evacuation Questionnaire

Part I Basic Information

1. Gender:

○Male

○Female

2. Age: ___

3. Experiment number: ___

4. A class leader or not:

○Yes (Please skip to question 6)

○No

5. Your relationship with the class leader:

○ Intimate

○ More familiar

○ General

○ Unfamiliar

6. Closer classmates in class :___ [If not, fill in 0]

7. Have you experienced sudden events such as gas leaks, fires, etc. in a crowded state?

○Yes

○No

8. Have you participated in an emergency evacuation drill?

○Yes

○None

9. Your familiarity with the internal environment of Qiushi Building such as passageways, signage facilities, etc.:

○A Very familiar

○B Somewhat familiar

○C General (Please skip to question 11)

○D is not familiar (Please skip to question 11)

10. Please select the building environment and facilities you are familiar with:

☐ Evacuation routes

☐ Evacuation signs

☐ Safety exit

☐ Other __________

11. Choose the exits you use frequently [Select one or more answer choices]

☐Exit 1

☐ Exit 2

☐Exit 3

☐Exit 4

12. Your personality type:

○A. I like to think independently and will not be influenced by the opinions of others.

○B. Like to exchange opinions with others, easily influenced by the environment and other people.

○C. Judgment based on self-feelings, emotional, and easy to shift targets under the influence of external triggers.

○D. Use reason to dominate action rather than subjective emotions, and repeatedly weigh the pros and cons before acting.

〇E. Strong self-control, once the goal is established, it is not interfered by other factors.

〇F. The above types of characteristics are included.

13. You tend to use southeast and northwest to describe my surroundings.

〇A. Highly incompatible

〇B. Slightly incompatible

〇C. Not sure

〇D. Partially compatible

〇E. Fully compatible

14. You can usually remember a new route that you have walked only once.

〇A. Highly incompatible

〇B. Slightly incompatible

〇C. Not sure

〇D. Partially compatible

〇E. Fully compatible

15. You will act according to the new development plan, rather than waiting for others to take countermeasures.

〇A. Highly incompatible

〇B. Slightly incompatible

〇C. Not sure

〇D. Partially compatible

〇E. Fully compatible

16. To achieve the groups' goal, personal rest time, loss of benefits, and possible risks are bearable.

○A. Highly incompatible

○B. Slightly incompatible

○C. Not sure

○D. Partially compatible

○E. Fully compatible

17. When making decisions about class events, you tend to:

○A. Take the initiative to put forward your own suggestions and opinions, and collect the ideas of others

○B. Set aside your own thoughts and listen to the opinions of others.

18. Group members need to collaborate to complete an activity, in order to better accomplish the task. You:

○A. Clarify the work objectives and role division of the members to ensure the task is completed more effectively.

○B. Wait for the group to assign tasks and diligently complete your own part.

19. This is your first time in an office building with unfamiliar terrain and a very complex structure. You:

○A. Not anxious at all

○B. Not very anxious

○C. Moderately anxious

○D. Somewhat anxious

〇E. Extremely anxious

20. When you find yourself turning the wrong corner and getting lost, you try to go back to a familiar place. You:

〇A. Not anxious at all

〇B. Not very anxious

〇C. Moderately anxious

〇D. Somewhat anxious

〇E. Extremely anxious

Part II Evacuation behavior and decisions

21. When entering and exiting the school building, do you often actively observe evacuation signs, safety exits, or emergency escape routes?

〇A. Strongly disagree

〇B. Not very agreed

〇C. Uncertain

〇D. Somewhat agreed

〇E. Strongly agree

22. When an emergency occurs, your first response is:

☐A. Panic

☐B. Loses of sense of direction

☐C. Nervousness

☐D. Calm down

☐E. Others ________________

23. What is the most important factor that determines when you start to evacuate?

○A. The sound of the evacuation announcement

○B. Diffuse of smoke

○C. Actions of people around them

○D. Directive actions of the staff

24. Your possible reaction during evacuation:

○A. Find a place to hide nearby, such as a corner, toilet, etc

○B. Always stay with everyone

○C. Find a way out on your own

○D. Think calmly, make a correct judgment about the emergencies and guide everyone

25. During the evacuation process, you are forced to give up or change your thoughts and decisions under pressure from the surrounding group.

○A. Strongly disagree

○B. Not very agreed

○C. Uncertain

○D. Somewhat agreed

○E. Strongly agree

26. How would you choose the evacuation route?

○A. Follow the flow of people

○B. The passage that you are used to

○C. Avoid the flow of people and choose a passage with less traffic

○D. Follow the evacuation signs

27. Which exits do you prefer?

○A Exit with low flow of people and no congestion

○B. The exit closest to you

○C. Exit that is familiar for you

○D. The exit chosen by most individuals

28. During an evacuation, I would abandon the evacuation route I think is correct and conform to the behavior of the majority.

○A. Strongly disagree

○B. Not very agreed

○C. Uncertain

○D. Somewhat agreed

○E. Strongly agree

29. If the situation is extremely critical and the nearest safety exit to you is crowded, you would:

○A. Exit orderly with the crowd

○B. Desperately push forward to leave as quickly as possible

○C. Look for other available exits

○D. Organize classmates around you to look for other exits together

30. Whether wear glasses or not:

○Yes

○No

Post-Evacuation Questionnaire

1. Your experiment number is: _____

2. Reaction when you hear evacuation announcement: [Select one or more answer choices]

☐A. Nervousness

☐B. Anxiety

☐C. Loss of direction

☐D. Panic

☐E. Others ________________

3. When you hear the evacuation announcement, you:

○A. Go immediately

○B. Observe the behavior of people surrounding you

○C. Stay put, waiting for the command

○D. Notify others

○E. Others: __________

4. You encounter a fork in the road during evacuation and need to make a direction choice, please order the importance of the following factors that influence your direction choice: [Sorting questions, please fill in the numbers in parentheses] *

(Very important - almost useless)

[ ] A. Visibility of stairs

[ ] B. The direction of the flow of people

[ ] C. Direction indicated by evacuation signs

5. Effect of visibility on the evacuation process during evacuation.

○A. Not affected at all

○B. Slightly affected

○C. Uncertain

○D. Somewhat affected

○E. Highly impacted

6. Effect of evacuation signs on the evacuation process during evacuation.

○A. Not affected at all

○B. Slightly affected

○C. Uncertain

○D. Somewhat affected

○E. Highly impacted

7. There are multiple bifurcation positions, The direction chosen by most people:

○A. Not affected at all

○B. Slightly affected

○C. Uncertain

○D. Somewhat affected

○E. Highly impacted

8. You believe that most of your classmates are evacuating incorrectly, you would choose to follow most of your classmates, you:

○A. Strongly disagree

○B. Not very agreed

○C. Uncertain

○D. Somewhat agreed

○E. Strongly agree

9. Reflecting on the evacuation drill you just participated in; the safety exit you chose is :

□A Th exit with low flow of people and no congestion

□B. The nearest exit to you

□C. The exit that is familiar

□D. The exit chosen by most individuals

10. Reflecting on the evacuation drill you just participated in; the evacuation route you chose is:

○A. Follow the flow of people

○B. The passage that you are familiar with

○D. Avoid the flow of people and choose a passage with less people

○E. Follow the evacuation signs

11. Reflecting on the evacuation drill you just participated in; your evacuation style:

○A. Follow most people to escape

○B. Follow the evacuation signs to escape

○C. Organize the rest of the people to escape together

Semi-structured interview

1. Did your decision-making change during the evacuation process? If so, what was the reason for the change?

A. Physical exhaustion

B. Anxiety, wanting to find an exit sooner

C. Look for the nearest exit

D. Unfamiliarity with the route

E. Other: ____

2. What were your thoughts in the situation where visibility was reduced, and the evacuation information received was insufficient or unclear?

3. During the evacuation process, what factors helped you make the quickest decision on evacuation and enabled you to escape?

4. During the evacuation process, were the evacuation signs clearly visible? Did the evacuation signs play a significant role in your choice of evacuation route?

5. Did you choose to escape by following a friend you are familiar with?

6. During the evacuation process, your reason for following the majority of the crowd is:

A. Most students were taking similar actions; I didn't want to risk choosing a different route than the majority, so I kept in line with them, believing their evacuation decisions were correct.

B. I was unfamiliar with the evacuation route, unsure of the distance to the safety exit, and the evacuation information I had was vague. Others might have more evacuation information, which could help me make a decision.

7. Regarding the choice of a safety exit, which style do you belong to?

A. To evacuate as quickly as possible, I chose the least crowded exit.

B. I chose the most crowded exit to avoid evacuating alone. Since the behavior of most others is trustworthy, the safety exit they chose is the right one.

Gensim library in Python

Import package. The core package is re、gensim、spacya and pyLDAvis. In addition，we need to use matplotlib、numpy and panases for data processing and visualization.

```
import re
import numpy as np
import pandas as pd
from pprint import pprint

# Gensim
import gensim
import gensim.corpora as corpora
from gensim.utils import simple_preprocess
from gensim.models import CoherenceModel

# spacy for lemmatization
import spacy

# Plotting tools
import pyLDAvis
import pyLDAvis.gensim    # don't skip this
import matplotlib.pyplot as plt
%matplotlib inline

```

21. # Enable logging for gensim - optional

22. import logging

23. logging.basicConfig(format='%(asctime)s : %(levelname)s : %(message)s', level=logging.ERROR)

24.

25. import warnings

26. warnings.filterwarnings("ignore",category=DeprecationWarning)

Import stop words

27. # NLTK Stop words

28. from nltk.corpus import stopwords

29. stop_words = stopwords.words('english')

30. stop_words.extend(['from', 'subject', 're', 'edu', 'use'])

Import dataset

1. # Import Dataset

2. df = pd.read_json('https://raw.githubusercontent.com/selva86/datasets/master/newsgroups.json')

3. print(df.target_names.unique())

4. df.head()

Build Latent Dirichlet Allocation topic model

1. # Build LDA model

2. lda_model = gensim.models.ldamodel.LdaModel(corpus=corpus,

3. id2word=id2word,

4. num_topics=20,

5. random_state=100,

6. update_every=1,

7. chunksize=100,

8. passes=10,

9. alpha='auto',

10. per_word_topics=True)

Visualize the keywords for each topic and the weight of each keyword.

1. # Print the Keyword in the 10 topics

2. pprint(lda_model.print_topics())

3. doc_lda = lda_model[corpus]

Calculate the model's perplexity and coherence score

1. # Compute Perplexity

2. print('\nPerplexity: ', lda_model.log_perplexity(corpus)) # a measure of how good the model is. lower the better.

3.

4. # Compute Coherence Score

5. coherence_model_lda = CoherenceModel(model=lda_model, texts=data_lemmatized, dictionary=id2word, coherence='c_v')

6. coherence_lda = coherence_model_lda.get_coherence()

7. print('\nCoherence Score: ', coherence_lda)

Visualize topic-keywords

1.# Visualize the topics2. pyLDAvis.enable_notebook()3. vis = pyLDAvis.gensim.prepare(lda_model, corpus, id2word)4. Vis

Informed consent form

University of Nottingham Ningbo China

Research Ethics Checklist for Staff and Research Students

[strongly informed by the ESRC (2012) Framework for Research Ethics]

A checklist should be completed for every research project or thesis where the research involves the participation of people, the use of secondary datasets or archives relating to people and/or access to field sites or animals. It will be used to identify whether a full application for ethics approval needs to be submitted.
You must not begin data collection or approach potential research participants until you have completed this form, received ethical clearance, and submitted this form for retention with the appropriate administrative staff.

The principal investigator or, where the principal investigator is a student, the supervisor, is responsible for exercising appropriate professional judgement in this review.

Completing the form includes providing brief details about yourself and the research in Sections 1 and 2 and ticking some boxes in Sections 3 and/or 4, 5, 6. **Ticking a shaded box in Sections 3, 4, 5 or 6 requires further action by the researcher**. Two things need to be stressed:

- Ticking one or more shaded boxes does not mean that you cannot conduct your research as currently anticipated; however, it does mean that further questions will need to be asked and addressed, further discussions will need to take place, and alternatives may need to be considered or additional actions undertaken.
- Avoiding the shaded boxes does not mean that ethical considerations can subsequently be 'forgotten'; on the contrary, research ethics - for everyone and in every project – should involve an ongoing process of reflection and debate.

The following checklist is a starting point for an ongoing process of reflection about the ethical issues concerning your study.

SECTION 1: THE RESEARCHER(S)

1.1: Name of principal researcher:Minrui Ni

1.2: Status: ☐ Staff

☒ Postgraduate research student

1.3: School/Division: Faculty of Science and Engineering

1.4: Email address: Minrui.Ni@nottingham.edu.cn

1.5: Names of other project members (if applicable):

1.6: Names of Supervisors (if applicable):Liang Xia

	Yes	No
1.7: I have read the University of Nottingham's Code of Research Conduct and Research Ethics (2021) and agree to abide by it: code-of-research-conduct-and-research-ethics.pdf (nottingham.edu.cn)	☒	☐
1.8: (If applicable) I have familiarized myself with the "Internet Research: Ethical Guidelines 3.0" accessible at: http://aoir.org/reports/ethics3.pdf	☒	☐
1.9: When conducting research on people (Section 5) I will prepare both a participant consent form as well as a *participant information sheet.* I am aware that the following templates • "Participant consent form", and • "Participant Information Sheet", (English and Chinese) are available on the Ethics webpage: https://www.nottingham.edu.cn/en/research-and-business/ethics.aspx	☒	☐

SECTION 2: THE RESEARCH

2.1: **Title of project:**

Individual herding behavior in evacuation process in public building

2.2: **Research question(s) or aim(s)**

Aim 1: To understand the mechanism and process of herding tendency in the process of evacuation.

Aim 2: To explore the influence of herding behavior on the choice of evacuation routes and evacuation decisions.

2.3: **Summary of method(s) of data collection**

Method 1：survey collection

The participants are all college students, who have no adverse physical reactions and psychological inadaptive behaviors, have the ability of independent decision-making and evacuation-related knowledge and skills, and understand the purpose of the questionnaire survey. A total of 330 students will be selected for our research. The main contents of the questionnaire include individual demographic information, evacuation behavior and habits, and analysis of decision-making process.Firstly,the researcher first present the main information of the experiment to all participants, and how participating might affect him/her personally such as benefits, risks, and information about procedures adopted for ensuring data protection/confidentiality/privacy, including duration of storage of data. It must minimize the possibility of coercion or undue influence, and the subject must be given sufficient time to consider participation.

The questionnaire includes:

1) personal information

2) Evacuation habits (customary exit); Awareness of indication signs and safety exit signs, etc.)

3) Personal traits (sense of direction; Leadership style, etc.)

4) Characteristics of decision-making before and after evacuation (basis for choosing evacuation route; Have/have no herding tendency, etc.)

Data collected will be allocated a code to preserve anonymity where necessary. All information about participants will be kept strictly confidential. The only personal data will be the identification of participants for the consent process. Each participant will be given a unique number. The signed consent forms and the data collected will be stored in a secure location, accessible only to the researcher Minrui Ni and her supervisors at UNNC. No foreseeable ethical issues are anticipated.

Method 2：Eye data acquisition based on eye-tracking device.We will screen participants in order to wear the eye tracking device. The criteria for screening are: 1) Visual acuity of 1.0 or above and not wearing glasses in daily life. 2) As the subject of this study is to investigate the pattern of evacuation of people and to analyse the influence of herding behaviour on the choice of evacuation routes. Therefore, we will screen subjects with a high tendency to follow the crowd (score of 80 or above in the questionnaire).during the evacuation process. The eye movement data include the fixation area, the fixation duration, etc. The device is non-intrusive and harmless.

Method 3: Interview. After the experiment. Based on the questionaire, some participants will be asked to participate in the interview. The purpose of the interviews is to further understand the participants' mental activities and decision-making process during the evacuation. During the discussion, the potential participants can clearly talk with the researcher, understand the questions and have the ability to communicate his/her decision.

2.4: **Proposed site(s) of data collection**

The research place selected in this study is a university in Langfang, Hebei Province. The school needs to improve the evacuation emergency plan. In addition, there are many laboratories where chemicals are stacked in the school, so the prevention of safety accidents is very important.

2.5: **How will access to participants and/or sites be gained?**

To invite more residents to participate. We would contact the person in charge of the laboratory building, tell the purpose and process of this research, and get the full support of the partner. The partner provide us with experimental sites and healthy college students. We would provide an evacuation plan that considers individual psychological activities and states, hoping to provide evacuation guidance for our partner.

SECTION 3: RESEARCH INVOLVING USE OF SECONDARY DATASETS OR ARCHIVES RELATING TO PEOPLE

If your research involves use of secondary datasets or archives relating to people all questions in Section 3 must be answered. If it does not, please tick the ‘not relevant’ box and go to Section 4.

NOT RELEVANT	☒

Please answer each question by ticking the appropriate box.

	Yes	No
3.1: Is the risk of disclosure of the identity of individuals low or non-existent in the use of this secondary data or archive?	☐	☐
3.2: Have you complied with the data access requirements of the supplier (where relevant), including any provisions relating to presumed consent and potential risk of disclosure of sensitive information?	☐	☐

SECTION 4: RESEARCH INVOLVING ACCESS TO FIELD SITES AND ANIMALS

If your research involves access to field sites and/or animals all questions in Section 4 must be answered. If it does not, please tick the 'not relevant' box and go to Section 5.

NOT RELEVANT	☒

Please answer each question by ticking the appropriate box.

	Yes	No
4.1: Has access been granted to the site?	☐	☐
4.2: Does the site have an official protective designation of any kind?	☐	☐
If yes, have the user guidelines of the body managing the site a) been accessed?	☐	☐
b) been integrated into the research methodology?	☐	☐
4.3: Will this research place the site, its associated wildlife and other people using the site at any greater physical risks than are experienced during normal site usage?	☐	☐
4.4: Will this research involve the collection of any materials from the site?	☐	☐
4.5: Will this research expose the researcher(s) to any significant risk of physical or emotional harm?	☐	☐
4.6: Will the research involve vertebrate animals (fish, birds, reptiles, amphibians, mammals) or the common octopus (Octopus vulgaris) in any capacity?	☐	☐
If yes, will the research with vertebrates or octopi involve handling or interfering with the animal in any way or involve any activity that may cause pain, suffering, distress or lasting harm to the animal?	☐	☐

SECTION 5: RESEARCH INVOLVING THE PARTICIPATION OF PEOPLE

If your research involves the participation of people all questions in Section 4 must be answered.

Please answer each question by ticking the appropriate box.

A. General Issues

	Yes	No
5.1: Does the study involve participants age 16 or over who are unable to give informed consent? (e.g. people with cognitive impairment, learning disabilities, mental health conditions, physical or sensory impairments?	☐	☒
5.2: Does the research involve other vulnerable groups such as children (**<u>aged under 16</u>**) or those in unequal relationships with the researcher? (e.g. your own students)	☐	☒
5.3: Will this research require the cooperation of a gatekeeper* for initial access to the groups or individuals to be recruited?	☐	☒
5.4: Will this research involve discussion of sensitive topics (e.g. sexual activity, drug use, physical or mental health)?	☐	☒
5.5: Could the study induce psychological stress or anxiety or cause harm or negative consequences beyond the risks encountered in normal life?	☐	☒
5.6: Are drugs, placebos or other substances (e.g. food substances, vitamins) to be administered to the study participants or will the study involve invasive, intrusive or potentially harmful procedures of any kind?	☐	☒
5.7: Will this research involve people taking part in the study without their knowledge and consent at the time?	☐	☒
5.8: Does this research involve the internet or other visual/vocal methods where people may be identified?	☐	☒
5.9: Will this research involve access to personal information about identifiable individuals without their knowledge or consent?	☐	☒
5.10: Does the research involve recruiting members of the public as researchers (participant research)?	☐	☒
5.11: Will the research involve administrative or secure data that requires permission from the appropriate authorities before use?	☐	☒
5.12: Is there a possibility that the safety of **the researcher** may be in question?	☐	☒
5.13: Will financial inducements (other than reasonable expenses and compensation for time) be offered to participants?	☐	☒

**Gatekeeper- a person who controls or facilitates access to the participants*

B. Before starting data collection

	Yes	No

6.12: My full identity will be revealed to all research participants.	☒	☐
6.13: All participants will be given accurate information about the nature of the research and the purposes to which the data will be put. (*An example of a Participant Information Sheet is available for you to amend and use* at: *https://www.nottingham.edu.cn/en/research-and-business/documents/ethics/participant-information-sheet.doc*	☒	☐
6.14: All participants will freely consent to take part, and, where appropriate, this will be confirmed by use of a consent form. Consent Form is available, for you to amend and use, at: https://www.nottingham.edu.cn/en/research-and-business/documents/ethics/participant-consent-form.doc	☒	☐
6.15: All participants will freely consent to take part, but due to the qualitative nature of the research a formal consent form is either not feasible or is undesirable and alternative means of recording consent are proposed.	☐	☒
6.16: A signed copy of the consent form or (where appropriate) an alternative record of evidence of consent will be held by the researcher.	☒	☐
6.17: It will be made clear that declining to participate will have no negative consequences for the individual.	☒	☐
6.18: Participants will be asked for permission for quotations (from data) to be used in research outputs where this is intended.	☒	☐
6.19: I will inform participants how long the collected data will be kept.	☒	☐
6.20: Incentives (other than basic expenses) will be offered to potential participants as an inducement to participate in the research. Incentives include cash payments and non-cash items such as vouchers and book tokens.	☐	☒
6.21: For research conducted within, or concerning, organisations (e.g. universities, schools, hospitals, care homes, etc) I will gain authorisation in advance from an appropriate committee or individual.	☒	☐

C. During the process of data collection

	Yes	No
6.25: I will provide participants with my University contact details, and those of my supervisor (*where applicable*) so that they may get in touch about any aspect of the research if they wish to do so.	☒	☐
6.26: Participants will be guaranteed anonymity only insofar as they do not disclose any illegal activities.	☒	☐
6.27: Anonymity will not be guaranteed where there is disclosure or evidence of significant harm, abuse, neglect or danger to participants or to others.	☒	☐
6.28: All participants will be free to withdraw from the study at any time, including withdrawing data following its collection.	☒	☐
6.29: Data collection will take place only in public and/or professional spaces (e.g. in a work setting	☒	☐
6.30: Research participants will be informed when observations and/or recording is taking place.	☒	☐

6.31: Participants will be treated with dignity and respect at all times.	☒	☐

D. After collection of data

	Yes	No
6.32: Where anonymity has been agreed with the participant, data will be anonymised as soon as possible after collection.	☒	☐
6.33: All data collected will be stored in accordance with the requirements of the University's Code of Research Conduct	☒	☐
6.34: Data will only be used for the purposes outlined within the participant information sheet and the agreed terms of consent.	☒	☐
6.35: Details which could identify individual participants will not be disclosed to anyone other than the researcher, their supervisor and (if necessary) the Research Ethics Panel and external examiners without participants' explicit consent.	☒	☐

E. After completion of research

	Yes	No
6.37: Participants will be given the opportunity to know about the overall research findings.	☒	☐
6.38: All hard copies of data collection tools and data which enable the identification of individual participants will be destroyed.	☒	☐

If you have not ticked any shaded boxes, please send the completed and signed form to the School's Research Ethics Officers, with any further required documents, for approval and record-keeping.

If you have ticked *any* shaded boxes **you will need to describe more fully how you plan to deal with the ethical issues raised by your research**. Issues to consider in preparing an ethics review are given below. Please send this completed form to the Research Ethics Officer who will decide whether your project requires further review by the UNNC Research Ethics Sub-Committee and/or whether further information needs to be provided.

Please note that it is your responsibility to follow the University's Research Code of Conduct and any relevant academic or professional guidelines in the conduct of your study. This includes providing appropriate information sheets and consent forms, and ensuring confidentiality in the storage and use of data. For guidance and UK regulations on the latter, please refer to the Data Protection Policy and Guidelines of the University of Nottingham:

Policy and guidelines - https://www.nottingham.ac.uk/governance/records-and-information-management/data-protection/data-protection-policy.aspx

Any significant change in the project question(s), design or conduct over the course of the research should be notified to the School Research Ethics Officer and may require a new application for ethical approval.

Signature of Principal Investigator/Researcher:

Signature of Supervisor (where appropriate): Liang Xia

Date 23/12/2022

Research Ethics Panel response

☒ the research can go ahead as planned

☐ further information is needed on the research protocol (see details below)

☐ amendments are requested to the research protocol (see details below)

Please specify how you will select the participants with eye tracking device (Method 2 in page 3). Please complete the following A. LIST OF POINTS TO CONSIDER WHEN SUBMITTING AN ETHICS REVIEW in page 8 and 9.

Unit REO……Sherif Welsen…………Byung-Gyoo Kang… Date …02 Feb 2023………

A. LIST OF POINTS TO CONSIDER WHEN SUBMITTING AN ETHICS REVIEW (taken from ESRC (2012) Framework for Research Ethics).

Risks

1. Have you considered risks to:
    - the research team?
    - the participants? Eg harm, deception, impact of outcomes
    - the data collected? Eg storage, considerations of privacy, quality
    - the research organisations, project partners and funders involved?

The purpose of our study is to investigate the evacuation pattern of people and the research method is evacuation drills. All subjects have experience of the exercise and there is no deception or physical harm to the subjects themselves. The research team will work with the chemical engineering department of a university, and the chemistry laboratory director, the teacher of the course, is informed and help to contact the subjects who wish to participate.

2.Might anyone else be put at risk as a consequence of this research?

There will be no physical or psychological harm to any of the subjects participating in the experiment.

3. What might these risks be?

4. How will you protect your data at the research site and away from the research site?

Questionnaires will be locked, and the key will be kept in supervisor Liang Xia 's office. The data disposal will be conducted three years after Minrui Ni completes her Ph.D. research.

Digital data will be deleted with no chance of recovery. Consent forms will be shredded in the workplace.

5. How can these risks be addressed?

Details and recruitment of participants

6. What types of people will be recruited? Eg students, children, people with learning disabilities, elderly?

Students

7. How will the competence of participants to give informed consent be determined?

The subjects are all adults, socially identified as university students, with basic judgement skills. Competent to consent to their participation in the study.

8. How, where, and by whom participants will be identified, approached, and recruited?

Subjects for this study will be recruited by the head of the chemical engineering department and the head of laboratory safety at the partner school, and the subjects will all be current undergraduates in the chemical engineering department.

9. Will any unequal relationships exist between anyone involved in the recruitment and the potential participants? No

10.Are there any benefits to participants?

The aim of this experiment is to enhance students' emergency evacuation skills and to spread knowledge of evacuation safety. These will help students to cope comfortably in a real evacuation environment.

11. Is there a need for participants to be de-briefed? By whom? No

Research information

12.What information will participants be given about the research?

The subject of the experiment, the start of the operation and the arrangements after the end of the evacuation exercise.

13.Who will benefit from this research?

Students,the partner university and the researchers ourselves

14.Have you considered anonymity and confidentiality?

Yes.To ensure anonymity and to avoid any potential harm, the consent form will not include the name or signature of the participant.Directly identifying information (e.g. names, contact details, or pictures) will not be collected as part of the survey data. Contact details for key informants and focus groups participants will only be collected temporarily for arranging interview.

15.How will you store your collected data?

Questionnaires will be locked, and the key will be kept in supervisor Liang Xia 's office. The data disposal will be conducted three years after Minrui Ni completes her Ph.D. research.

16.How will data be disposed of and after how long?

All experimental data will be processed within two months.Digital data will be deleted with no chance of recovery. Consent forms will be shredded in the workplace.

17. Are there any conflicts of interest in undertaking this research? Eg financial reward for outcomes etc. No

18. Will you be collecting information through a third party? No

Consent

19. Have you considered consent? Yes

20. If using secondary data, does the consent from the primary data cover further analysis? No

21. Can participants opt out? Yes

22. Does your information sheet (or equivalent) contain all the information participants need? Yes

23. If your research changes, how will consent be renegotiated?

The purpose of the study, precautions, etc. in the informed consent form will be modified. Subjects have the right to be informed of the subject and purpose of the study.

Ethical procedures

24. Have you considered ethics within your plans for dissemination/impact? Yes

25. Are there any additional issues that need to be considered ? Eg local customs, local 'gatekeepers', political sensitivities No

26. Have you considered the time you need to gain ethics approval? Yes

27. How will the ethics aspects of the project be monitored throughout its course?

Throughout the experiment, the subjects' rights will be respected in order to safeguard their interests. There will be a consensus between the collaborators and our research team that the progress of the study will be clearly defined and monitored in real time.

28. Is there an approved research ethics protocol that would be appropriate to use? Yes

29. How will unforeseen or adverse events in the course of research be managed?

Eg do you have procedures to deal with any disclosures from vulnerable participants?

The subjects selected for this study are adults in good physical and mental health who are capable of dictating their own behaviour. In the event of an adverse event, we will make a careful judgement of the expected benefits and expected risks of the study based on its frequency and severity, and make decisions such as meeting review, protocol modification, modification of informed consent, suspension or termination of the study in the interest of protecting the subjects.

Description of technical equipment and parameters

Tobii Pro Glasses 2

Technical Specifications

1. **Sampling Rate**: 50Hz or 100Hz (optional)
2. **Tracking Range**: Horizontal field of view around 82°, vertical around 52°
3. **Tracking Accuracy**: In lab environments, accuracy can reach approximately 0.63°, depending on the experimental setup
4. **Latency**: Data transmission latency is less than 10 milliseconds
5. **Device Weight**: Approximately 45 grams, designed as glasses for natural wear
6. **Video Resolution**: Camera resolution of 1920x1080 pixels
7. **Connection**: Connects via WiFi to a data logging unit or computer

Calibration Method

The calibration process for Tobii Pro Glasses 2 is straightforward and generally involves the following steps:

1. **Prepare Calibration Point**: A single fixed point is used as the calibration target, which can be a point on a screen or a marker.
2. **User Gazes at Calibration Point**: The participant, wearing glasses, gazes at the calibration point at a certain distance while keeping their head stable.
3. **Calibration Initiation**: Using companion software, like Tobii Pro Glasses Controller, eye-tracking data is recorded as the participant gazes at the point to establish a relationship between the gaze direction and actual point of interest.
4. **Calibration Completion**: The system automatically adjusts the eye-tracking algorithm, making subsequent data collection more precise. Calibration typically takes only a few seconds and adapts well to different environments.

Data Collection Accuracy

The data collection accuracy of Tobii Pro Glasses 2 is as follows:

1. **Gaze Point Accuracy**: Usually within 0.63° (with minor variation depending on environmental conditions).
2. **Spatial Resolution**: Under standard lighting, the gaze tracking error remains minimal, allowing for stable gaze direction tracking.
3. **Dynamic Error Compensation**: The device includes real-time error compensation algorithms that manage head movement effects, ensuring stability in data collection.
4. **Data Output**: Supports synchronized collection of gaze data, pupil data, and video data, which can be used for detailed analysis.