Dynamic Motivation in Crowds: Insights from Experiments and Pedestrian Models for Goal-Directed Motion

Ezel Üsten

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Abstract

The actions that pedestrians take to reach a destination or move are always influenced by their motivation. Even though motivation has been thoroughly studied in various contexts in psychology, in the context of pedestrian dynamics, it has primarily been simplified as a dichotomous parameter, categorized into high and low motivation. However, to gain a comprehensive understanding of pedestrian activities and the consequent safety measures, it is crucial to thoroughly investigate the dynamics of motivation and its associated outcomes, including emotion and behavior. This involves exploring the subject in depth, as it has been studied in other contexts. Doing so will enable researchers within the field to incorporate these psychological characteristics and their relationships into the already established topics within engineering and safety fields. The primary objective of this cumulative thesis is to present recent investigations on motivation topic. To achieve this, four publications are presented (of which three have been published), each exploring motivation as an umbrella concept within pedestrian dynamics context while focusing on motivational outcomes.

The first publication explores the psychological effects of being stopped while moving forward through two studies. These studies used interruption events as a basis for investigation. The studies focused on two aspects: interruption timing (early or late interruptions) and interruptions at different levels of motivation (high and low motivation). The research focused on whether impatience or boredom, as state emotions, were experienced during these interruption scenarios, and examined how these goal-dependent emotions were related to their motivation and overall pedestrian dynamics. To achieve this, various data collection methods were employed. These include psychological investigations into emotions and motivation, monitoring physiological responses like heart rate, and using physical data collection methods such as density calculations.

The second publication focuses on pushing behavior and develops a systematic content analysis method for categorizing forward motion based on pedestrian motivation and behavior. To achieve this, the researchers thoroughly investigated previous experiment videos conducted by various researchers, with a specific focus on individual motion, to explore the parameters of these behaviors. Subsequently, a classification system based on the previously established forward motion parameters was created, consisting of the following categories: Strong pushing, mild pushing, just walking, and falling behind. To assess the reliability and usability of the category system, two

trained raters annotated various experiment videos, achieving a satisfactory reliability level. The overall aim of the study was to demonstrate that motivation-driven actions are not homogeneous; rather, they exhibit significant diversity within the crowd. Additionally, these actions were observed to be dynamic, as pedestrians were constantly changing their behavior over the course of the experiments.

In the third publication, the category system established in the second publication was used to showcase the spatial and temporal characteristics of different types of forward motion and pushing behavior. The primary aim was to demonstrate how pushing behavior changes, increases, or decreases throughout the experimental runs. The link between pushing behavior and pedestrian motivation was evident, as their motivation fluctuated over the course of the experiment, leading to varying forms of forward motion at different times and places. To illustrate this relationship effectively, various analysis methods were employed. These methods included conducting time and distance calculations, dividing the experimental areas into semi-circles, and creating colored experiment platform maps based on the pushing categories collected in specific cells.

The final publication initiates a discourse on incorporating the concept of motivation into computer modeling. To do this, it presents a preliminary study which has not been published yet. The study involves the development of a spatially distributed motivation model using high and low motivation. To achieve this, established modeling parameters, such as pedestrian speed and the time taken to close gaps with neighboring agents—factors that previous research has suggested were motivational in a general sense—were incorporated into the study. However, the bottleneck area has been divided into different sections, each generating varying levels of motivation, to create a more realistic and heterogeneous representation. The analyses included evacuation time and time/distance calculations. The intention behind this approach was to establish the foundation for a comprehensive and dynamic motivation model, one that incorporates general motivational theories from psychology literature and moves away from the simplified static dichotomy of high and low motivation.

Zusammenfassung

Die Handlungen, die Fußgänger ausführen, um ihr Ziel zu erreichen oder sich fortzubewegen, werden immer von ihrer Motivation beeinflusst. Obwohl Motivation in der Psychologie bereits in verschiedenen Zusammenhängen gründlich untersucht wurde, wurde sie im Kontext der Fußgängerdynamik in erster Linie als dichotomes Merkmal vereinfacht und in hohe und niedrige Motivation unterteilt. Um jedoch ein umfassendes Verständnis für Fußgängeraktivitäten und die daraus resultierenden Sicherheitsmaßnahmen zu erlangen, ist es entscheidend, die Dynamik der Motivation sowie die damit verbundenen Auswirkungen, einschließlich Emotionen und Verhalten, gründlich zu untersuchen. Dies erfordert eine eingehende Erforschung des Themas, wie es in anderen Kontexten bereits geschehen ist. Dadurch wird es Forschern auf diesem Gebiet ermöglicht, diese psychologischen Merkmale und ihre Beziehungen in bereits etablierte Themen der Ingenieurs- und Sicherheitswissenschaften zu integrieren. Das Hauptziel dieser kumulativen Dissertation besteht darin, aktuelle Untersuchungen zum Thema Motivation vorzustellen. Dafür werden vier Publikationen präsentiert (von denen drei veröffentlicht sind), die jeweils Motivation als ein übergreifendes Konzept im Kontext der Fußgängerdynamik untersuchen und sich auf die motivationalen Auswirkungen konzentrieren.

In der ersten Publikation werden anhand von zwei Studien die psychologischen Auswirkungen, wenn man in der Vorwärtsbewegung gestoppt wird, untersucht. Diese Studien verwendeten Unterbrechungssituationen als Grundlage für die Forschung. Dabei wurden zwei Aspekte berücksichtigt: Der Zeitpunkt der Unterbrechung (frühe oder späte Unterbrechungen) und die Unterbrechung bei unterschiedlicher Motivation (hohe und niedrige Motivation). Die Forschung konzentrierte sich darauf, ob während dieser Unterbrechungsszenarien Ungeduld oder Langeweile – als State-Emotionen – empfunden wurden, und untersuchte, wie diese zielabhängigen Emotionen mit der Motivation sowie der allgemeinen Fußgängerdynamik zusammenhingen. Dazu wurden verschiedene Datenerhebungsmethoden verwendet. Diese umfassen psychologische Befragungen zu Emotionen und Motivation, die Erfassung physiologischer Reaktionen wie die Herzrate und die Verwendung physikalischer Datenerhebungsmethoden wie Dichteberechnungen.

Die zweite Publikation konzentriert sich auf Drängelverhalten und entwickelt eine systematische Inhaltsanalysemethode zur Kategorisierung der Vorwärtsbewegung basierend auf der Motivation und dem Verhalten von Fußgängern. Dazu untersuchten die Forscher gründlich frühere Experimentvideos, die von verschiedenen

Forschern durchgeführt wurden, mit besonderem Augenmerk auf individuelle Bewegungen, um die Parameter dieser Verhaltensweisen zu ermitteln. Anschließend wurde auf Grundlade der zuvor erfassten Parameter für Vorwärtsbewegung ein Klassifizierungssystem erstellt, das aus den folgenden Kategorien besteht: Starkes Drängeln, leichtes Drängeln, nur Gehen und Zurückbleiben. Um die Reliabilität und Anwendbarkeit des Kategoriensystems zu überprüfen, annotierten zwei geschulte Rater verschiedene Experimentvideos, wobei sie ein zufriedenstellendes Reliabilitätsniveau erreichten. Das übergeordnete Ziel der Studie bestand darin, zu zeigen, dass motivationsgetriebene Handlungen nicht homogen sind, sondern vielmehr eine erhebliche Vielfalt innerhalb der Menschenmenge aufweisen. Darüber hinaus wurde beobachtet, dass diese Handlungen dynamisch sind, da Fußgänger ihr Verhalten im Verlauf der Experimente ständig änderten.

In der dritten Publikation wurde das in der zweiten Publikation eingeführte Kategoriensystem verwendet, um die räumlichen und zeitlichen Merkmale verschiedener Formen von Vorwärtsbewegung und Drängelverhalten aufzuzeigen. Das Hauptziel bestand darin, zu zeigen, wie sich das Drängelverhalten im Verlauf der Experimente ändert, zunimmt oder abnimmt. Der Zusammenhang zwischen dem Drängelverhalten und der Motivation der Fußgänger war offensichtlich, da ihre Motivation im Laufe des Experiments schwankte, was zu variierenden Formen der Vorwärtsbewegung zu unterschiedlichen Zeiten an unterschiedlichen Orten führte. Um diesen Zusammenhang zu verdeutlichen, wurden verschiedene Analysemethoden eingesetzt. Dazu gehörten Zeit- und Entfernungsberechnungen, die Unterteilung der Experimentbereiche in Halbkreise und die Erstellung farbiger Karten der Experimentplattform basierend auf den Drängelkategorien, die in den jeweiligen Zellen erfasst wurden.

Mit der letzten Publikation wird ein Diskurs über die Integration des Konzepts der Motivation in die Computermodellierung eingeleitet. Dazu wird eine noch nicht veröffentlichte Vorstudie präsentiert. Die Studie beinhaltet die Entwicklung eines räumlich verteilten Motivationsmodells unter Berücksichtigung von hoher und niedriger Motivation. Um dies zu erreichen, wurden etablierte Modellierungsparameter wie die Geschwindigkeit der Fußgänger und die Zeit, die benötigt wird, um Lücken zu benachbarten Agenten zu schließen - Faktoren, die bisherige Forschung als allgemein motivationsbezogen angesehen hat - in die Studie integriert. Der Bereich der Engstelle wurde jedoch in verschiedene Abschnitte unterteilt, die jeweils unterschiedliche Motivationsniveaus erzeugen, um eine realistischere und heterogenere Darstellung zu schaffen. Die Analysen umfassten Evakuierungszeit und Zeit-/Entfernungsberechnungen. Die Absicht hinter diesem Ansatz war es, die Grundlage für ein umfassendes und dynamisches Motivationsmodell zu schaffen, das allgemeine Motivationstheorien aus der psychologischen Literatur integriert und sich von der vereinfachten statischen Dichotomie von hoher und geringer Motivation entfernt.

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Interestingly, right now, I am also a part of another division due to some administrative purposes, but I would like to express my gratitude to all the people in this division for making me feel welcome and not homesick. To be honest, as a psychologist, I never anticipated feeling such sense of belonging within a computer science division. Moreover, our collaboration extended to various projects, most of them playing an essential role in this thesis. Therefore, I want to extend my thanks to Jette Schumann, Ahmed Alia, Jacob Cordes, and Tobias Schrödter individually for their unique contributions and different perspectives, which have greatly enriched the studies and the thesis.

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List of Publications

Publication I
Üsten, E.; Lügering, H.; Sieben, A. “Pushing and Non-pushing Forward Motion in Crowds: A Systematic Psychological Observation Method for Rating Individual Behavior in Pedestrian Dynamics.” Collective Dynamics 2022, 7, 1–16.

Publication II
Üsten, E.; Sieben, A. “Don’t stop me now: Psychological effects of interrupting a moving pedestrian crowd and a video game.” PLoS ONE 2023, 18(7), e0287583.

Publication III
Uesten, E.; Schumann, J.; Sieben, A. “Exploring the Dynamic Relationship between Pushing Behavior and Crowd Dynamics.” Collective Dynamics 2023, 8, 1–29.

Publication IV
Üsten, E.; Cordes, J.; Chraibi, M.; Sieben, A.; Seyfried, A. “Towards Dynamic Motivation: Integrating Psychological Theories of Motivation in Pedestrian Modeling for Bottleneck Scenarios” Ready for submission.

CHAPTER 1

Introduction

1.1 Motivation of the thesis

Pedestrian dynamics is an essential aspect of our daily lives, given the contemporary existence of societies and cultures that revolve around people gathering and residing in relatively dense areas such as cities. In order for all these individuals to coexist effectively, humans have developed a series of strategies to manage both traffic and pedestrian flows harmoniously. While these rules are built upon decades of experiences and research, the dynamics continue to evolve due to changing societal circumstances and adaptations to new world conditions. As a result, researchers from various fields are devoted to uncovering these dynamics and developing new adaptation approaches. However, there are still many aspects that remain unexplored within the concepts of mathematical or physical calculations of flows, computational representations of crowds, and the complexities of societies and human brain, and consequently, human psychology.

As indicated, pedestrian dynamics is currently being regarded as a multidisciplinary field that encompasses various scientific communities. However, this interdisciplinary approach was not the initial state of the field, each discipline developed within their own perspectives. In terms of social sciences, the integration with other major fields can be considered relatively late, and this delay might be attributed to how crowds were initially treated and described in the social sciences. For a long time, the dominant view held that crowds were violent and lacked rationality [1, 2], due to being biased and subjectively represented by Gustave Le Bon in the late nineteenth century [3, 4]. This perspective was later shown to be incorrect or highly circumstantial, influenced by Le Bon's political views [5, 6], and subsequent findings indicated that crowds may exhibit behavior that is quite the opposite [7, 8]. Following Le Bon's work, there were many studies focusing on crowds, either challenging or extending his findings [9–13], but the initial debate still persists, albeit to a lesser extent, even up to the present day (for an exemplary contemporary study using Le Bon's ideas, see [14]). During this period, as the twenty-first century approached, physics and computer sciences began to take a dominant role in the field of pedestrian dynamics.

In the last few decades, psychology, social psychology, and sociology have made significant advancements in researching crowds and evacuations within the broader context of pedestrian dynamics. They have successfully integrated with other fields [15–18], contributing to the development of this multidisciplinary research area. Researchers in this field have started to focus new and longstanding research concepts such as collective action [19–21], behaviors [22] and emotions [23], social identification [24, 25], motivation [26, 27], disproving the concept of mass panic [28, 29], and many others. However, despite the numerous remarkable studies that have been conducted and the well-established results obtained, many works focusing on pedestrian dynamics from this interdisciplinary perspective currently lack extensive repetition and may contain gaps in terms of inclusivity in different crowd contexts. For instance, while emotion subject is extensively studied in social sciences [30], its applicability to crowds and crowd dynamics remains an area that requires further exploration.

The aim of this thesis is to adapt one of these concepts, namely motivation, into the field of crowd dynamics, specifically in the context of moving or reaching a destination. Motivation is a concept that has been extensively studied in general psychology but has been used in a limited way in crowd studies. It was primarily employed as a dichotomous force to demonstrate how crowd dynamics and their physical measurements change at different motivation levels [27, 31–36]. While this thesis and its subsequent publications do not aim to disprove or abandon this perspective, the overall objective is to study the subject more extensively in various contexts and delve into the behaviors and goal-dependent emotions related to pedestrian motivation.

1.2 Motivation subject

Motivation is a vast concept, consisting of many different contexts and areas of focus, along with various research methods to explore its complexities. The primary aim of this thesis is to delve into a relatively less-explored area within pedestrian dynamics, specifically, the motivation to move or reach a destination, by using previous well-established theories and methods. To provide a comprehensive understanding of the research conducted in this thesis, this section serves as a summary chapter for the related works of motivation and its major psychological theories.

Motivation gained significant attention from psychologists in the mid-twentieth century. Researchers such as Kurt Lewin [37] began to exclusively focus on various aspects of motivation, such as organizational [38], cognitive [39, 40], or social elements [41]. This focus expanded as major theories emerged, addressing topics like action and behavioral change [42], achievement [43], emotion [44, 45], and more.

Achievement motivation, while not directly linked to our main context, as it mainly focuses on academic and organizational success, is relevant due to its core idea of exploring how motivation influences an individual's success in a particular goal. These goals have primarily been explored in the context of academic or organizational behavior, such as preparing for a test, striving for good grades, or completing a job before a deadline [46, 47]. However, such tasks could also extend to pedestrian environments, such as, where individuals aim to reach a destination on time or wait in a queue until it disperses. Even though some tasks in pedestrian environments are mundane or routine, such as returning home after work, they remain goal-oriented, and pedestrians achieve something in the end. It is quite plausible that the motivation of pedestrians also affects their success rate, depending on their specific goals, such as reaching home before a particular hour after work.

Expectancy and value theory [48], one of the most significant psychological theories in the context of achievement motivation, has proven to be highly effective in understanding the motivation of individuals. This theory proposes that motivation is influenced by an individual's expectations of success and the value they assign to achieving their desired outcomes. While many existing approaches using expectancy and value theory focus on long-term academic [49] and career [50] achievement, such as the desire to perform well in school or the motivation to attain a degree or a job, in the context of crowds, these expectations and values may be linked to an individual's desire to reach a specific destination or exit a crowd safely and efficiently. Although these contexts are short-term, we believe that the expectancy and value definition of motivation could be well-suited to explaining motivation in such environments because it considers the individual's expectations (likelihood of reaching a destination in time) and the value they place (the importance of reaching a destination in time) on achieving their goals.

However, motivation is often viewed as one aspect of the path that leads to behavior and goal-dependent emotion, and numerous researchers have explored this topic along with its antecedents and subsequent concepts [38, 45, 51, 52]. The process, in its basic form, unfolds as follows: after a decision is made, motivation leads to a behavior, and a subsequent emotion is produced [42]. Decision making itself is a vast cognitive concept and would likely require another thesis to thoroughly explain and study it within the context of pedestrian dynamics and crowds. However, motivation, action, and emotion, as well as their interconnectedness, though they can be studied separately, would be beneficial to include in terms of broadening the scope of the thesis. The subsequent sections within the thesis includes these concepts. The behavior of pedestrians, the emotions evoked in goal pursuit, and the general motivation of pedestrians have all been examined and considered in the context of motivation.

1.2.1 State of Research

There are various research studies in pedestrian dynamics and crowd behavior that focus on individual or group motivation, spanning various contexts such as political protests, gatherings, concerts, and more. Initially, Le Bon [3] argued that motivation in crowds is primarily directed towards conforming to the group, gaining approval, and avoiding disapproval. Allport [9] introduced motivation as a shared predisposition in his description of homogeneous crowds. Turner and Killian [11] were among the first to treat motivation as a diverse force that contributes to the formation of collective behavior, characterizing distinct motivation types. McPhail [53] delved deeper into this issue, arguing that simple and dominant collective motives are insufficient to explain complex crowd behavior, and individual motivations can vary significantly in group settings. Furthermore, motivation has been explored within different psychological frameworks, such as social identity [54], group conformity [55], values [56], and more, within the context of crowds and collective behavior.

However, many of these studies primarily focus on participation in crowds or crowd behavior related to specific, often political goals, such as protests. In contrast, the context of this thesis and subsequent publications investigate motivation to move or reach a destination from a pedestrian perspective in everyday scenarios. While there is existing research in this context, motivation within pedestrian dynamics has frequently been oversimplified. It has often been treated as a binary force, categorizing individuals as either highly motivated or not motivated at all [27, 31–36], instead of recognizing it as a variable that can vary in intensity. Furthermore, motivation has often been portrayed as a static force, assuming it remains constant, while in reality, it is dynamic and subject to fluctuations over time due to various factors.

As a result, numerous studies have explored the effects of this dichotomous motivation on pedestrians in bottleneck scenarios. Researchers have investigated various corridor shapes, widths, and scenarios while manipulating participants' motivation levels using a high versus low dichotomy [27, 31–36]. Motivation was typically primed through pre-instructions, in which participants were asked to imagine scenarios artificially increasing their motivation (exemplary instruction for high motivation: "Imagine you are on your way to a concert by your favorite artist..."). Unsurprisingly, the crowd dynamics, such as density, flow, and acceleration, showed distinct differences between high and low motivation groups [32]. Crowds instructed with high motivation tend to exhibit more active and pushy behavior, displaying a greater eagerness to reach the bottleneck quickly. Consequently, physical properties such as density are more pronounced in high motivation groups when compared to those instructed with low motivation.

As mentioned before, this perspective has not been abandoned in the current studies of the thesis. All four publications employed high and low motivation, and the consequent data were used to explore the results of the hypotheses. However, while the dichotomous approach is still being used, the studies attempted to enlarge the scope of what these motivation instructions create, mainly in terms of goal-driven emotion and behavior. Additionally, until now, research utilizing motivation in this context has not been grounded in a theoretical framework, lacking the application of any well-established psychological theories of motivation. The aim was to establish a foundational framework and illustrate the dynamic nature of motivation through its various outcomes, which fluctuate and are circumstantial depending on the level of motivation, being highly dynamic.

1.3 Objectives and Approach

The main aim of this thesis is to explore, analyze, and establish a foundation for understanding the role of motivation and its impact on behavioral and emotional outcomes in various pedestrian contexts. While motivation as a core concept is examined throughout different events, the central focus of the general thesis and the subsequent publications lies on the goal-driven emotional and behavioral outcomes. To study these complex and extensive concepts, diverse analysis methods and study types were utilized. Experiments were conducted using new designs and incorporating previously conducted studies. The research employed various approaches and methods, both quantitative and qualitative, including surveys, self-drawing scales, feedback terminals, physiological data acquisition devices, observations, content analysis methods, trajectories, trajectory-based time and space calculations, as well as data visualizations to comprehensively explore the subject.

Based on these objectives and approaches, four subsequent studies were developed, each focusing on different aspects of the overall umbrella concept of motivation. Firstly, interruption incidents were examined to observe how changing motivations resulted in different psychological and physiological outcomes. This area of study holds significant importance as interruptions are common in our daily lives and directly relate to our motivation. Furthermore, emotions triggered by interruptions can potentially lead to safety issues, as some may induce reckless behavior, such as impatience. This aspect was initially explored within a non-pedestrian context due to Covid-19 restrictions in place during that time period (Publication I). Participants were instructed to play a video game for an hour while wearing a heart rate device and were also presented with a series of questionnaires and self-drawing scales to assess their motivational, behavioral, and emotional responses.

Later, when it became possible to conduct studies within a pedestrian context, a large-scale laboratory experiment series was conducted to observe the effects of interruptions on motivation and the subsequent outcomes in arousal, behavior, and emotion (Publication I). Participants were once again asked to wear heart rate devices and were presented with questionnaires. Additionally, participants wore orange caps that assisted the extraction of their trajectories from top-down cameras using the software PeTrack [57, 58]. Both quantitative and qualitative analyses were conducted on both studies based on the data collection methods presented above.

Following studies developed an observation method and subsequently analyzed crowds using this method from bottleneck experiment videos conducted earlier by various researchers [27, 32, 59–61]. Participants in these videos were once again wearing orange caps for their trajectory extraction from top-down cameras. Firstly, an annotation system for forward motion and pushing behavior of pedestrians was created from these video recordings using a content analysis method (Publication II). This annotation system consisted of various parameters (such as shoulder position or interaction with other pedestrians) that collectively indicated specific behaviors. Four behavior types were categorized as ratings, and all the pedestrians in several experiment videos were categorized based on these parameters and behaviors. Since establishing a rating system based on content analysis requires at least two raters, two researchers jointly collaborated in this study.

Using this established annotation system, the exploration of overall crowd dynamics based on the categorized behaviors was the focus of the next study (Publication III). Fourteen bottleneck experiment videos previously conducted for different studies [32, 61] were utilized again and annotated by two raters. The ratings and the subsequent categories were then used to visualize the crowd using different approaches, such as examining the time and distance relationship of the ratings or mapping the behavioral categories with colors within equally divided cells. The general consensus of both studies was that the dynamic motivation of pedestrians in different temporal scenarios leads to different behavioral outcomes, which was the main objective of both studies - to illustrate this notion.

The objective of the last study was to integrate motivation into the field of computer modeling. The plan involved initiating a phased approach, progressing from a basic version to a more complex one. The study included in the thesis serves as the initial stage of this effort (Publication IV). It created an environment where motivation was distributed spatially, simulating a simplified version of dynamic motivation within a bottleneck environment. Established motivation parameters, such as desired speed and time to close gaps, were employed. The study incorporated three different scenarios with varying pedestrian numbers. The bottleneck area was divided into three motivational areas using semi-circles that expanded as one moved farther from the bottleneck. The permutation of these areas (e.g., the first area: high motivation, the second area: low motivation, the third area: low motivation) was utilized to calculate evacuation times and time/distance trajectories.

CHAPTER 2

Results

The dissertation comprises five studies and four publications. The following sections are dedicated to discussing the main research questions and overall results of all the studies. For detailed information on the individual publications, please refer to the section at the end.

2.1 Publication I

Publication I consists of two separate studies focusing on different aspects of interruption events within a motivational context. Two experiments were conducted to investigate whether interruption timing, such as early and late interruption (Study I), and having high or low motivation while being interrupted (Study II), affect the emotions, motivation, and behavior of the individuals. The significance of these studies lies in their relevance to everyday life events, as people frequently encounter interruptions due to the intersecting objectives of other individuals or systems. The affected motivation, the emotions triggered, and the behavior exhibited when interrupted are of equal importance, given the potential safety concerns, such as reckless behavior arising from certain emotions (e.g., impatience). Moreover, even milder forms of interruption can disrupt the comfort of reaching a destination. However, it's worth noting that interruptions can vary widely, and their consequences were hypothesized to differ accordingly. The findings revealed that interruption timing does not significantly impact the results, but having high and low motivation leads to distinct emotional and motivational outcomes. The subsequent sections will focus on the research questions and provide a summary of the results from these two studies.

2.1.1 Study I

Study I focuses on interruption events and their consequent motivational outcomes from a timing perspective. The main objective was to explore whether interruption timing produces distinct effects on individuals, particularly in their emotions, behavior, and motivation. This assumption that different timings would lead to different outcomes is based on previous research and concepts, namely valuation and goal proximity concepts, where people are believed to value their goals more when they are close to achieving them [62–66]. Consequently, it has been shown that an interruption is potentially more disruptive and produces more annoyance when people have a higher value on their goals [67, 68].

The hypotheses were shaped accordingly based on previous research. It was hypothesized that interrupting people when they are in the early stages of their goal pursuit would result in significantly weaker emotional and physiological responses, including reduced cardiac response and feelings of boredom, and would have a minimal impact on motivation due to low valuation. Conversely, it was expected that interrupting individuals when they are in the later stages of their goal pursuit would lead to a higher heart rate and feelings of impatience, significantly affecting motivation. Due to Covid-19 restrictions at that time, it was decided not to conduct a pedestrian study, and the study design was changed to a setting where one participant at a time could participate in the experiments. Participants were interrupted while playing a video game, either in the early stages of the given task or when they were about to finish it.

However, the results indicated that interruption timing does not significantly impact individuals in the hypothesized experimental conditions. The interruption itself produced a greater annoyance, which can be seen in the cardiac and questionnaire responses, as well as in the qualitative data collected from participants. While this part was a clear-cut outcome, the annoyance was valid for both conditions. Late interruption did not affect participants more than early interruption. However, we treated these results as the foundational findings on the subject and continued studying the interruption events in different contexts.

2.1.2 Study II

Study II, like its predecessor, focuses on interruption events and their motivational outcomes. However, this time the perspective shifts to examine the effects of having different levels of motivation before the interruption. The main research question was to investigate the high and low motivation dichotomy and its effects on interruption: whether having distinct levels of motivation produces different effects on individuals, their emotions, and motivation. This assumption is based on existing literature suggesting that high or low motivation leads to distinct outcomes in attention, performance, and learning [69]. Consequently, motivation has been identified as one of the key factors in crowd dynamics [32].

The hypotheses for Study II were formulated similarly to Study I. It was hypothesized that interrupting individuals who received low motivation instructions would result in significantly weaker emotional and physiological responses, including reduced cardiac response and feelings of boredom, and would have a minimal impact on their overall motivation. On the other hand, it was expected that interrupting participants who received high motivation instructions would lead to a higher heart rate and feelings of impatience, ultimately resulting in a decrease in their motivation levels. As Covid-19 restrictions were lifted, Study II was conducted using a pedestrian experiment [36]. All participants took part in the experiments simultaneously, being positioned on a platform and passing through a bottleneck scenario.

The results showed that interrupting pedestrians with different levels of motivation led to different outcomes, partly as predicted by the hypotheses. When pedestrians who received low motivation instructions were interrupted, they reported feeling bored, and their motivation levels remained stable. However, the interruption produced feelings of impatience and a decrease in motivation among participants who were highly motivated. Interestingly, the predictions regarding higher and lower heart rate levels in the respective high motivation and low motivation groups were not observed. Instead, it was found that preventing participants from moving during the interruption decreased their heart rates for both groups, showing no significant difference between the two groups in terms of heart rate response to interruption.

2.2 Publication II

Publication II focuses on a different aspect of motivation, namely motivation-driven behavior, in contrast to Publication I, which directly focuses on physiological and emotional responses. Rather than conducting new experiments, the study utilizes old experiment videos previously conducted by various researchers [27, 32, 59–61] and repurposes them to explore new ways of investigating pedestrian behavior and forward motion. The main objective was to establish a structured system that could demonstrate the dynamic nature of crowded situations based on pedestrians' motivation, as indicated by heterogeneous behavior observed within the crowd.

As mentioned before, so far, motivation has been used as a dichotomous instruction or a priming tool, representing high and low motivation, to induce contrasting behaviors in pedestrians during various experiments. However, even though crowd dynamics show distinct outcomes when people are highly or lowly motivated, such as density or flow speed [32], in reality, pedestrians' behaviors are never identical and never constant. They always change or fluctuate, and different pedestrians may exhibit different manifestations of behavior, even when they were instructed with the same motivation. This variation in behavior poses challenges, as the same behavior cannot be consistently reproduced within these experiments. For instance, modeling a particular experiment would not result with the exact same behaviors due to the inherent diversity in pedestrians' actions.

Publication II constructed a flexible categorization system capable of detecting all the changes and fluctuations in pedestrian behavior, forward motion, and pushing behavior, in order to accurately collect data for further studies. To establish this category system, various pedestrian behavior parameters were developed through a content analysis procedure, and all pedestrians in selected videos were rated based on the pre-established categories.

To assess the reliability of the system from the perspectives of different individuals, two raters independently conducted the rating procedure. The results demonstrated that the ratings and the category system were reliable and could be utilized by further studies and different researchers. Moreover, the findings revealed that regardless of the instructed motivation, all the data was highly heterogeneous, containing contrasting behaviors in different situations. For example, slow movements were observed in high motivation experiments, and pushing behavior occurred in low motivation experiments. This variation in behavior highlights the dynamic nature of pedestrian responses and behaviors in crowded situations.

2.3 Publication III

As a follow-up to Publication II, Publication III also centers on motivation-driven behavior. The primary aim was to comprehensively demonstrate dynamic pedestrian behavior in relation to certain aspects of crowd dynamics, such as spatial and temporal distribution. To achieve this, the previously established category system from Publication II, along with findings from prior research, were employed [32, 70]. The study once again utilized archived experiment videos (fourteen bottleneck videos) previously conducted by researchers in the field of pedestrian dynamics [32, 61].

The hypotheses were formulated based on insights gained from previous research, where the assumption was that pushing behavior increases as pedestrians approach a bottleneck. This assumption applies to both the spatial and temporal dynamics of the crowd. It aligns with well-known motivation theories, such as the expectancy and value theory, which suggests that an individual's motivation increases as they expect to reach a goal [48]. Similarly, the goal proximity concept posits that people are more motivated when they are nearer to achieving their goals [66]. By utilizing the same category system introduced in Publication II, it was hypothesized that intense behavior categories would become more prominent as pedestrians approached the bottleneck compared to other categories. These assumptions were tested under both high and low motivation conditions and across various corridor widths.

The results indicated that, for the majority of cases, the hypotheses held true. Intense behavior categories were indeed more prevalent as pedestrians approached the bottleneck. Conversely, individuals farther away from the bottleneck exhibited a lower frequency of pushing behavior and a higher proportion of less intense behavior categories. Furthermore, a consistent trend was observed where all categories displayed gradual peaks as pedestrians moved closer to the bottleneck. Concerning temporal dynamics and their relation to corridor width, it was observed that individuals who engaged in pushing behavior, and thus were likely more motivated, tended to reach the bottleneck faster in certain scenarios, particularly in wider corridor widths.

2.4 Publication IV

In Publication IV, the study presented in this thesis directly integrated the concept of motivation into computer modeling, with a specific focus on its role as the primary driver of behavior in bottleneck scenarios. The primary objective was to initiate a series of studies where the complex motivation concept, drawing from established psychology theories such as expectancy and value theory, as proposed in Atkinson's motivation model [48], would be incorporated into pedestrian modeling. This integration involves using specific parameters to guide the agents dynamically and heterogeneously within the model. Given the ambitious nature of this idea, the proposed work was divided into a staged series, with the established motivation parameters (desired speed and time to close gaps) showcased by Rzezonka et al. [18] serving as the starting point. The study for Publication IV was conducted as the initial stage, with the primary aim of creating a heterogeneous crowd that includes both highly and lowly motivated agents in the same simulation, without yet implementing the changes of motivation over time.

The computer science community in pedestrian dynamics has thus far incorporated motivation into their work, although with a limited theoretical framework and employing a simplified version of motivation. Consequently, binary distinctions between high and low motivation have been utilized in certain modeling studies [18, 71], resulting in a range of outcomes. The study presented in Publication IV also employed a similar dichotomous approach but created a more heterogeneous version of it as the initial stage of the grand objective.

In this model, the bottleneck area was divided into three semi-circle areas at an equal distance from each other, with the first semi-circle positioned at the front of the bottleneck. Depending on the initial location of the agents—whether in the first, second, or third semi-circle—they were assigned different parameters representing either high or low motivation. These areas were given distinct motivation instructions with various combinations (e.g., first area: high motivation, second area: low motivation, third area: high motivation), and the objective was to explore these combinations. It was anticipated that high motivation groups positioned at the back would generate contagions due to their eagerness to push forward. Simultaneously, it was expected that placing a high motivation group in the first semi-circle would yield more realistic results, aligning with observations from real-life experiments where highly motivated participants often position themselves in front of the bottleneck before the experiments start. Time-distance analyses and evacuation time calculations were employed to examine the differences between these various combinations.

The results showed that, contrary to our expectations, the location of the motivation groups did not significantly influence the overall evacuation time. For instance, in cases where there was only one high motivation group, whether it was positioned at the first semi-circle or the last, the evacuation time was fairly similar. However, the number of motivation groups had a significant impact on the evacuation time. Having three high motivation groups resulted in the quickest evacuation, followed by two high motivation groups and one low motivation group, and so on. On the other hand, the location of the groups did affect the time/distance calculations, as highly motivated groups often disrupted the overall flow by attempting to push forward, even though this did not significantly accelerate or delay the evacuation time.

The subsequent steps of the initial stage were also discussed in Publication IV. While the study addressed the heterogeneity aspect of motivation, it still relied on a binary classification of high and low motivation for agents. The outline for the next studies discussed the inclusion of a more realistic approach regarding heterogeneity, assigning motivational parameters not as fixed categories but as values within a range. These values would be calculated based on the relative positions of agents to their neighbors and their distance from the bottleneck. Importantly, these values would change over time as the positions of the agents shifted. Building upon the premise of, the next study aims to fully integrate dynamism and heterogeneity in terms of pedestrian motivation into the modeling framework.

CHAPTER 3

Discussion and Outlook

The studies presented in this thesis shift the focus onto motivation within the context of pedestrian dynamics. Previously, motivation to move or to reach a destination had been employed as a methodological tool to investigate other research questions in this field, due to its utility in distinguishing between more active and less active crowds, along with its high degree of observability in real-life situations. In contrast, in-depth examinations of motivation had primarily taken place in general psychology, particularly in areas such as achievement motivation in work or academic settings. The primary objective here was to elevate motivation to a central investigative point in the context of crowds, analyzing it across various pedestrian scenarios by adapting well-established theories primarily focused on other contexts, as well as forming a fundamental framework of motivation within pedestrian and crowd dynamics. Although not all studies and corresponding outcomes aligned with initial hypotheses, they nonetheless created new discussion areas and introduced novel perspectives within the field, ultimately achieving their main objective.

In the first two studies, presented in Publication I, motivation was explored through interruption events across different study designs. These studies investigated goal-driven emotions, changes in motivation, and psychological and physiological arousal in various conditions within the interruption context. The emotional outcomes of motivation were categorized as impatience and boredom. It was hypothesized that individuals who were not highly motivated and were interrupted would tend to feel bored and have low arousal (early interruption and low motivation instruction condition), while the opposite would hold true for impatience (late interruption and high motivation instruction condition). Although the expected outcomes were observed only in one study design (high and low motivation instruction), the central idea was to establish a connection between decreased motivation and boredom along with low arousal, as well as increased motivation and impatience along with high arousal.

The results of Study 2, which investigated interruptions in both high and low motivation scenarios, revealed that individuals perceived their emotional states in accordance with their initial motivation levels. Participants with high motivation who experienced interruptions tended to associate their emotional state with impatience, while those with low motivation associated their state with boredom when interrupted. Furthermore, it was found that interruption leads to a decrease in motivation in the high motivation group as shown by questionnaires, qualitative observations, heart rate monitoring, and spatial analyses.

The fact that the anticipated results were not consistently seen in both early and late interruption conditions in Study 1 could be attributed to various factors. These might include the study design failing to create a realistic environment or potentially the absence of a clear link between interruption timing and the degree of motivation, arousal, and subsequently, impatience and boredom. Nonetheless, for future research, it would be beneficial to further explore this aspect by introducing new types of interruption, such as short and long interruptions, or considering whether participants are informed about the interruption in advance or not.

However, there are some interesting results that could be beneficial for further discussion. To start, Study 1 utilized an alternative data collection method where participants were instructed to illustrate their emotional experiences on a time/emotion scale using a line. These scales, referred to as graphic self-scales, were administered to participants with the aim of capturing the temporal changes in feelings of impatience and boredom throughout the interruption period, which emerged due to the obstruction of their goal and, potentially, because of the decrease in motivation. While the primary intent of these scales was to identify any relationship between the emotional trends indicated by the scales and the participants' heart rate changes, initial observations did not support this correlation. Notably, during the interruption period, participants' heart rates marginally decreased, while their perceived levels of boredom and impatience increased.

Nevertheless, it was later decided to include a qualitative discussion of the merged scales since they did not suggest a significant difference between early and late interruptions but exhibited variations within each other. Analysis of the drawings revealed different patterns for both conditions: some participants showed constant emotional states, while others displayed emotions increasing at the beginning, middle, or end of the interruption period, and some experienced emotions that fluctuated throughout. This diversity indicated that even though participants were experiencing the same emotion due to the interruption of their goals, the intensity of these emotions varied at distinct time periods. For instance, some participants felt impatience predominantly at the beginning of the interruption, while others experienced it more intensely in the middle or at the end. This pattern held true for boredom as well. This outcome suggests that while a dominant emotion may arise from the interruption, the timing and intensity of that emotion can differ significantly among individuals. In the context of state emotion research, this finding opens up opportunities for further investigation into how short-lived emotional experiences at specific time points influence broader perceived emotional states.

Another notable outcome was derived from Study 2 in Publication I. Although Study 2 primarily focused on emotional reactions related to goal interruption and motivation, various data collection methods were employed to provide robust support for the results. One such method involved density calculations, revealing significant differences in density in front of the bottleneck when comparing situations where pedestrians were not interrupted and situations where they were interrupted.

Subsequently, the questionnaire items concerning motivation indicated a decrease in pedestrians' motivation following interruptions during high motivation condition runs. We interpreted this finding as follows: Interruptions lead to decreased motivation, and reduced motivation contributes to a less dense environment. While this mediation is logically coherent, it has not been scientifically demonstrated before. Moreover, this outcome holds substantial relevance to real-life scenarios and potential applications in crowd management. It establishes a direct connection between a crowd management strategy (interruption) and a desired outcome (lower density). Nonetheless, further investigation is needed to identify the inherent limitations of this phenomenon. For instance, the desired outcome could potentially have unintended consequences, as information about the interruption might not reach the entire crowd. For example, if there are thousands of pedestrians at a sports event or concert entrance, it would be much more challenging to inform all the pedestrians about the interruption. Consequently, pedestrians at the rear might unknowingly push forward, while pedestrians at the front sides were waiting, resulting in a denser and potentially hazardous environment.

Continuing with the later studies, presented as Publication II and Publication III, we gain insights into how motivation-driven behavior operates spatially and temporally in bottleneck scenarios. In the first study (Publication II), a rating system was developed to categorize the forward motion types of pedestrians in bottleneck experiments. The primary objective was to demonstrate the dynamic nature of pedestrian behavior, highlighting variations between individuals and changes over time, thus describing the crowd as a heterogeneous entity. This dynamic nature of pedestrian behavior was intrinsically linked to the broader subject of pedestrian motivation. Unfortunately, the latter aspect could not be fully verified due to the utilization of older experiment videos conducted by other researchers [27, 32, 59–61] as the primary data source. These experiments lacked questionnaire items concerning changes in motivation during the experimental process. Nonetheless, the interpretations and connections made concerning motivation in Publication II and Publication III are consistent with the existing literature on motivation and are also supported by insights from Publication I. The category system introduced in Publication II was carefully established and subsequently validated accordingly. It is intended for utilization in future research aimed at addressing relevant research questions and to be used by various researchers within the field.

While Publication II established a systematic approach for investigating dynamic pedestrian behavior, Publication III utilized this approach to demonstrate how, where, and when the behavior changes, fluctuates, intensifies, and generally manifests its dynamics. Various experimental videos previously conducted by other researchers were utilized again, and with the aid of the newly established categorization system, all pedestrians in those videos were individually rated, second by second. The resulting data was then visualized using various methods to illustrate different aspects of crowd dynamics, including temporal and spatial relationships. One of the most significant findings was that forward motion and subsequent pushing behavior intensified primarily in front of bottleneck areas, showing a gradual increase as pedestrians moved closer to the bottleneck. This outcome also aligned with generic motivation theories, which suggest that motivation tends to increase as individuals approach their goals [48].

Additionally, Publication III contributed to the field of pedestrian dynamics by investigating certain terms that are used informally in the field but have never been studied before, such as the “carrot effect,” derived from the English idiom “carrot and a stick.” This concept posits the idea, discussed above and framed within the expectancy and value concept [48], that people would be much more motivated when they approach their goal as their expectancy to reach their goal gets higher, which is also observed in the data. Also, the “sorting effect” was investigated, suggesting that the motivation instructions might have been so impactful that participants might have already positioned themselves in the front part of the crowd before the experiments began. Results from temporal analyses suggested that while there was a tendency for people to increase their forward motion categories in the first few seconds, there were also other peak points, implying that while the “sorting effect” exists, there were other factors leading pedestrians to increase their categories in a patterned way at other time points, which needs further investigation.

Lastly, Publication IV, the preliminary study in a staged research series, incorporated motivation as the primary driving force in computer modeling. Insights from the simulation analyses suggested that creating crowd heterogeneity based on diverse motivations, as attempted by dividing the bottleneck platform into different motivation areas, showed clear results in terms of evacuation time. Specifically, the presence of more high motivation groups led to faster evacuation times. However, the concept was relatively simple, with the platform divided into only three areas, each assigning different motivational parameters to the agents. Additionally, these parameters remained constant as agents moved into different areas. While motivation, as described and presented in previous publications, is both heterogeneous and dynamic, the preliminary simulation study only incorporated the diversity aspect to a limited extent and did not consider the dynamism aspect. Future research as later stages, following Publication IV, opted to prioritize a comprehensive integration of motivation into computer modeling based on expectancy and value theory [38, 48]. This integration would encompass various aspects, including motivation diversity based on individual differences related to distance from the bottleneck (expectancy), the number of agents (competitiveness), and the instructions provided to the agents (value). Furthermore, it would consider that motivation is dynamic and subject to change, as all these aspects can fluctuate during goal pursuit.

In total, all the aspects utilized in the studies to explore motivation within crowds exhibited significant results, whether showing a relation or not, they contributed to building a fundamental framework for motivation in pedestrian dynamics. Emotional, motivational, psychological, and even physiological consequences caused by blocking the goal pursuit, along with actual behavior variety and dynamism during the goal pursuit, were investigated, whether through experiments directly or via observation methods, or attempted simulation. This framework can serve as a foundation for future research and suggest certain policies for safety measures in crowd management, given that impatience, for example, is linked to aggressive or reckless behavior [72], or motivation decrease could be linked to a decrease in density. It is emphasized that these aspects should be further explored, and the framework should be developed further, potentially benefiting from the structured approach of the publications presented in this thesis.

Concrete future research ideas that can be derived from this thesis and the concept of motivation in pedestrian dynamics may include field studies with real crowd investigations into the concepts incorporated in the thesis, such as interruptions, movement behavior, goal-driven emotions, and so on. Additionally, exploring different interruption types beyond those addressed in this thesis, such as short and long interruptions, while considering their impact on motivational decreases and emotional reactions, could provide valuable insights. Investigating different crowd interruptions within this framework could directly benefit crowd management at events such as concerts or sports events, enhancing crowd monitoring and safety measures. Furthermore, the framework used in this thesis introduces a new discourse to the field of motivation, emphasizing mainly diversity and dynamism, with a focus on short-term motivation for movement or to reach a destination. Motivation theories used in this thesis, such as Atkinson's expectancy and value theory [48] or Lewin's conceptualizations [37], primarily address longer timeframes related to academic or work success. In contrast, the motivation framework developed in this thesis is designed and structured specifically to pedestrian activities in entrance scenarios, highlighting diversity within crowds and the fluctuations of motivation throughout goal pursuit, distinguishing it from the theories from which it is based. In future studies, this adaptation can be extended by integrating other related concepts, potentially leading to a newer version of these theories. Additionally, future research may apply this formulation of motivation to other contexts focusing on crowds, pedestrians, and short-term goal pursuits in scenarios such as protests, commercial events, evacuations, religious gatherings, and more.

Another noteworthy discussion point is how motivation was addressed in this thesis. With the exception of Study 1 in the first publication, all other studies explored scenarios where pedestrians formed groups or crowds. While motivation was treated as the sum of individual motives and incentives in a crowd, and this perspective was suitable for the hypotheses at hand, it doesn't provide the sole explanation for investigating motivation to move or reach a destination. Social influences can be just as significant as intrinsic motivations. For example, the main difference between Study 1 and Study 2 in the first publication arose from the contrast between being interrupted alone and in a crowd or in a social environment, potentially affecting the outcomes. The emotions resulting from obstructed motivation, such as impatience and boredom, might have been intensified or mitigated due to the social context or simply because being in a crowd can evoke different emotions that impact the concepts under investigation. For instance, Goffman [73] suggests that awkwardness occurs when individuals are unable to act freely due to external factors, which could significantly influence how interruptions affect motivation or goal-driven emotions. In another context, as demonstrated by Lügering, Alia, and Sieben [74], pushing behavior, as observed in Publication III as it increases as pedestrians approach the bottleneck, could also be influenced and increased by interactions with neighboring pedestrians, highlighting the importance of social dynamics among pedestrians. While the studies in this thesis primarily focused on individual effects and outcomes, the social dimension of motivation to move or reach a destination was somewhat overlooked in the publications. Future research could greatly benefit from considering motivation within its social contexts, which may provide equal importance and influence over the results.

As the final point, discussing how motivation and the respective outcomes of the studies could be transferred to real-life scenarios would be a valuable stance, as they might hold significant importance in certain situations. Motivation, while it's a psychological construct, has significant implications for crowd safety and engineering due to its pivotal role in influencing behavior. The thesis investigated two scenarios: one involving the interruption of goal-directed motivation and the other centered on motivation in entrance situations. It was found that when highly motivated individuals encounter a motivation block, it can trigger impatience, potentially leading to reckless behavior. Furthermore, the results revealed a connection between increased motivation and pushing behavior. Both of these results are known to have unintended consequences in crowds and pedestrian environments. While it may be tempting to suggest that the primary aim of crowd and pedestrian management should be to manipulate motivation levels optimally to minimize their effects on behavior, in reality, this approach would be impractical due to the complexity of the concept. Therefore, the main objective should be optimizing the resulting behavior, especially when motivation is known to be high. This can be achieved through effective crowd management, utilizing information from scientific literature, and pedestrian engineering practices, which may include creating effective queuing systems in crowds, minimizing intersections that could lead to disruptive interruptions, and designing pedestrian walkways accordingly, with a specific focus on areas where motivation is generally observed to be high.

In summary, this thesis takes a decisive step toward a comprehensive conceptualization of motivation in pedestrian and crowd dynamics. It explores various psychological and contextual aspects across different scenarios, attempting to create a generic framework that can inform future research and guide effective policy development. As humans continue to inhabit densely populated areas and remain interconnected within their social environments, all while pursuing their individual motives, it becomes crucial for researchers in crowd dynamics to explore relevant concepts, connect them to real-life situations, and propose efficient management strategies. Motivation stands out as one such concept, exerting a wide-ranging influence on behavior, including activities such as walking, running, pushing, or waiting, all serving as means for reaching the goal objective. These behaviors often intersect in crowded spaces, either directly or indirectly, highlighting their essential importance in human lives. Hence, we must continue investigating motivation and related concepts until effective management strategies are fully implemented.

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Don’t stop me now: Psychological effects of interrupting a moving pedestrian crowd and a video game

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Don’t stop me now: Psychological effects of interrupting a moving pedestrian crowd and a video game

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Abstract

Interruptions are a part of our everyday lives. They are inevitable in complex societies, especially when many people move from one place to another as a part of their daily routines. The main aim of this research is to understand the effects of interruptions on individuals from a psychological and crowd dynamics perspective. Two studies were conducted to investigate this issue, with each focusing on different types of interruptions and examining their psychological (emotion, motivation, arousal) and physiological (heart rate) components. Study 1 examined interruptions in a video game setting and systematically varied goal proximity (N = 61). It was hypothesized that being interrupted in the later stages of goal pursuit would create a high aroused impatience state, while interruptions in the earlier stages would produce a low aroused boredom state. However, the results showed that the hypothesized groupwise differences were not observed. Instead, interruptions created annoyance in all conditions, both psychologically and physiologically. Study 2 investigated interruptions in pedestrian crowds (N = 301) and used a basic motivational dichotomy of high and low motivation. In the experiments, crowds (80-100 participants) were asked to imagine that they were entering a concert hall consisting of a narrow bottleneck. The low motivation group reported feeling bored during the interruption, while the high motivation group reported feeling impatient. Additionally, a motivational decrease was observed for the high motivation group due to the interruption. This drop in motivation after the interruption is also reflected in the measured density (person/m2) in front of the bottleneck. Overall, both studies showed that interruption can have significant effects on individuals, including psychological and physiological impacts. The observed motivational decrease through interruption is particularly relevant for crowd management, but further investigation is needed to understand the context-specific effects of interruptions.

Keywords: Interruption; motivation; impatience; boredom; crowd dynamics; pedestrian dynamics; arousal

1 General Introduction

Being interrupted is one of the most common incidents in our daily lives. The natural order of the world, as well as many actions of individuals or groups, intersect at some level, making it improbable that these would never clash. A person can get interrupted while thinking, focusing, deciding, acting, or trying to finish something. This interruption can occur via a sudden noise, a message on the phone, a power cut, an earthquake, or just a random shift in attention. There are countless things that can interrupt people, and human brains are trained to cope with these surprise encounters to some extent [1].

Because it is so common, researchers have extensively studied and conceptualized interruption throughout the history of psychology. Interruption has been elaborated within various contexts such as memory [2, 3, 4], recovery of attention [5, 6, 7], learning [8], emotion [9], motivation [10], organizational behavior [11, 12], and so on. Some notable studies have found that interruption promotes better recall [2], creates a tendency or urge to return to the unfinished task [13], produces emotional behaviors [9, 14, 15], can evoke anxiety [12, 14, 16], or even spark positive feelings [12, 17].

Pedestrian events can be seen as a prominent context for interruptions to occur. The modern world has complex and effective transportation and pedestrian systems with many modes of transport (trains, cars, planes, sidewalks, etc.), however, the cost of having multimodal traffic is that people must wait for the intersecting objectives and routes of other travelers from time to time. This situation is heavily normalized since people expect a 'pause' to some extent and have a higher tolerance for the event (e.g., waiting at a stoplight, train delay). However, interruption also has a "surprise" component, which can be seen in many studies as mentioned above [1]. Even though it is normal for pedestrians to wait for a stoplight to some degree, some stoplights do not turn green quickly depending on the road and intersection density, or one might encounter more stoplights than expected (or no crosswalks) due to insufficient infrastructure.

So far, few studies have addressed interruption within the field of pedestrian dynamics. Tang, Huang, and Shang [18] added interruption (i.e., ticket control) as a component to their pedestrian-following simulation of plane boarding to acquire a more realistic model. Khan and Hoque [19] discussed the topic in a vehicle traffic context and argued that smooth traffic could be achieved with fewer interruption. Chen and Wang [20] investigated whether unexpected pedestrian crossings, as an interruption to vehicle flow, are a significant factor for overall traffic. Unfortunately, studies on the topic of pedestrian interruptions are far too few, and so far, the focus has solely been on the "flow disruption" of either pedestrians or vehicles. However, to have an overarching understanding of the subject, the psychological perspective of interrupted pedestrians must be investigated, and various types of interruption must be explored. This paper aims to provide a basis for a discourse on the above issues. A motivational framework, along with basic psychophysiological responses (heart rate) and crowd dynamics parameters (density), was chosen for investigating how different conditions result in different reactions to the interruption of pedestrian flow.

From the perspective of motivational theory, the phase of moving toward a goal is called the volitional process. The implementation of goal pursuit (volitional process) is set in motion as the post-decisional action, after the expectancy and value arrangement of the motivational state of mind [3]. An anticipated pause, such as waiting momentarily at the stop lights, would not affect the person since coping with what is expected is part of the process. However, if people do not expect to spend time waiting for more than usual, an interruption can alter the volitional process and potentially produce psychophysiological and psychological reactions.

Previous psychology studies with similar contexts investigated interruption and found varied results. It has been found that people may feel irritated and describe the situation as frustrating and unfair [21]. The situation can alter a person's perception and subjectively increase the delay time, making it seem longer than it actually is [21, 22, 23]. People can experience an impatience state [23], boredom [24], or anger [25] depending on the situation of the interruption event and the psychological background of the person (i.e., personality traits). Previous findings regarding psychophysiological reactions are also illuminating for exploring interruption in a pedestrian context. Studies with similar aims found that interruption causes an increase in heart rate and skin conductance levels, and has detrimental effects on working memory after the interruption [26, 27].

So, what makes these reactions vary in different interruption events during pedestrian activities? One explanation could lie within the 'valuation' concept, which implicitly increases the given value for the goal as time passes, that is, as the person is getting closer to the goal [23, 28]. A high valuation could potentially result in a more negative and aroused reaction when there is an interruption, whereas a low valuation could result in a more neutral reaction. Study 1 will focus on this distinction and formulate interruption as 'early' and 'late,' with different motivational and emotional responses, respectively.

Another possible explanation for different reactions to interruption could be a simple motivational distinction, that is, whether a person's motivation is high or low from the beginning. High or low motivation is known to alter attention, performance, and learning differently [29]. The starting motivation could likely lead to different outcomes if maintained until the interruption and could potentially alter the motivation after the interruption. Study 2 will, therefore, investigate and explore this notion while distinguishing between having 'high' and 'low' motivation.

2 Study 1

2.1 Introduction

'Valuation' is a concept whose potential to effect different interruption outcomes seems apparent since goal proximity is directly associated with the timing of the interruption. The goal proximity concept states that when people are close to their goals, then the valuation of the goal is much higher when compared with others who are still at the beginning of their goal pursuit [23]. In other words, being closer to an end (perception-wise, lengthwise, timewise) for achieving a goal increases the attractiveness of the task and its outcome.

When people are attracted to their goals, an interruption is potentially more disrupting and produces more annoyance when compared to situations in which people have low or no goal attraction [30, 31]. It can be assumed that a high physiological and psychological arousal would emerge within people when they are interrupted at the end of their goal pursuit. In contrast, people would be in a state of low arousal when they are interrupted at the beginning of the goal action.

What exactly do people feel in these kinds of situations? Motivation and state emotion literature provide some hints for structuring the different states that people experience in these kinds of situations. Although it has been studied in many different contexts, arousal theories define "state boredom" as unwanted arousal when there is a discrepancy between the task and the environment [32]. This discrepancy can easily be caused by an interruption event since the task cannot be completed due to the environment. Additionally, most studies have divided state boredom into high arousal and low arousal boredom (arousal in both physiological and psychological terms) [32, 33]. So far, studies have not agreed on a universal explanation for why boredom varies so much while it manifests itself physiologically and psychologically [32]. High arousal boredom has components of agitation with a higher heart rate, connected to a negative feeling, and an urge to flee from that state, while low arousal boredom is more related to a lethargic experience and tiredness with a lower heart rate [34].

While low arousal boredom can be considered as a more 'conventional' boredom, high arousal boredom has an 'impatience' component, and some studies have described state impatience similarly to what has been described for high arousal boredom [35]. Unfortunately, state impatience (or volitional impatience) that occurs in the post-decisional process has received little attention in the literature so far and does not include detailed theorizing, but it can still be used for labeling the state to create a more basic contrast with boredom. Most importantly, it can be assumed that people are expected to perceive a subjective time pressure, which is a key component of state impatience [35], when they are highly goal-focused, and an interruption occurs.

In this study, instead of using predefined state boredom components, impatience and boredom concepts were used separately, with their respective definitions in the state boredom discourse. Hypotheses for Study 1 were formed based on the expected psychological and physiological outcomes of the interruption state. An early interruption would produce a low arousal state, which would consequently be labeled as boredom. A low arousal state consists of a higher score on the disengagement subscale of state boredom and a lower heart rate. On the other hand, being interrupted while being nearly at the end would produce a highly aroused state due to the high valuation of the goal, and this state would thus be considered impatience. A high arousal state consists of a higher score on the high arousal subscale of state boredom and a higher cardiac output.

Due to Covid-19 restrictions during the study period, it was not feasible to conduct experiments with multiple participants in a pedestrian context. Thus, the study design was modified to solely focus on a game-playing context, involving one participant at a time. The study was designed to analyze how interruptions affected participants' emotions and heart rate levels while they were engaged in a video game.

2.2 Method

2.2.1 Participants and design

61 participants between the ages of 18 and 50 (mean age = 24.5; 41% female, 59% male) were recruited from Germany (18) and Turkey (43). The experiments were conducted in two countries due to practical reasons: participant collection in Germany during May and June 2021 was not successful enough to complete half of the quota due to the Covid-19 pandemic. The remaining participants were recruited in Turkey during July and August 2021, when/where the Covid-19 regulations were not too strict. Both samples had an equal number of participants distributed between experimental conditions.

After receiving a written ethical approval from the ethical committee of Bergische Universität Wuppertal, participants were recruited through Facebook posts, university announcements, physical posters, or verbal calls among acquaintances. All participants were provided with explanation links of the procedure and the payment (20 euros) they would receive for a two-hour experiment in which they would play a computer game.

The study design was a between-subject design; hence, all participants were randomly assigned to a condition (early interruption = 31 or late interruption = 30) without their knowledge of which condition they would take part in or whether there would be any condition at all. The true nature of the study was withheld from the participants until the completion of their respective experiments.

2.2.2 Measures

Scales
Two factors of the Multidimensional State Boredom Scale [32] were used to assess the overall state of participants. The scale consists of five factors: Disengagement, high arousal, low arousal, inattention, and time perception. Only the first two factors (disengagement and high arousal; 10 and 5 items, respectively) were used in this study as a two-dimensional measurement. Half of the items in the disengagement subscale were not used due to their association toward a broader time period, rather than focusing solely on the situation or the event (e.g., "Everything seems repetitive and routine to me"). Consequently, a total of 10 items (5 items from each factor) were used in this study to assess the state emotion of the participants. Throughout the article, these subscales will deliberately be written as "boredom" and "impatience" to avoid confusion with the other measurement methods. The response format was a 7-point Likert scale from 1 = Strongly disagree to 7 = Strongly agree, and higher scores indicated

higher levels of the boredom/impatience-related state. These items were hidden and scattered among self-made deceptive items. Approximately 30 items were created to hide the main items so that participants would not be suspicious that the interruption was intentional. The deceptive items varied in context and included happiness, excitement, anger, etc.

EcgMove 4 – ECG and activity sensor
Heart rate data was collected using an EcgMove 4 [36] device during the participants' gameplay and interruption periods. The device included two electrodes and was presented to participants as an easy-to-wear product that they could attach to their lower-left chest by themselves. Participants wore the device before the experiment began, and the recording started before they attached the device and stopped when the data was being exported.

As the device was unable to start and stop the recording remotely, we cut the raw data of each participant into their respective time periods (interruption, game playing, baseline) using Unisens Viewer software [37]. We used the exact time points that were collected during the experiment (i.e., start of the interruption and end of the interruption) for this purpose. Afterward, we calculated beats-per-minute averages of participants for the cut periods individually with Unisens Analyzer software [37]. The numerical data was then stored as an xls file for hypothesis testing in SPSS.

Due to the distortions and artifacts within the heart rate data, approximately one-third of the data was excluded from the main dataset. The main reason for this was that the experiments were held in the summer season, and it was up to 40 degrees Celsius in Turkey (average outdoor temperature for the experiment days = 36.2°C) at the time. The experiments were conducted in private offices with air conditioning, but it was not enough to create environment equivalent to that of Germany (average outdoor temperature for the experiment days = 24.4°C) in terms of temperature. For some cases, the heart rate device could not correctly gather the data due to the participants sweating before they arrived at the experiment location. The remaining data were processed as explained above.

2.2.3 Procedure

Each participant took part in the experiment individually. The time slot was decided as two hours for each participant since the experiment could have potentially lasted for more than one and a half hours. The approximate finishing time among participants was around one hour. The true nature of the experiment was withheld from the participants until the debriefing at the end.

Upon arrival, participants were informed that they would be playing a computer game [38] while wearing a heart rate device to measure their excitement level. They were also instructed to fill out a questionnaire about their overall experience at the end of the game. The experimenter explained that they would be monitoring the participants' game play via a Zoom screen share to record the exact times they entered specific locations. The game involved finding a specific place and playing hide-and-seek with a talking rock. The participants needed to find the talking rock three times to complete the experiment.

In reality, the experimenter only observed the participants to monitor their overall progress. In the "early interruption" condition, the experimenter interrupted the participants 15 minutes into their gameplay session by knocking and opening the door of the experiment room. The participants were informed that they needed to stop playing due to a technical problem with the heart rate device that needed to be addressed, and they were instructed to wait for "a little while". In the "late interruption" condition, the process was similar, but there were no set time markers; the interruption time was decided when the participants were close to completing the given task (i.e., finding the rock twice). The late interruption time points varied from half an hour to one and a half hours. Interruptions lasted exactly ten minutes in each condition.

During this ten-minute interruption, participants were asked to wait without doing anything. They were not allowed to play the game, go out of the room, check their phones, or use the computer in front of them. After the interruption finished, the experimenter came to the room again and acted as if the problem was solved but stated that the situation was also interesting for them. The experimenter recommended that the questionnaires should be filled out now instead of after finishing the game. While filling out the questionnaires, participants were asked to focus on the interruption experience rather than the actual game experience. After finishing the questionnaires, participants were asked to choose whether they wanted to continue playing or stop the experiment.

After quitting the game, participants were briefed about the true nature of the study and the reasons for the deception. They were told that they could withhold their consent if they wished to. Participants were also asked whether they had realized what was happening. Around ten participants (15%) stated that they were suspicious, but they had no idea about the exact nature of the study. Their data was also considered valid since they did not suspect the actual reason for the interruption.

2.3 Results

2.3.1 Boredom and Impatience

To explore whether early and late interruption produced different emotional / motivational states, two independent samples t-tests were conducted. The first analysis tested whether early interruption produced a boredom state more than late interruption. The analysis showed that there was no significant difference between early ($M = 4.05$, $SD = 1.3$) and late ($M = 4.02$, $SD = 1.19$) interruption in terms of boredom; $t(59) = .08$, $p = .94$, suggesting that the predicted increasing effect of early interruption on boredom state was not found. The following analysis was conducted to analyze whether late interruption produced an impatience state in the participants more than early interruption. The analysis also showed that there was no significant difference between late ($M = 3.56$, $SD = 1.28$) and early ($M = 3.72$, $SD = 1.38$) interruption in terms of impatience; $t(59) = .47$, $p = .64$.

2.3.2 Heart Rate

Mean beats per minute (BPM) were measured for every participant to explore the heart rate differences across variables. The mean of the interruption period (approximately 8 minutes; M = 84.28, SD = 11.31) and game-playing period (approximately 8 minutes; M = 82.72, SD = 11.84) were calculated for analyzing the main hypotheses. Additionally, a baseline period (questionnaire filling after the interruption period; approximately 8 minutes; M = 82.56, SD = 10.66) was calculated to see whether both game playing and interruption periods differed from a low arousal-inducing activity.

A repeated measures ANOVA showed that mean BPM differed significantly between different time periods regardless of whether the interruption period was early or late; F(2, 72) = 4.71, p = .012, np2 = .12 (Figure 1). The post hoc Bonferroni corrections revealed that there was a significant difference between the baseline and interruption periods (p = .013), but the difference between the baseline and the game-playing periods was not significant (p = 1). However, follow-up paired samples t-tests showed a significant difference between the mean BPM of overall playing and interruption periods, t(42) = -2.65, p = .011. The results indicate that the game-playing period does not differ from the baseline in terms of heart rate and can be described as a “normal” activity. Consequently, the interruption period significantly differs from both and can be interpreted as an “arousal-inducing” activity.

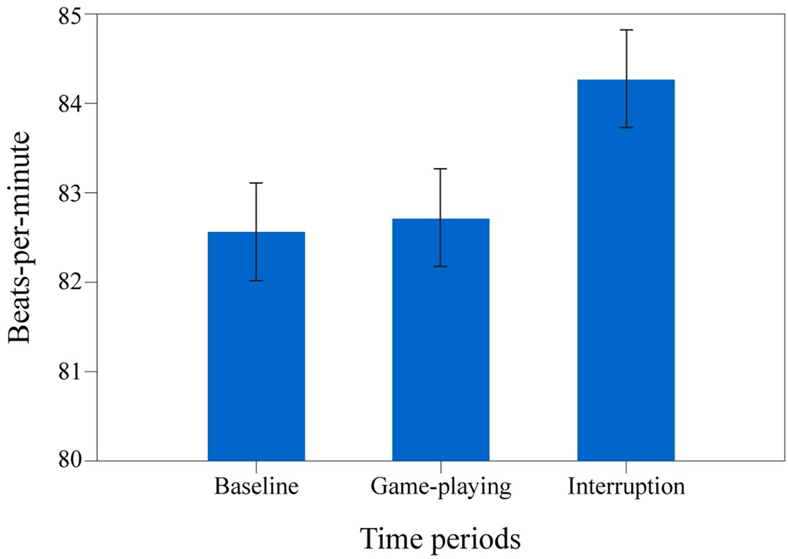

Figure 1: Mean values of participants’ heart rate. Baseline, game playing, and interruption time periods.

Paired and independent samples t-tests, along with ANOVAs, were conducted to explore whether early and late interruptions produce different outcomes in terms of heart rate. Focusing only on the interruption period, the analysis of the mean BPM of the interruption time between the early interruption group (M = 85.7, SD = 9.77) and the late interruption group (M = 81.52, SD = 12.1) showed that there was no significant difference between the conditions, t(45) = -1.3, p = .2, indicating that the interruption produces approximately the same effect in both conditions.

A 2 (BPM: playing & interruption) x 2 (condition: early & late interruption) mixed-design ANOVA (see Figure 2) revealed a significant main effect of the BPM period, F(1, 41) = 6.88, p = .012, np2 = .14. As previously stated, the interruption period had a significantly higher BPM than the game-playing period. However, the main effect of interruption type, F(1, 41) = .88, p = .35, np2 = .02, and the interaction between BPM period and interruption type, F(1, 41) = .02, p = .89, np2 = .00, were non-significant. Although the analysis was not significant, Figure 2 suggests that BPM was generally higher in the early interruption than in the late interruption condition. The overall course of the experiment can potentially explain this situation: the heart rate data for all participants showed a decreasing trend throughout the experiment period. Still, the effect is plausible since the arousal can often arise in a vague or ambiguous situation [39], such as participating in a psychology experiment. After time passes, the arousal can fade throughout the period if the event begins to be perceived as normal.

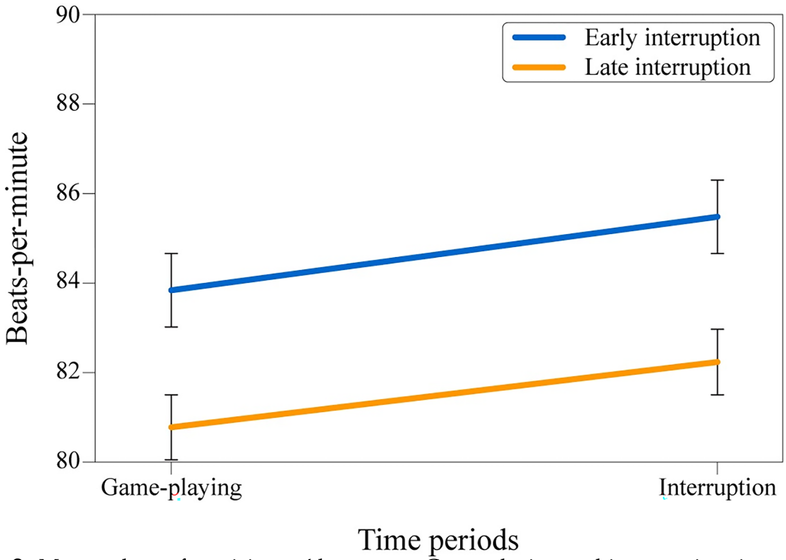

Figure 2: Mean values of participants' heart rate. Game playing and interruption time periods across conditions.

Lastly, samples from Turkey and Germany were analyzed with independent samples t-tests to observe whether these two groups differed. Neither the interruption period nor the game-playing period showed a significant difference between participants from Turkey and Germany, t(45) = -1.3, p = .19, and t(47) = -1.2, p = .87, respectively.

2.4 Discussion

Study 1 investigated whether interruption time, as early and late interruption, has a differentiating effect on the perceived emotional state and physiological arousal of people. It was hypothesized that early interruption leads to a 'bored' state and late interruption leads to an 'impatient' state, both psychologically and physiologically. The collected data showed no evidence for these hypotheses.

According to the results of the boredom and impatience questionnaire items, it does not appear that people associated their respective states with boredom when they were interrupted right after they started their goal pursuit, nor did perceived impatience increase when people were interrupted in the later stages of their goal pursuit. Furthermore, heart rate data showed an overall increase during the interruption period. The expectation was that a higher increase would be observed in the late interruption group than in the early interruption group. However, the increase was only valid for the whole sample but not for the two experimental conditions. Different location samples (Germany and Turkey), gender, or other demographic variables also showed no difference between their respective groups in any means of data collection.

To summarize, the timing of the interruption does not seem to have an effect on producing different negative state emotions. However, interruption itself led to an overall increase in perceived annoyance, both physiologically and psychologically, and there was no difference in annoyance levels between early and late interruptions.

3 Study 2

3.1 Introduction

Study 2 focuses on interruption outcomes in a crowd context. Due to the ease of Covid-19 restrictions, it was possible to have a 'crowd' experiment by taking into consideration the adjusted health rules. Study 2 had a bottleneck setup in which 80 to 100 participants were instructed to rush towards and through a gate to enter an imaginary concert (for six consecutive runs). Additionally, two levels of a motivational drive were used in this study: High and low motivation for reaching the bottleneck. Previous studies have shown that high or low motivation produces distinct outcomes in attention, performance, and learning [29]. Furthermore, motivation has proven to be one of the key factors in crowd dynamics [40]. It is expected that the experience of an interruption depends on motivation and is more disruptive in a goal pursuit while highly motivated when compared with low motivation. Psychological and physical arousal during an interruption is expected to be higher in people with high motivation and lower in people with low motivation. Unlike Study 1, which used "timing" (early & late) as an interruption component, Study 2 used instructed motivation (low & high) instead. Impatience and boredom factors were also assumed to be significant for this setup since the definition of state boredom as "unwanted arousal caused by task and environment discrepancy" is still heavily related to the experimental setting.

The hypotheses for Study 2 were formulated based on the same framework as Study 1. It was hypothesized that an interruption for people with low motivation would result in a low aroused state, and this state can consequently be labeled as boredom. A low aroused state consists of a higher point in the disengagement subscale of state boredom and a lower heart rate. In contrast, an interruption for people with high motivation would lead to a highly aroused state, and this state can be considered impatience. A high aroused state consists of a higher point in the high arousal subscale of state boredom and higher cardiac output. However, due to the movement factor of the experiment, an increase in heart rate during the interruption period compared to the walking phase was not hypothesized. As people would not be able to move forward during the interruption period, a “constantness” for the heart rate was hypothesized instead of an increase. Details regarding this aspect will be discussed in the next sections. An additional questionnaire item was created for people with high motivation, and it was hypothesized that an interruption for highly motivated people would reduce their level of motivation.

3.2 Method

3.2.1 Participants and design

The experiments in Study 2 were part of a larger set of experiments in that included various crowd studies conducted over four days, with a total of 1200 participants [41]. The experiments were conducted at Mitsubishi Electric Halle in Düsseldorf, a concert venue, in October 2021. All participants were recruited through local newspapers and media announcements, and they were briefed about the experiments and any risks involved. Participants signed informed consent forms before participating, and a written ethical approval for the experiments had been obtained from the ethical committee of Bergische Universität Wuppertal prior to conducting the experiments. Each participant received 70 euros per day (between 10 a.m. and 4 p.m.). The study experiment was held on the third day after the lunch break. Three groups, each consisting of 80-110 participants, were randomly selected for the interruption experiments, resulting in a total of 301 participants. The age of the selected participants ranged from 18 and 75 (Mean age = 35,6). The gender distribution among participants consisted of 154 (51%) women, 128 (42%) men and 19 (7%) others.

The study design for Study 2 was a mixed design, where each group participated in the study twice (three groups, a total of six runs); first without interruption and then with interruption. Once again, participants were not informed about the true nature of the study at the beginning, as the interruption event was not mentioned beforehand. The three groups were divided based on their assigned condition, with two groups having high motivation and one group having low motivation. The assigned motivation condition was used for both runs, with and without interruption.

3.2.2 Measures

Scales

Two factors (disengagement and high arousal; a total of 10 items) of the Multidimensional State Boredom Scale [32] were used to assess the overall state of participants within an interruption context as in Study 1. The response format was a 7-point Likert scale ranging from 1 = Strongly disagree to 7 = Strongly agree, with higher scores indicating higher levels of the boredom/impatience-related state.

The Motivation Scale, created for CroMa-Project, was also used to measure how people felt during a bottleneck/interruption situation. After their experimental run had finished, the scale was presented to participants twice, and they were asked to evaluate two different situations: one considering the time period before the interruption and another considering the time period after the interruption. The aim was to measure the change in motivation of the participants depending on the interruption.

Due to time constrains and the rapid structure of the experiments in Study 2, no deceptive questionnaire items were employed. These items were exclusively administered to participants in Study 1 to conceal the primary objective. However, in Study 2, presenting these items (which comprised more than 60% of the overall items) was deemed redundant and time-consuming, given that interruptions are inherent in pedestrian experiences. Following the questionnaire, participants were debriefed on the true nature of the study.

EcgMove 4 – ECG and activity sensor

20 EcgMove 4 [36] devices (maximum number of devices at our disposal) were used to collect HR and HRV data from participants during the experiments. 20 participants from each group (a total of 60) were randomly selected and instructed to wear the device before the experiment began.

The raw data of each participant was then cut manually into their respective time periods (interruption, before interruption, and after interruption) using Unisens Viewer software [37]. These time periods, along with their start and end time points, were recorded during the experiments (as in Study 1). The recorded time points were based on the entire group's action: The before interruption time period started when participants were instructed to go to the bottleneck area and ended when they were interrupted; the interruption time period ended when they were informed that they could proceed; the after interruption time period ended when the last person went through the bottleneck.

After the cutting process, beats-per-minute averages of participants for the cut periods were calculated individually with Unisens Analyzer software [37]. The numerical data was then stored as an xls file, for hypothesis testing in SPSS.

Feedback terminal

Participants were presented with a smiley feedback terminal [42] as they exited the bottleneck area. They were encouraged to tap one of the smiley buttons on the device to provide feedback on their overall experience of the experiment. The terminal displayed the question "How did you feel in the experiment?" and included four different smileys, namely, very happy (4), happy (3), unhappy (2), and very unhappy (1). Almost all participants clicked on the device in each experimental run. The data was then stored as an xls file for testing in SPSS.

Video recordings
Video and audio recordings were taken from three top-down cameras (focusing on different parts of the experiment area) to capture the trajectory data of pedestrians. These trajectories were later used to calculate the density of each group in different time periods. The procedure was as follows: PeTrack software [43] was used to detect the trajectory paths of all pedestrians. All trajectories were individually checked and corrected using PeTrack. Manually corrected trajectories from the three cameras were then merged into one full trajectory file for each experimental run. These files were in .txt format and contained pixel coordinates for everyone for each frame. These files were then used to calculate individual Voronoi densities and plot them using the PedPy package in Python [44].

Video recordings were also used in this study to gather the exact timing of the heart rate recordings and for observational purposes. Participants were briefed about the recordings prior to the experiment.

3.2.3 Procedure

Study 2 had a bottleneck/pedestrian context and was designed to withhold the interruption information from participants. Experimenters acted again as if a technical problem caused the interruption.

Participants were asked to imagine a context where they are about to watch their favorite singer in a concert. In the high motivation condition, participants were told the following: “Imagine you are on your way to a concert by your favorite artist. You know that at the back you can hardly see anything at all or only the video screen. You absolutely want to be standing next to the stage and therefore want to access the concert as fast as possible. After a signal, we will open the entrance” (translated from German). In the low motivation condition, they were instructed: “Please imagine that you are on your way to a concert by your favorite artist. You know that everyone will have a good view. Still, you would like to access the concert quickly” (translated from German).

After these instructions, each group walked to the area directly in front of the bottleneck and waited for the bottleneck to be opened. The first run for each group was always a “without interruption” run: Participants were able to cross the platform after the bottleneck was opened. In the “with interruption” runs, experimenters interrupted the participants after a couple of seconds with a verbal ‘stop’ order while acting as if there was something wrong with their technical equipment. The interruption lasted approximately two minutes, and participants were instructed to wait and not cross the bottleneck during this period while remaining in their position (see Figure 3 for the complete process).

The first group was the low motivation group. The second and third groups were high motivation groups because a repetition was thought to be needed; a

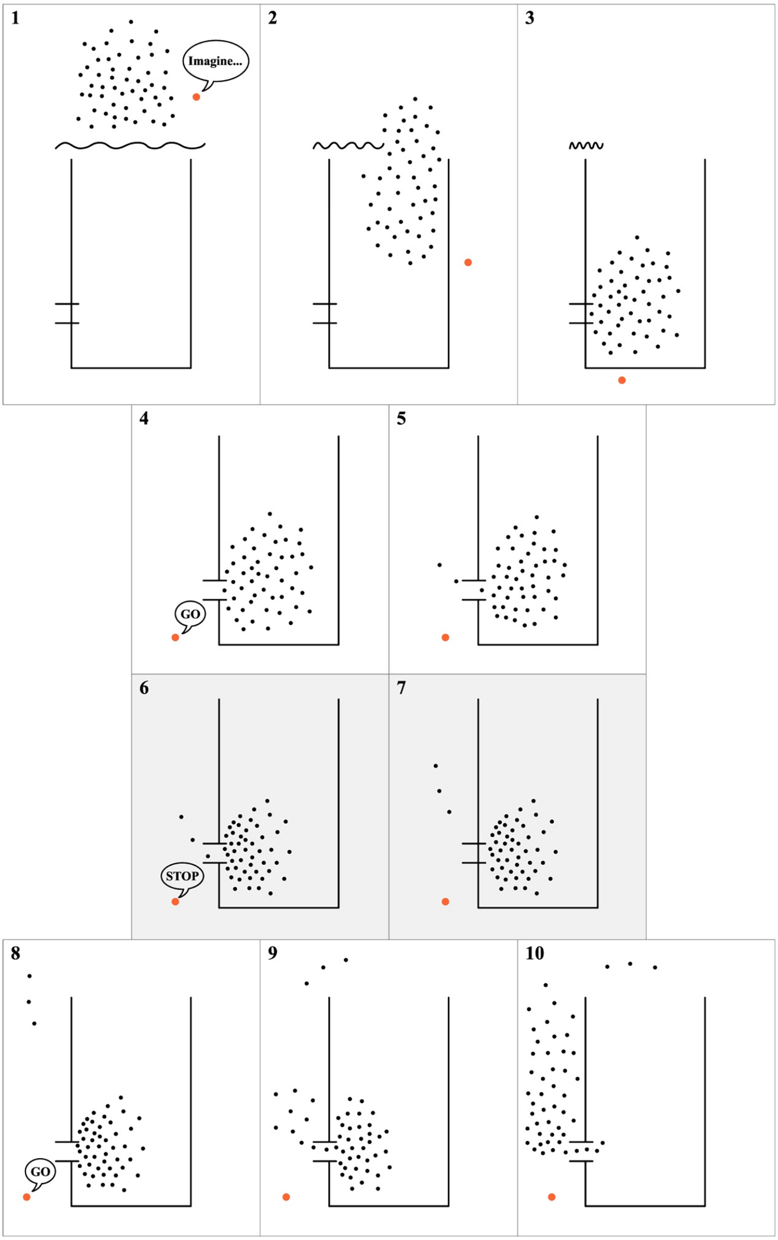

Figure 3: Complete experimental process. The order of the drawings can be followed through the image numbers. The grayed background drawings represent the interruption period (two minutes). The orange dot represents the position of the experimenter giving instructions.

person fell to the floor in the second group during the run, although it was later decided to use the data of both high motivation groups.

After each run, participants were directed to tap the feedback terminal and were instructed to fill out a questionnaire. Afterward, participants were briefed about the true nature of the experiment.

3.3 Results

3.3.1 Feedback terminal

A two-way ANOVA was conducted to examine the effect of interruption (without [M = 3.24, SD = 0.94] and with [M = 2.71, SD = 1.02]) and the motivational condition (high [M = 2.45, SD = 1.02] and low [M = 3.49, SD = 0.72] motivation) on the overall mood of the participants. There was no significant interaction effect ($F(1, 588) = 3.156$, $p = .076$, np2 = .001, see Figure 4) but there were two main effects: A significant difference in the mood of the participants between motivation groups ($p < .001$), and between runs with and without interruption ($p = .004$). These results indicate that the mood was better during low motivation runs than the high motivation runs and better during runs without interruption compared to runs with interruption.

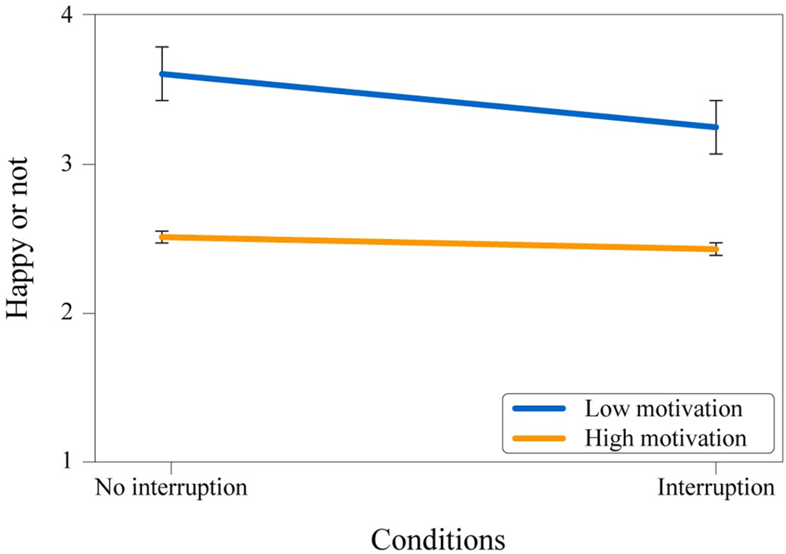

Figure 4: Mean values of participants' mood on interruption (with/without) and experimental condition. 1: Very unhappy, 4: Very happy.

3.3.2 Boredom and impatience

To explore whether having high and low motivation produces different emotional states, two different independent samples t-tests were conducted for the interruption runs. The first analysis aimed to test whether having low motivation during an interruption incident produces a greater sense of boredom in participants than having high motivation. The analysis showed a significant difference between low motivation (M = 4.22, SD = 1.48) and high motivation (M = 3.82, SD = 1.56) in terms of the participants' perceived boredom state; t(293) = 2.12, p = .035, indicating that an effect of low motivation on boredom perception.

The second analysis was conducted to see if having high motivation produces an impatience state in the participants more than having low motivation during the interruption. The analysis confirmed that there was a significant difference between having high motivation (M = 3.37, SD = 1.55) and having low motivation (M = 2.69, SD = 1.46) for the impatience state; t(296) = 3.69, p < .001. These results correspond to the initial hypothesis.

Follow-up tests were conducted for all runs (without interruption and interruption runs combined) to explore solely impatience and boredom items (I feel bored & I am impatient right now) because only these items were presented to the participants in without interruption runs instead of the whole scales. A two-way ANOVA was conducted to examine the effect of interruption and instructed motivation on the "I feel bored item." There was no significant interaction between the dependent variables on this item; F(1, 596) = .38, p = .54, np2 = .001. However, simple main effects analyses showed that there was a significant difference in feeling bored between motivation groups (p = .001), and there was a significant difference in feeling bored between the runs with and without an interruption (p < .001) (see Figure 5). Another two-way ANOVA was conducted to examine the effect of interruption and instructed motivation on the "I am impatient right now" item. There was a significant interaction between the dependent variables on this item; F(1, 601) = 4.3, p = .039, np2 = .007, indicating the impact of being interrupted or not on impatience depends on the initial motivation level (see Figure 6). Simple main effects analyses also showed that there were significant differences in being impatient between motivation groups (p < .001), as well as between whether interruption happened or not (p = .038).

3.3.3 Motivation

A 2 (motivation level: motivation before the interruption & motivation after the interruption) x 2 (condition: high or low motivation instruction) mixed-design ANOVA (see Figure 7) was conducted to observe whether motivation levels decreased due to the interruption event. The analysis showed that there was no significant main effect of the interruption on motivation level; F(1, 589) = 3.34, p = .068, np2 = .006. However, the main effect of the initial motivational instruction was significant, F(1, 589) = 79.67, p < .001, np2 = .119, along with the interaction between the initial motivational instruction and interruption, F(1, 589) = 24.03, p < .001, np2 = .039. Results indicated that the interruption decreases the motivation level when people are highly motivated but it has the opposite effect when people have low motivation.

3.3.4 Heart Rate

Mean beats per minute (BPM) were measured for 20 participants in each group for a total of 60 participants (high motivation, M = 90.16, SD = 12.25; low motiva-

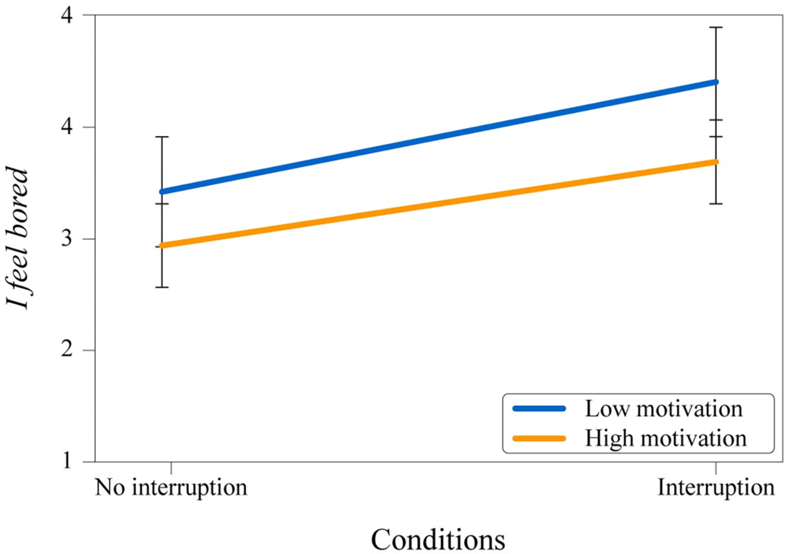

Figure 5: Mean values of "I feel bored" item. Interruption (with/without) and experimental condition.

tion, M = 85.09, SD = 16.07) to explore the heart rate differences across variables. The mean of interruption period (approximately 2 minutes; M = 82.9, SD = 15.17), the mean of "before interruption" period (approximately 2 minutes; M = 92.14, SD = 15.98), and the mean of "after interruption" period (approximately 2 minutes; M = 91.61, SD = 13.36) were calculated for analyzing the main hypotheses for the interruption runs. Due to the distortions and artifacts within the heart rate data, the data of five participants were excluded from the dataset.

A repeated measures ANOVA showed that mean BPM differed significantly between different time periods in interruption runs regardless of the instructed motivation; F(2, 90) = 30.21, p < .001, np2 = .401. The post hoc Bonferroni corrections revealed that there was a significant difference between before interruption and interruption periods (p < .001) and after interruption and interruption periods (p < .001): The BPM was lowest during the interruption period. However, there was no significant difference between before and after interruption periods (p = 1). Therefore, the expected increase or constancy between the interruption period and the other periods was not found; heart rate data showed a significant decrease during the interruption period. The discussion section will explore possible reasons for the unexpected 'opposite direction' effect.

An independent samples t-test was conducted to explore whether having high or low motivation matters regarding the participants' heart rate. Focusing only on the interruption period, the analysis of the mean BPM between high (M = 84.05, SD = 14.52) and low (M = 80.53, SD = 16.68) motivation conditions showed that there was no significant difference between conditions, t(47) = .758, p = .45. The results showed that interruption produces the same effect in terms of heart rate in both conditions. Still, the relatively small sample size might have

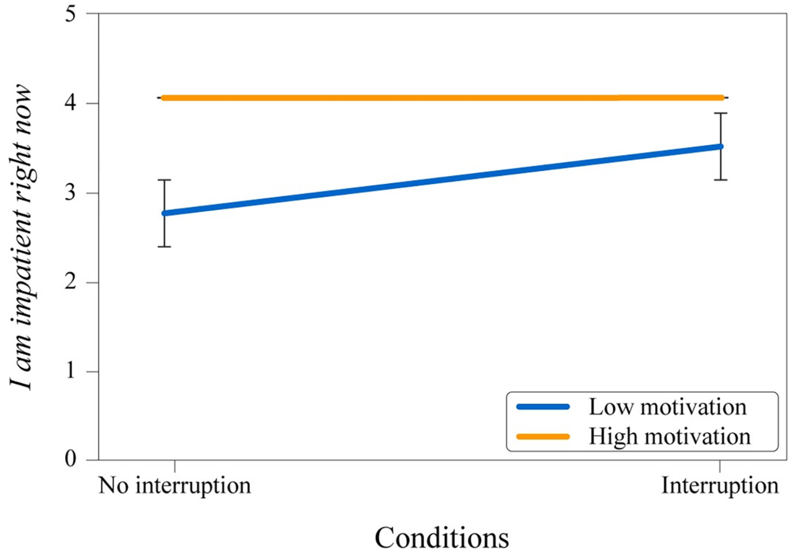

Figure 6: Mean values of "I am impatient right now" item. Interruption (with/without) and experimental condition.

caused this outcome.

A 3 (BPM periods: before & during interruption & after) x 2 (condition: low & high motivation) mixed-design ANOVA (see Figure 8) revealed that there was a significant main effect of the BPM period, F(2, 88) = 24.763, p < .001, np2 = .36, indicating that periods had significantly different heart rate outputs. However, the main effect of motivation type, F(1, 44) = 1.43, p = .238, np2 = .032, and the interaction between BPM period and motivation type, F(2, 88) =1.89, p = .157, np2 = .041, were not significant (potentially caused by the relatively small sample size). The results suggested that the effect of motivation type over heart rate was not found.

Lastly, a 2 (BPM periods: before interruption period & after interruption period) x 2 (condition: low & high motivation) mixed-design ANOVA (see Figure 9) was conducted to explore hypothesized motivational decrease across conditions in the heart rate context. The analysis revealed that the main effect of the BPM period; F(1, 44) = .03, p = .86, np2 = .001, the main effect of the motivation type; F(1, 44) = 2.23, p = .143, np2 = .048, and the interaction between BPM period and motivation type; F(1, 44) = 1.46, p = .233, np2 = .032, were all non-significant. The results suggested that an observable effect of the heart rate between conditions and interruption was not found. Although the outcomes were not significant, the direction of the effect indicated a decrease in the "after interruption" period for the high motivation group and an increase for the low motivation group, similar to the motivation questionnaire results.

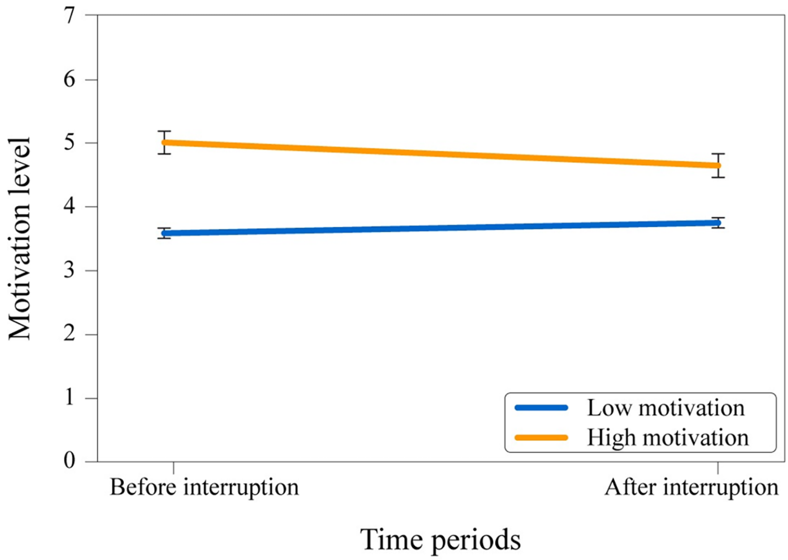

Figure 7: Mean values of different motivation time periods and experimental conditions.

3.3.5 Density

Using a 1.5x1.5 square meter measurement area, located half a meter away from the entrance, individual Voronoi density time-series data were calculated and plotted for all participants in each experimental run. The time periods were named "before," "interruption," and "after" for the interruption runs (see Figure 3 for the overall experiment procedure), and "before" and "after" for the without interruption runs. The interruption runs consisted of two high motivation and one low motivation, a total of three runs. Similarly, the without interruption runs consisted of one high motivation and two low motivation, also a total of three runs.

The density plots of the three interruption runs are shown in Figure 10. The density levels vary significantly throughout these three runs, although the pattern is similar. The "before" period shows a steep increase, followed by a plateau. The "interruption" period is characterized by a constant density. During the "after" period, the density decreases quickly or slowly, depending on the level of motivation.

It's worth noting that before the interruption starts, there was always a small time window where participants were allowed to pass through the bottleneck (see Figure 3 for the overall experiment procedure). This time period was colored orange in Figure 10, the same as the "after" time period since it had the same properties. In the high motivation runs, a spike in density occurred before this small time window, presumably due to the excitement of participants at the prospect of reaching their goal after positioning themselves around the bottleneck area. This situation can be seen as a result of high motivation, although the same spike did not occur with the same intensity after the "interruption" time period finished, when participants were free to exit the bottleneck with-

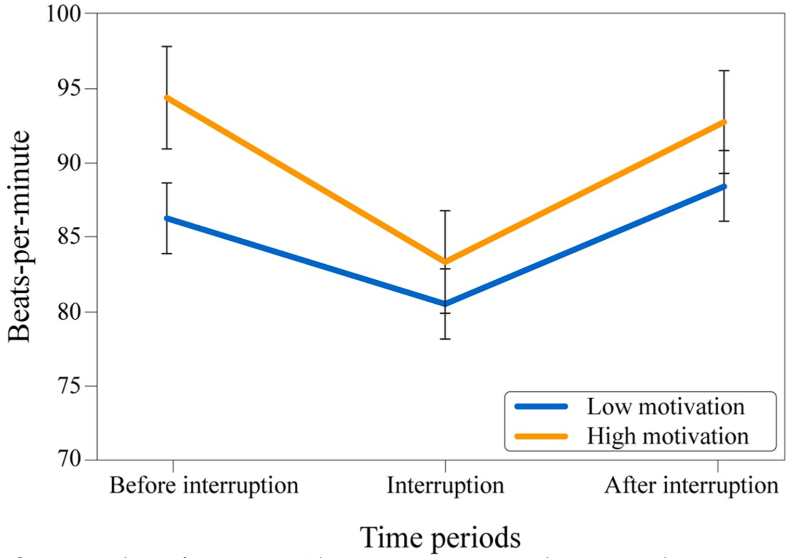

Figure 8: Mean values of participants' heart rate. Experimental time periods across conditions.

out further interference. A motivational decrease caused by the interruption, as found in the questionnaire data (also hinted in the heart rate data), could be the explanation for this situation as well. The same density-increasing environment did not appear after the interruption in high motivation runs. On the other hand, we did not find an effect like this in the low motivation run, neither in the questionnaire data nor in the density plots.

Regarding the without interruption runs, the density plots can be easily interpreted. The density increases throughout the first placement period as participants move to the bottleneck area. A plateau can be observed afterward. The density decreases gradually after participants were instructed to exit the bottleneck (Figure 11).

3.3.6 Qualitative observations

It was later decided that explorative-qualitative behavior analysis in video recordings was also to be conducted to capture the complete picture of the experiments and to provide insights for future research. Initial observations regarding the different motivation instructions mainly focused on how people behaved during the interruption. These observations were done during the experiments and written as notes while the experimenters were within a few meters of the crowd, just outside the bottleneck area. It was observed that participants who had received the low motivation instruction were mostly in a relaxed state during the interruption (i.e., yawning, relaxed body postures). On the other hand, participants who had received the high motivation instructions showed more tense body postures and constantly looked around to understand what was going on. One participant was noticeably clicking his pen during the whole interruption period. Regarding the motivation between and after the interruption, it was

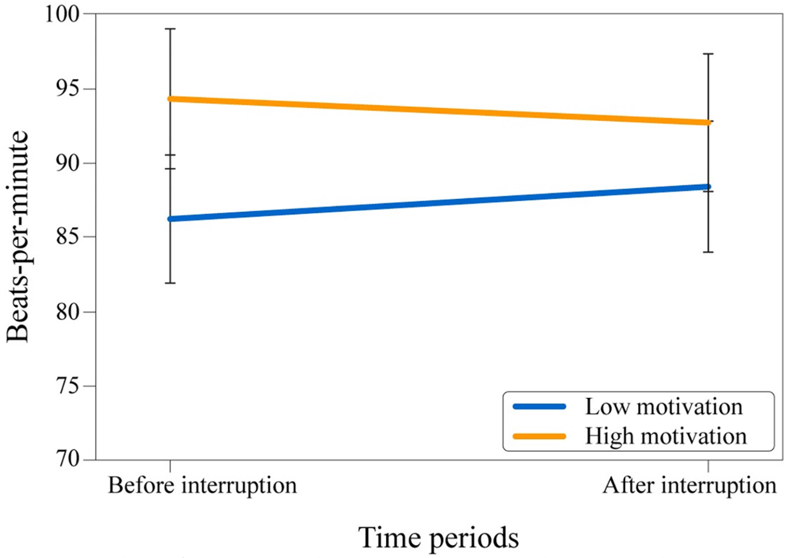

Figure 9: Mean values of participants' heart rate. Experimental time periods across conditions.

observed that participants were relatively slower (or relatively lacking interest) when exiting the bottleneck.

Additional observations were made afterward from video recordings. During the low motivation runs (Figure 12), the waiting behavior caused by the interruption did not seem as arousal-inducing. People were not moving regularly; that is, they were mostly standing still apart from occasional head movements to check the environment. They occasionally talked with each other, seemingly trying to make sense of what caused the interruption. The density was not high in the sense that the participants had enough personal space to make themselves comfortable in a crowd situation. It might be the case that the relative relaxation occurred from the low-density environment, although the low motivation instruction was what created this environment to begin with.

On the other hand, in the high motivation runs (Figure 13), participants moved more frequently, and made more head movements, which can be interpreted as being in a higher state of arousal during the interruption period compared to the low motivation interruption period. The most distinct body posture during the interruption was the "crossed-arms" position. Participants talked to each other more regularly and laughed from time to time, presumably due to the unexpected close-body-contact situation. The density was much higher, and people were close to each other, especially near the bottleneck area. The high-density formation seemingly created a crowded but awkward situation where participants checked the environment more frequently as they tried to make sense of it.

In addition, a decrease in motivation was observed during the high motivation runs. Initially, most participants were relatively fast and pushed others to reach the bottleneck when the experiments started. However, after the interrup-

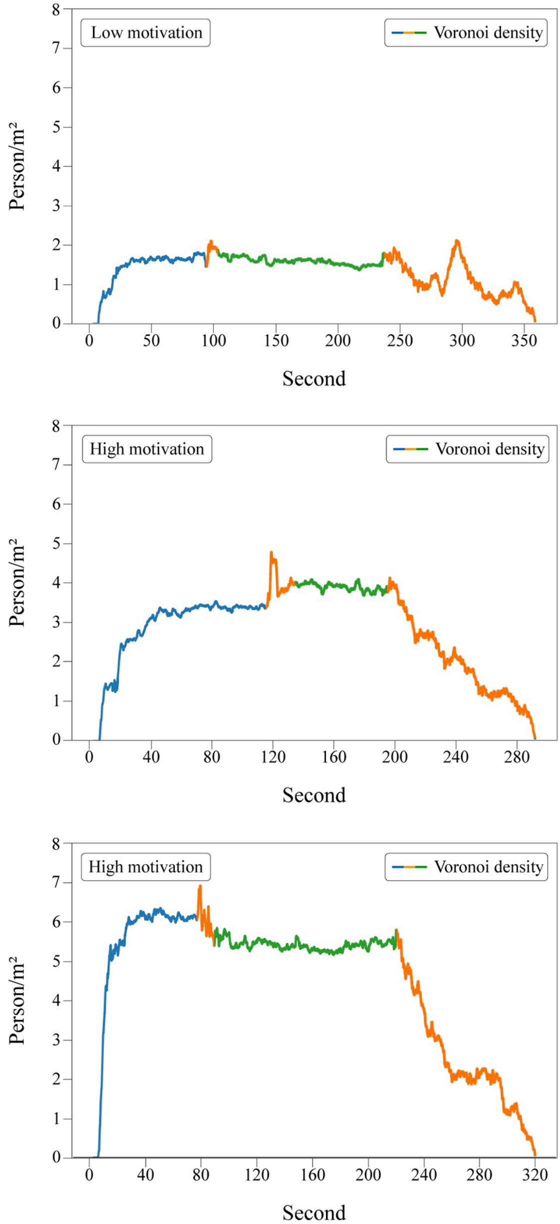

Figure 10: Merged density plots for interruption runs. Colors represent the time periods: 'Blue' indicates the time when participants were moving towards the gate while it was still closed. 'Green' indicates the interruption time period. 'Orange' represents the time when the gate was open, and participants were exiting through the bottleneck. Note that the gate was first opened, then closed for the interruption, and then opened again. Both periods were represented as orange accordingly.

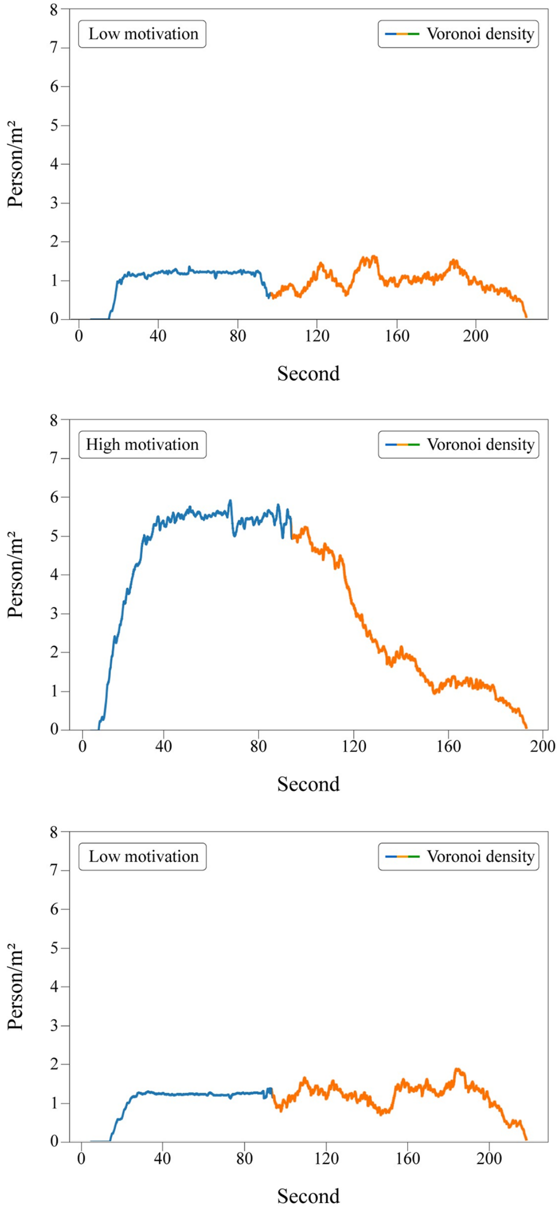

Figure 11: Merged density plots for without interruption runs. Colors represent the time periods: 'Blue' indicates the time when participants were moving towards the gate while it was still closed. 'Orange' represents the time when the gate was open, and participants were exiting through the bottleneck.

Figure 12: A screenshot from low motivation experimental runs, during interruption.

Figure 13: A screenshot from high motivation experimental runs, during interruption.

tion, only a small group of participants (approximately 20) who were directly in front of the bottleneck continued to behave in this manner. The rest of the participants created their own personal space and put small distances between themselves and the others during the interruption time period. They waited for these 20 participants to move forward and started to exit the bottleneck one by one without showing excessive acceleration or pushing.

3.4 Discussion

Study 2 explores whether low or high motivation levels cause different emotional or psychophysiological reactions during an interruption event. It was hypothesized that having low motivation when interrupted leads to a 'bored' state but having high motivation when interrupted leads to an 'impatient' state, both psychologically and physically.

The results of the boredom and impatience scales showed that people perceived their respective emotional states in accordance with the initial motivation priming that they were given. If they had high motivation and got interrupted, they associated themselves with an impatience state. Similarly, they associated their respective state with boredom if they had low motivation and got interrupted. Sole impatience and boredom items (I feel bored & I am impatient right now) were also investigated separately. It was found that whether people were bored or impatient mainly depended on their initial motivation instruction, but they were more bored if there was an interruption for the low motivation instruction. The same outcome was also valid for being impatient for high motivation priming, although the effect was smaller. People with high motivation priming were substantially more impatient when there was an interruption and slightly less when there was no interruption. Perhaps this situation was caused by the high motivation priming being more intense than anticipated.

Regarding the heart rate results, no differences were found between the conditions. While this was unexpected, finding the hypothesized outcomes regarding heart rate was difficult to begin with due to the "movement" factor of the experiment. This factor may have had a greater impact on heart rate than the difference between high and low motivation or the interruption. Normally, it would be assumed that an interruption would increase heart rate due to annoyance, but in the context of the experiment, people were forced to move forward during every other time period apart from the interruption period. During the interruption, people were expected to remain still because the path forward was blocked. Taking this into consideration, it was not expected that heart rate would increase, but a non-decrease situation was predicted. However, the results showed that the heart rate meaningfully decreased during the interruption period for all groups. It might be the case that the hypothesis undervalued the effect of the movement.

The hypothesis that the interruption causes a decrease in motivation (as measured before and after the interruption) received expected statistical support. Motivation significantly decreased due to the interruption for the high motivation group, which was consistent with the observations in the experiment area of participants moving slower after the interruption, especially for the high motivation group. Additionally, a sharp increase in density when the bottleneck opened was only measured in high motivation runs before the interruption, not after. However, heart rate data did not show a meaningful decrease for the time period after interruption for the high motivation group – the trend in this direction was not significant.

4 General Discussion

The present studies investigated different types of interruption events in pedestrian dynamics and game-playing contexts. Firstly, as the literature suggests, it was found that interruption itself affects the respective emotional and motivational state of a person regardless of the type of the interruption, and this particular state often has a negative connotation [15, 21, 23, 24, 27]. Following these notions, two different dichotomies, namely early vs. late and low vs. high motivation interruptions, were explored throughout the studies. Early and late interruption yielded no difference, indicating that valuation and goal proximity concepts either had no effect on increasing the annoyance and arousal of the person through an interruption event or the study design failed to create a corresponding environment to produce the effect. However, low or high motivation showed a meaningful contrast between the emotional and motivational states of people exposed to the interruption. It can be cautiously concluded that the interruption timing has no importance for differentiating the emotional state of a person, but the initial motivation produces varied psychological and psychophysiological outcomes when there is an interruption.

Regarding boredom and impatience assumptions, it was found that these states are indeed distinct, even though state impatience literature does not have detailed theorizing so far [35]. State boredom normally includes impatience as a factor within its discourse [32, 33], but it was found that people were keen to perceive themselves as impatient rather than bored in certain situations. If people are highly motivated and get interrupted, they perceive themselves as high aroused or impatient. If people have low motivation and get interrupted, they consequently express their state as being bored or in a state of low arousal.

Continuing with the psychophysiological properties of the hypotheses, the collected data provided mixed results. Few differences were found in the timing of the interruption and the motivational effects of the interruption. Although the direction of the heart rate was as predicted for most cases, the data did not show a statistically significant difference in most situations. People did not have a higher heart rate when they were interrupted in the later stages of their goal pursuit, nor did they have an increase in heart rate when they were interrupted while they were instructed to be highly motivated. However, notably, while the data showed an increase in the heart rate during the interruption period for people in a 'resting' situation (Study 1), the results showed the opposite for people in a 'moving' environment (Study 2). These results show that measuring heart rate with moving participants is challenging.

Lastly, although not studied in Study 1, a decrease in motivation caused by interruption was hypothesized and found in several data from Study 2, suggesting that interruption can impact motivational processes. The participants' motivation decreased for the high motivation group, aligning with what was observed during the experiments. Furthermore, the spike in density after the first bottleneck opening was not repeated after the second opening, suggesting that participants were more active before the interruption compared to after it.

4.1 Limitations

Study 1 had a unique nature due to the Covid-19 situation, which greatly affected experimental research worldwide. Initially, it was decided to hold a crowd experiment, but the experiment context was later changed to individual participation in video game playing because of the restrictions. The early and late interruption conditions should be replicated and put into perspective in a crowd scenario in the future.

Another limitation was encountered for Study 1 while collecting the heart rate data of participants. The collected data were relatively good for the participants in Germany, but there were many instances of data corruption and artifacts from the heart rate data collected from participants in Turkey (see Study 1 - Method - Measures - EcgMove 4). Nearly one-third of the data was unable to be used, presumably because of the heat.

The last limitation of the study is the selected video game: It is possible that the game was not alluring for most participants and therefore did not promote a meaningful annoyance after they were interrupted.

Study 2 did not have any major limitations, almost all experimental runs were held according to the plan, and the collected data did not contain any problems. However, the experimental runs consisted of approximately 100 participants, but we could only provide 20 heart rate devices to the participants due to the limited number of devices at our disposal. We believe that the collected data from 20 devices were enough to represent the rest, but it was still a limitation that might potentially influence the generalizability of the data. Some data show a clear picture but do not reach the threshold of significance (i.e., Figure 9), and this might partly be due to the comparatively small sample size. Furthermore, the heart rate data showed the effects of movement more strongly than expected, which potentially overlayed other effects such as impatience. One direct solution to avoid this situation would be to create a crowd experiment in which the participants are interrupted while they are already waiting, thereby excluding the movement effect (i.e., an unexpected delay in starting the entrance procedure).

4.2 Future directions and implications

Future studies could expand on various types of interruption. This paper examined whether early or late interruption, or having high or low motivation, has a different impact on the state emotion of the individual who experienced an interruption. A potential future study could explore whether a brief interruption period can elicit a different emotional response compared to a prolonged interruption period. Another possible idea would be to investigate whether interruption and waiting have varying effects on emotional states when individuals are informed about the reasons for the wait.

The results of these studies can also have implications for pedestrian dynamics and traffic contexts. The findings suggest that people's reactions to interruptions can vary, and they may experience states such as boredom and impatience, but it is also known that impatient reactions can pose a risk to traffic safety [35]. People may behave recklessly when it comes to route choices or driving, which can lead to safety issues if interruptions occur during goal pursuit, even if the goal is a routine one such as reaching home. Perhaps the main objective of future policies should be to achieve traffic and pedestrian flow which consist of the minimum number of interruptions possible.

Another valuable aspect to explore in future studies is the sole effect of interruption on motivation, which was statistically observed in Study 2. If this effect of a motivational decrease during interruptions exists in other scenarios, it could be utilized as a method to reduce "motivation" in tense crowd environments. However, the length of the interruption and other factors must be thoroughly studied, as prolonged interruptions could potentially worsen the crowd's tension, as seen in situations such as concerts or sporting events. Furthermore, interrupting only a portion of the crowd could potentially lead to increased density, as individuals in the rear may attempt to push forward. Therefore, it is necessary to make the interruption information accessible to the entire crowd to avoid this unintended consequence.

Broadly viewed, the experiments in this paper contribute to an overall individualistic perspective on motivation. Only individual emotions, bodily reactions, or intentions were measured in both studies. Although a crowd was used in Study 2, it was treated as a large sample size of individuals moving toward a goal. Future studies can potentially investigate the social aspects of interruption events since both individualistic and social effects are intertwined in a crowd context. It is worth exploring what people do to pass the interruption time and how different social contexts affect motivation and emotions during an interruption. As Goffman [45] suggested, awkwardness occurs in social situations where people cannot do anything due to external factors (such as an interruption event). Future research should focus on these interactive aspects of interruptions in crowd dynamics.

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PUBLICATION II

Pushing and Non-pushing Forward Motion in Crowds: A Systematic Psychological Observation Method for Rating Individual Behavior in Pedestrian Dynamics

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Pushing and Non-pushing Forward Motion in Crowds: A Systematic Psychological Observation Method for Rating Individual Behavior in Pedestrian Dynamics

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Abstract

Pushing behavior impairs people's sense of well-being in a crowd and represents a significant safety risk. There are nevertheless still a lot of unanswered questions about who behaves how in a crowded situation, and when, where, and why pushing behavior occurs. Beginning from the supposition that a crowd is not thoroughly homogenous and that behavior can change over time, we developed a method to observe and rate forward motion. Based on the guidelines of quantitative content analysis, we came up with four categories: (1) falling behind, (2) just walking, (3) mild pushing, and (4) strong pushing. These categories allow for the classification of the behavior of any person at any time in a video, and thereby the method allows for a comprehensive systematization of individuals' actions alongside temporal crowd dynamics. The application of this method involves videos of moving crowds including trajectories. The initial results show a very good inter-coder reliability between two trained raters with a 90.5% overlap (KALPHA = .79) demonstrating the general suitability of the system to describe forward motion in crowds systematically and quantify it for further analysis. In this way, pushing behavior can be better understood and, prospectively, risks better identified. This article offers a comprehensive presentation of this method of observation.

Keywords: Pushing behavior; Forward motion; Crowd psychology; Observation method; Content analysis; Rating system

1 Introduction

Imagine a crowd of excited fans waiting to enter a concert hall: There is no queuing system and everyone wants to be the first in the hall, for there are no seat reservations either. If you had a bird's eye view to observe this crowd from above, you would likely get the impression that it is just one big throng in which everyone is pushing and shoving. Examining each person individually, however, reveals that the crowd is not actually homogeneous and not everyone is behaving the same. This paper introduces an observation method which focuses on individual behaviors in such crowds and allows for an appraisal of who is pushing at which moment in time to draw a more differentiated picture. The assessment and evaluation of individual behavior is performed by trained observers using videos of crowds and the extracted trajectories.

Crowded situations are common and happen—at least before COVID-19—almost every day. Just think about the jostling at the train station. As ordinary as it may be, the consequences can be very serious. Pushing behavior not only impairs satisfaction during the crowd experience [1], it also poses a safety risk. Different studies show that high motivation, which often involves pushing and shoving, increases density [2, 3], and reports from real-life scenarios indicate that pushing from behind can lead to life-threatening density and pressure resulting in injuries and fatalities [4]. Although there is broad evidence of cooperative behavior in emergencies [4, 5, 6, 7], pushing may also occur during evacuations, further increasing the danger. [8] Several simulations of pedestrian crowds have therefore tried to integrate this behavior [9, 10] but without providing a systematic psychological basis.

Aside from the safety issues, pushing and shoving were generally evaluated as inappropriate and unfair in recent studies with a bottleneck set-up [2, 11]. It is quite surprising, though, that the same participants mentioned these behaviors as the most promising strategies for faster access. Whether individuals actually move forward faster by jostling depends, however, on their strength and the density of the crowd. With respect to the crowd as a whole, it has not yet been conclusively determined whether increasing the pressure by pushing changes the flow through the bottleneck. Although it has been suggested that pushing actually decreases the flow—the so called "faster-is-slower" effect [12, 13] — Haghani et al. [3] found no conclusive evidence for this general occurrence in a review of current experimental literature. Their own experiment, however, indicated that at least strong and aggressive pushing prolongs the egress time in a bottleneck situation.

However, not everyone in a crowd pushes to the same extent. In Adrian et al. [2], the percentage of participants engaged in this behavior varied from 29.2 to 78.6%. Reasons for non-pushing were, for example, avoidance of danger or a general aversion to pushing. Additionally, identification with the crowd may influence pushing behavior—high-identification participants tended to push less and to give more help in a mass evacuation scenario [14]. Also, social norms (e.g., triggered by the spatial organization of the crowd) influence whether pushing is appropriate behavior or not. Queuing, for example, is a social system where norms prevail that are opposed to pushing [11, 15, 16]. These results show very clearly that pushing is a complex behavior influenced by several factors. Apart from this general decision for or against pushing, it is also natural that any human behavior is not static but dynamic and can therefore change over time. This means, of course, that pushing behavior is also dynamic and sometimes people push only to stop in the next moment. Researchers addressing crowd dynamics have nevertheless tended thus far to address pushing as a constant behavior in a homogeneous crowd. Our proposed rating method takes into account these fluctuating dynamics of pushing and non-pushing.

But before examining these complex dynamics, it is essential to understand which behaviors are included when talking about pushing. According to the Cambridge Dictionary "(to) push" means "to move forcefully, especially in order to cause someone or something that is in your way to move, so that you can go through or past them" [17]. Further, it must be distinguished between intentional and unintentional pushing [18]. Unintentional pushing is the physical reaction to a push from behind that results in one person being pushed forward into another person. In intentional pushing, on the other hand, individuals exert energy themselves to build up forward pressure. In recent studies [2, 11], participants mentioned the use of elbows, arms, or shoulders, as well as pushing to the front and pushing to the side as different forms of (intentional) pushing. Additionally, filling gaps is mentioned as a strategy for faster access. It is debatable whether filling gaps is a form of pushing behavior, as it is less aggressive, but it clearly leads to increased density and people moving forward faster. Consequently, for the purpose of our method, we include filling gaps as a form of pushing. This enumeration of possible forms of pushing strongly suggests that simply distinguishing between pushing and non-pushing is too simple to be helpful. Therefore, our method examines two different gradations of pushing, namely, mild and strong. Adapted to this, we also distinguish two gradations of non-pushing: a simple forward movement "with the flow" and a forward movement that is slower than the crowd as a whole and thus "falling back."

The general idea for the observation and rating method is based on quantitative content analysis as used in psychology and the social sciences [19, 20]. With the help of a complete coding system, this method captures the characteristics of a document. The coding system is created before the analysis and contains precise definitions of the characteristic expressions and assigns numbers to them. The details of the coding system, as well as useful examples and explanations for the coding process, are recorded in the codebook. Furthermore, the document is divided into precise units of analysis. The rating is performed by at least two trained raters, and reliability measures serve to ensure their concurrence. While content analysis was initially developed for text documents (such as newspaper articles, diaries), in recent years it has also been adapted for the analysis of images and video material.

Important steps of content analysis for both text and video analysis are [20]: (a) determination of the analysis material, and definition of units of analysis, (b) design of the coding system based on the literature and research questions, (c) tentative application and revision of the coding system, (d) discussion of the validity of the coding system, (e) training of raters, (f) reliability analysis (intercoder reliability), (g) complete data collection, and (h) statistical evaluation. In this paper, we present our content analytic method for capturing pushing behavior in crowd videos in a step-by-step fashion (with the exception of the last two steps (g and h)—for an analysis of the data at this level has yet to be performed).

2 Method

The method described here uses videos taken of crowds from overhead in confined areas such as in front of bottlenecks. Trained observers pick out individual people one by one and categorize their behavior in every second. To do this, they use a four-level category system that includes pushing and non-pushing behavior. The method is introduced here with a thorough step-by-step explanation, to facilitate its future use by other research groups.

2.1 Determination of the analysis material and definition of units of analysis

Although pushing behavior has been regularly observed in former experiments, an in-depth approach for defining and grading the behavior has not been one of the most prominent objectives in pedestrian dynamics so far. As a result, there is a wealth of video material that can be potentially "recycled" for constituting a base to analyze the behavior (see for example: Pedestrian Dynamics Data Archive [21]). Any video that contains pedestrians in forward motion can be used. The category system can be applied to experiments with very different crowd dynamics (i.e., fast or slow) because this method includes the entire spectrum of pushing and non-pushing behavior. Every participant can be categorized as to the degree and intensity of their behavior, whether pushing is observed or not.

Individual trajectories must be available or first extracted for the video to be evaluated. The detection is done via PeTrack software [22]. PeTrack was mainly developed for automatic extraction of pedestrian trajectories from video recordings that are captured from cameras with a top-down view for measuring the physical properties of crowds (e.g., density). The category system uses these trajectories for individual pedestrians to provide accurate timing (via frame numbers: 1 second is equal to 25 frames) of starting categories, category shifts, ending categories, and their spatial visualizations. PeTrack was upgraded specifically for the current category system; an annotation command and a feature allowing the video to be played in real time were added to the software (Version 0.8.15) in order to have an accurate-timing comment (rating: category 1 to 4) for a specific person and a specific frame. The txt file output shows the rating with the respective frame that is bound to the respective pedestrian.

The rating is executed in specific frames that contain a starting point, an ending point, or a behavior change, for every pedestrian. However, a human observer needs at least one second in order to comprehend the complex behavior (and its potential change in the next second) of an individual and therefore it does not make sense to use the frame units defined in PeTrack. For the category system, a unit of analysis is consequently defined as the behavior of an individual in one second. The frame rate of PeTrack is, however, 25 frames per second. Therefore, it was decided that the median of frame ratings within one second of one participant would be calculated and used as the minimum unit of the rating measure. The process of the rating of pushing behavior is as follows: After the experiment video selection, the ptc (PeTrack) files were gathered from the IAS-7 database and every pedestrian in the chosen video was annotated according to their behavior. The starting point was considered the first frame (usually frame 0) in which PeTrack detects the selected pedestrian, and the ending point was set as either in the last frame of the video or when (if) the pedestrian reaches the bottleneck. In the latter case, the ending frame was always annotated as "END."

2.2 Design of the coding system on the basis of literature and research questions

As outlined above, pushing is defined as a behavior that can involve using arms, shoulders, or elbows; or simply the upper body, in which one person actively applies force to another person (or people) to overtake, while shifting their direction to the side or back, or force them to move forward more quickly. Pushing usually correlates with speed acceleration. Our approach also includes using gaps as a form of pushing because this is a form of overtaking. We distinguish two gradations of pushing behavior: mild and strong. Accordingly, we also distinguish two gradations of non-pushing forward motion. As a result, a category system with four categories has been created: (1) falling behind, (2) just walking, (3) mild pushing, and (4) strong pushing; as two pushing (3 and 4) and two non-pushing (1 and 2) categories.

Six different parameters were used for rating individuals according to these categories: the position of their arms and hands; the position of their shoulders and heads; their personal space; their interaction with others; speed and acceleration; and attention to the exit. These parameters have different behavioral outputs depending on which category they are in, as can be seen below.

Falling behind (1) is the most passive category in terms of forward motion (Figure 1). People in this category use their hands and arms less. Their arms are generally crossed or dropped by their sides, apart from cases in which they were chatting with other people and using their hands to gesture (arms and hands position). They show frequent head movements because their attention is scattered; they can hence focus on non-specific things in their environment (shoulder and head position). They mostly have some distance to the group and minimal physical contact. In most cases, they are at the back of the crowd, but, when they are in the front, they may actively increase the distance to the person in front by slowing down (personal space). They might be actively involved in chatting with other participants (interaction with others). They are slow overall—even stopping in some cases or changing their direction to somewhere different than toward the exit—and obstruct the pedestrian flow (speed and acceleration). They are focused on other people or things in the environment or become distracted via cell phones instead of focusing on the exit (attention to the exit).

The second category, just walking (2), is applied to people who are not pushing but also not as passive as the people in the falling behind (1) category; they are basically just going with the flow (Figure 1). People in this category have similar properties with the former category as they can have crossed and dropped arm positions, but since they are mostly within the crowd, they can use their arms close to their upper body to protect against possible pushing behaviors and they may hold onto fixed objects or barriers to stabilize themselves (arms and hands position). They move slowly and methodically, and they can form a penguin-like waddling motion (shoulder and head position). While they are mostly maintaining their position relative to the crowd and staying in their line, they can be in close body contact with others around them if they are jammed or shoved but under normal circumstances they have sufficient space around them to avoid body contact, as they do not actively increase or decrease the distance to others under a length of half a meter (personal space). They sometimes chat while they are walking (interaction with others). They are also slow and steady, and they may let others go first (speed and acceleration). They can focus on protection or the environment while they are walking toward the exit (attention to the exit).

Mild pushing (3) is a genuine pushing category but, as the name implies, a less active category than the fourth (Figure 1). People in this category actively increase the density of the crowd. They may raise their arms to apply force to the back of other persons or extend their elbows and arms, or even stabilize themselves by holding on to barriers to prevent others from overtaking (arms and hands position). They often move fast and methodically; consequently, they can form a "fast" penguin-like waddling motion (shoulder and head position). They have much more body contact, they tend to close gaps, change their lines, and overtake for faster access, but without applying excessive force. They may be disproportionately close to the next person without trying to overtake as a tailgating movement or as "psychological pushing," or the closeness can even occur out of an affiliation motive such as hugging someone they know (personal space). They mostly do not chat with other people (interaction with others). They are fast, and they actively decrease their distance to others (speed and acceleration). Their attention is focused on the exit or possible gaps providing a better route (attention to the exit).

The last category, strong pushing (4) is created due to the need for an advanced pushing category for extreme cases (Figure 1). People with strong pushing behavior tend to use their elbows and hands more strongly to create gaps, they can use barriers to pull themselves forward, they may collide with other people or even pull other pedestrians backward, as they are actively changing their position (arms and hands position). They can move sideways and use a shoulder as a plow, and in most cases, they lean forward (shoulders and head position). They have the most physical contact, and they may create some space behind them due to their rapid movement (personal space). They might communicate with others to engage in coordinated pushing (interaction with others). They are fast and accelerate rapidly when possible (speed and acceleration). Like the mild pushers in the former category, the strong pushers' attention is focused on the exit or possible gaps that might provide a better route (attention to the exit).

All actions in these categories are fully observable in overhead video analysis. This does not mean, however, that people show every parameter in their respective category as they move forward. A person does not necessarily use their arms close to their upper body as protection in just walking (2) if there is no pushing behavior around. There might be no coordinated pushing for people

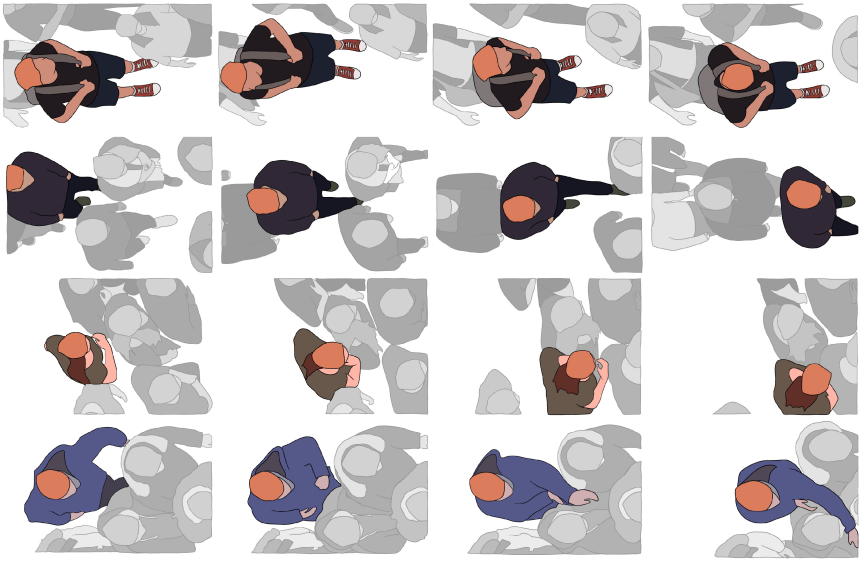

Figure 1: Illustrations of four categories. Each line represents one category. From top to bottom: Category (1) Falling Behind, Category (2) Just Walking, Category (3) Mild Pushing, Category (4) Strong Pushing

in the strong pushing (4) category if the strong pusher is alone. Consequently, people can be annotated and put in a category depending on their prominent behavior even if they do not meet all the parameters.

Another crucial point is that people are not bound to their initial category; as outlined above, they can change their behavior in real life and the category system adapts accordingly to account for these changes. A person might start out as just walking (2) but some time later switch to mild pushing (3) depending on the environment or a shift in motivation. This allows us to describe not only individual differences between people in the crowd but also to capture temporal dynamics.

2.3 Tentative application and revision of the coding system

Once the base structure and the technical properties of the pushing behavior system had been established, raters participated in a series of trials to develop the system further using existing datasets from the project BaSiGo [11, 23, 24] as well as interdisciplinary experiments performed at the University of Wuppertal [2, 25]. All the former experiment video recordings, along with trajectories of each pedestrian, had already been prepared for earlier research and studies and subsequently stored and published in the pedestrian dynamics data archive. The ethic statements for these experiments and recordings can be found in the corresponding papers; no additional ethical approval was necessary for the current study.

The selected empirical setup for the main trial video was an L-shaped bottleneck scenario, where all participants were instructed to reach the exit with high motivation [11, 23]. People were gathered on a platform, each wearing a unique hat (enabling their individual detection from cameras), and were instructed to pass through the bottleneck and exit the platform. Forty pedestrians were randomly selected (out of 123) for the trial dataset and rated accordingly.

The trial ratings revealed that understanding short-term behavior changes is notably challenging: Behavioral shifts of the pedestrians (i.e., category changes from 2 to 3) require more than a second to be comprehended by their actors since there were many examples of momentary behavioral changes for some pedestrians that appear to have happened only by accident (being pushed increases acceleration momentarily in a passive way) or to have been unconscious decisions on the part of the pedestrian (accidental line changing toward a gap), with the former behavior being resumed after one second. It was thus decided that the time gap for a valid and intentional behavioral change should be at least 2 or 3 seconds depending on its context.

2.4 Discussion of the validity of the coding system

Revision of the coding system after some trials revealed some significant points regarding the pushing behavior system. Raters were concerned that they were focused on the observable motivation (having high or low motivation) rather than actual pushing behavior in some cases. While being highly motivated and using strong or mild pushing behavior are potentially highly correlated, the actual behavior can possibly be disregarded while observing the crowd due to the primed motivation of the pedestrian. This vague issue has come up during high-motivation-priming video trials where it was observed that, although most of the pedestrians were highly motivated to reach the bottleneck, not all of them were using pushing behavior. Overall, the main concern was that raters might inadvertently appraise the motivation of the pedestrians instead of their observable pushing behavior.

After careful consideration, raters agreed to conduct the rating process with a context-dependent perspective to avoid this issue. For instance, being fast and accelerated in a calm and slow crowd was agreed to be an indicator for mild (3) or strong pushing (4), but the same behavior can be seen as just walking (2) if the crowd is highly energetic and the average flow speed is similar to the "fast" pedestrian. It is thus helpful to watch the video once before the actual rating to get a feel for the respective context. Raters favored this approach as it is much more accurate for detecting and annotating pushing behavior, as it frames the question to be answered in more concrete terms.

The exactness of timing was also an issue for the consistency between both raters: After several test appraisals, some selected annotations done by two raters were analyzed and found, in fact, to be comparable except for a small time slippage by one or two seconds. It was later decided that the observed behaviors were actually the same but coded differently in time either by mistake or by a time lag caused by the software. Nevertheless, it is only natural for human observers to have minor errors in the timing of their ratings in a highly detailed and complex dataset, and those minor errors should not be problematic especially if the raters are in agreement about what they have seen. Consequently, raters decided to look more closely at the cases with a time slippage of up to two seconds between ratings and select the proper timing together for the main dataset. This process was called "correction" and was done for all the related cases.

2.5 Training of raters

The same L-shaped bottleneck video [11, 23] was selected for use again as the training dataset for two raters to annotate pedestrians. The remaining participants from the main trial dataset (n = 83, out of 123) were annotated by the raters. The rating was done via PeTrack and a txt output was collected afterward.

The output shows only the respective frames for which a rate comment was inserted (i.e., frame 0 = 3, frame 523 = 4, frame 801 = 3, frame 1792 = END; for participant *number*), hence it always needs to be prepared for data analysis. The first preparation was done manually; the total frame numbers were written in Excel and all the ratings were dragged in between the frames (i.e., frame 0,1,2,3. . . .520,521,522 = 3). After every rating for every frame and every pedestrian was prepared, the median of the ratings for units of seconds was calculated and written accordingly. The final procedure was to assemble all the ratings in one column. These proceedings were done separately for the two annotations of two raters. Later, data columns of two raters were merged (as two columns) and collected in one Excel file. The file was stored for later analyses in IBM SPSS.

2.6 Reliability analysis (inter-coder reliability)

It was decided that the inter-coder reliability should be calculated via Krippendorff's alpha (KALPHA) [26]. Having multiple coders and an ordinal level of measurement (i.e., categories increase from 1 to 4 depending on the behavior), KALPHA was found to be the most effective reliability coefficient for our rating system.

For calculating KALPHA we used a macro by Andrew F. Hayes for IBM SPSS [27]. This macro provides a proper syntax where only the last line must be manually adapted to the respective data set and the required output. This looks as follows: KALPHA judges = judgelist/level = lev/detail = det/boot = z. "Judgelist" contains the names of the raters, "lev" is the measurement level (in our case: ordinal = 2), "det" is a selection of whether there is a need for a more detailed output (0 for only KALPHA value), and "z" is the bootstrapping number (in our case: 10000) [28]. As database for the inter-coder reliability, we used the ratings from the training section. So, N = 83 participants were rated by two independent raters. Please note that N = 43 participants were rated twice by one rater with 4.5 months in between because the first rating was performed before the method had been described in detail for this article. In the process of writing, the categories underwent additional differentiation and clarification, so we decided that both raters should conduct their observations at the same time.

As the quality of the first rating thus might remain below what is possible, we repeated it for this paper to demonstrate more accurately the potential of our system. The second rating round was almost a new one since the rating process is very complex and there was a big time gap between the two ratings. The rater could thus not remember the former ratings and was of course not aware of the rating of the second observer during the process. Finally, the dataset for reliability analysis consisted of 143,172 rated frames. After aggregating 25 frames into one second, 5,717 units of analysis remained. We adjusted 60 units due small time slippages as explained in Section 2.4. For this prepared data set, the results show 90.5% overlap between the raters and KALPHA = .79.

Even though De Swert [28] mentioned KALPHA = .80 as an established limit for good reliability, he also stated that lower values (minimum of .67, or even .60 for extreme cases) are acceptable if there are good reasons for it. In our case, there is an extremely large number of analysis units, and our categories further rely on rather minor behaviors which are context dependent and sometimes difficult to detect from above. Additionally, behavioral shifts over time are considered, and the analysis units are somehow dependent from each other (e.g., if one observer sees a shift to mild pushing and therefore changes the rating from 2 to 3 but the other evaluates the behavior differently, the rating does not only differ for one second but immediately for several). Given this complexity of the rating system, a value of .79 is, in our view, more than satisfactory.

Despite this high level of agreement between raters, we nevertheless have partially divergent ratings for some participants. If the data is to be used for further analysis, however, there cannot be two data sets with divergent values. Therefore, the question is how to combine these different values into one value. The calculation of the mean value, for instance, makes no sense for the method (e.g., 2.5 as mean between just walking and mild pushing). Instead, the raters have to reach a later compromise in cases of disagreement. For that purpose, all divergent cases must be observed again and discussed. This leads to a completely consistent data set that can be used to answer the following research questions. It is essential to note that this step may only be performed after the inter-coder reliability has proven to be high enough.

2.7 Preliminary visualization

For visualization of the rating, we took one video from the Pedestrian Dynamics Data Archive [2, 21, 25]. Screenshots are depicted in Figure 2 and the full video can be found in the 'Supplementary files' section. This visualization is only preliminary to illustrate our rating system. More sophisticate forms can be created using special software (e.g., JuPedSim) [29] or including other quantities (e.g., density).

3 Discussion

Pushing behavior impairs people' sense of well-being in a crowd and also poses a significant safety risk. Nevertheless, to date it has been barely investigated. Following the idea that a crowd is not thoroughly homogenous in behavior and

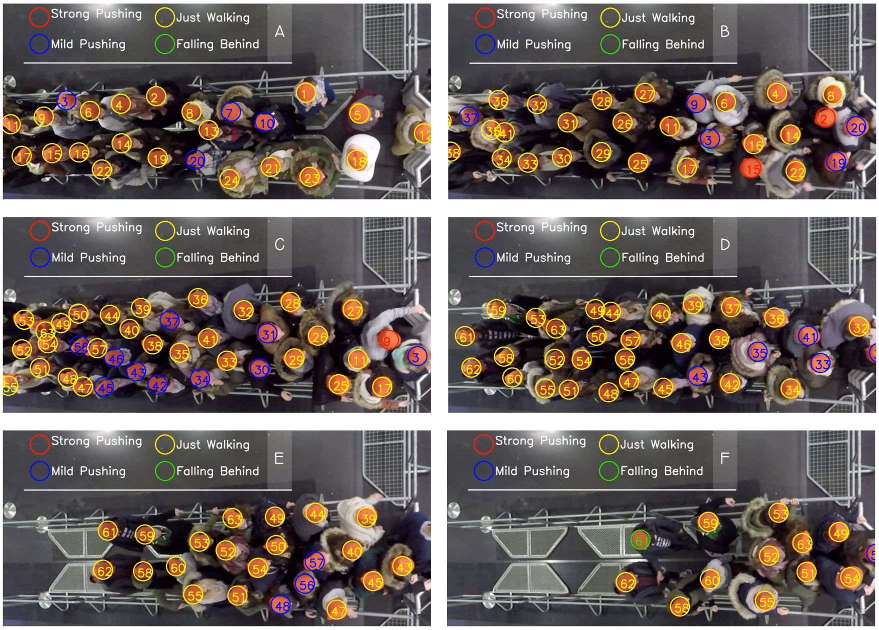

Figure 2: Preliminary visualization of ratings. Screenshots were taken from one exemplary video. Letters (A, B, C, D, E, F) state the order of the crowd flow. Timepoints of the screenshots are: A = 00.00 s, B = 00.08 s, C = 00.16 s, D = 00.24 s, E = 00.32 s, F = 00.40 s.

that there can also be changes over time, we developed a rating system of individual behavior in crowds. Prospectively, this can be used to systematize and quantify all kinds of forward motion as we not only capture pushing but also non-pushing behavior. However, since pushing can have various forms, having just a binary distinction would have been too easy. Therefore, we came up with four categories to take this diversity of forward motion into account: (1) falling behind, (2) just walking, (3) mild pushing, and (4) strong pushing. These categories thus enable us to classify the behavior of any person at any time in a video. In this way, we can not only consider the individuality of people but also the temporal dynamics of behavior. Our rating system was built on the scientific basis of content analysis [19, 20] and showed a very good inter-coder reliability between two trained raters.

3.1 Limitations

Although the rating system was found to be reliable, it is also worth mentioning its challenges and limitations in order to have a well-rounded perspective on the system. One major concern was noticed during the training process: The rating procedure was too time consuming. Annotating forward motions of numerous pedestrians involves repeated watching of the videos, focusing on a specific person, and determining the exact time periods of behavioral changes. Overall, annotating one pedestrian required at least five minutes of observation and consideration, as well as inserting the actual rates into the software. Complex cases, however, required as much as ten (or even fifteen) minutes. In order to have a complete annotation of 83 participants, each rater spent at least seven hours preparing the data. Raters spent an additional two hours correcting the data before the statistical analysis could occur (see Section 2.4). In the long run, these durations cannot and (more importantly) should not be decreased since the nature of the system depends on detailed observations. Speeding up the rating process might cause human observers to miss valuable information concerning the pedestrians.

The second observed issue was related to the properties of the selected video. Even though the video was high-resolution, image distortion (flattened fish-eye) sometimes made it hard to perceive and determine actual behavior. The software distorts images in this way to depict an accurate trajectory from the pedestrians from the first standing point through the bottleneck, but this also causes pedestrians to be shaped somewhat bizarrely when they move away from the center. The raters tried to adjust their observation and rate accordingly, although some information might have been lost throughout the process due to this situation. In a broader perspective, using only a bird's-eye view could potentially lead to a loss of information, as well, since the observation becomes slightly limited when seen only from this vantage point. Future studies could incorporate secondary cameras with frontal or side angles where it is thought that these could be beneficial.

Finally, the method was limited by the use of only one video for introducing the pushing behavior system. Even though the selected video contains a crowd scenario with varied behaviors, a different kind of environment (i.e., less crowded, high motivation, low motivation) could potentially be constructive for determining the applicability of the system itself. Raters have conducted some informal trials with different videos that suggest that the system is valid in all the cases mentioned. Additionally, investigating multiple exit scenarios or pedestrians moving in different directions could also be beneficial for showing how feasible the system is, although, we firmly believe that the system would be valid in these cases as well. If a crowd scenario contains forward motion of the pedestrians, then the system can potentially be used since it is based on individual observations regardless of the direction of the pedestrian moving. However, crowd contexts such as watching a sport or a music performance cannot be investigated with the current rating system because these situations do not contain forward motion. Nonetheless, regardless of the selected crowd scenario, it has proven beneficial for raters to confer in advance about the category system for each individual experiment and agree on a set of individual examples of the four categories. This minimizes the context effects.

3.2 Practical implications

While on the subject, possible future applications are described below. The first and probably the most prominent future study could be automating behavior detection by utilizing artificial intelligence (AI) [30, 31]. As it was mentioned in the limitations, the rating process is time consuming and laborious, but an automated AI system could dramatically decrease the rating time by assisting raters in appraising clear cases while flagging the ambiguous ones. All in all, the rating system and the actual annotations might be considered as the beginning of further pushing behavior-related studies since the system opens a door to measure behavior in space and time and can potentially be applied to related research questions. If an automated detection system could be created, later research could use it to acquire the annotations of multiple videos in a short time.

Regarding future research in social and crowd psychology, behavioral effects can be easily observed and measured with the rating system. Observing one person or one group within a crowd is quite difficult due to having a massive amount of information from the environment, but reducing this data to four ordinal categories could be useful for observing what is really happening in the crowd. For instance, behavior propagation can be observed if it exists (i.e., strong pushing behavior propagates between pedestrians over time via exposure) or behavioral clustering can be identified in some specific locations (i.e., mild pushing behavior localizes in front of the bottleneck). The authors are currently working on these research questions in regard to the rating system's future application. These examples could potentially yield crucial insights for crowd management and evacuation studies, as well, since the system allows interested parties to understand pushing and pushing-related behaviors. Ultimately, the rating system should make it easy to recognize if behavior categories affect each other in any way, depending on the time and their position.

Although the rating method is far too time consuming to be directly useful in the application field of crowd management, it directs the focus toward observing individual behavior as a key to understand the strategies people use in crowds. Such knowledge could be very useful for practitioners in the long run since (potentially dangerous) shifts in crowd movement could be better understood. Likewise, using the system can be beneficial in evacuation studies, such as observing the effects of given directions or instructions on the crowd at an individual level. Potentially, researchers can identify unfair or unwanted behaviors and their effects in an evacuation scenario, and then design or model alternate scenarios to avoid dangerous situations. Furthermore, the detailed descriptions of pushing behavior developed for this method could provide a starting point for thinking about automated observation tools for crowds to detect characteristic indicators of problematic behavior.

3.3 Conclusion

Our rating system provides an important and adequate basis for better understanding the complex dynamics of pushing behavior and forward motion in general. In the video we tested, the agreement between two raters was very good, and a consistent and highly reliable dataset can be generated through the subsequent strategy of compromising. In the future, however, the system must prove its suitability for other videos in different contexts (e.g., different motivations, different moving directions or even CCTV footage). An automated solution for speeding up the rating process would be also beneficial. In any case, this idea is worth pursuing since the quantification of pushing behavior is necessary to answer further research questions which will allow researchers to better understand crowds and thus contribute to public safety.

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PUBLICATION III

Exploring the Dynamic Relationship between Pushing Behavior and Crowd Dynamics

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Exploring the Dynamic Relationship between Pushing Behavior and Crowd Dynamics

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Abstract

Crowds, subjects of considerable complexity, have been extensively studied both as homogeneous entities and as collective sums of individual movements in various studies. However, crowd models, being grounded in physics, are limited in terms of incorporating psychological perspectives on individual behavior. Building upon the premise that crowd behavior is heterogeneous and dynamic, particularly in bottleneck scenarios, this study aims to explore the nuances of forward motion. Adopting the category system proposed by Lügering et al. [1] (consisting of the following categories: strong pushing, mild pushing, just walking, and falling behind), this paper investigates the circumstances and locations where pushing or non-pushing behaviors arise, intensify, or cease within crowds approaching bottlenecks. The study utilized 14 video materials obtained from previous laboratory pedestrian experiments to examine the spatial characteristics of forward motion and pushing behavior in relation to corridor widths and varied motivational instructions. Two trained raters independently annotated these videos, achieving satisfactory inter-rater agreement (KALPHA = .65), and a joint dataset was then created for each video. These videos consisted of both high (7 videos) and low (7 videos) motivation scenarios. The importance of corridor width was also considered: four videos featured a 5.6 m. width, another four featured a 4.5 m. width, and the remaining videos displayed widths of 3.4 m., 2.3 m., and 1.2 m. twice. Our findings suggest a tendency for increased pushing behavior or an increase in the categories as individuals approach the bottleneck, regardless of the width of the corridor or the motivational instruction. Furthermore, non-pushing behaviors were predominantly observed in the areas farther away from the bottleneck. A noticeable trend was observed in high motivation scenarios, which generally exhibited more instances of pushing behavior. The effect of corridor width indicated that, in certain cases, pedestrians who push in wider corridors experience faster access to the bottleneck. However, this effect is less significant in narrower widths. Additionally, temporal analyses indicated that category increases were most prominent in the initial quarter of the experiments, although other peak points were also observed. Calculations of the mean category values for each second revealed three distinct patterns: stability over time, a consistent slow decrease, and an initial increase followed by a decrease.

Keywords: Pushing behavior; Forward motion; Crowd dynamics; Rating system; Crowd psychology; Observation method

1 Introduction

Crowds are a common sight in everyday life, and can be found in public spaces such as streets, parks, and transportation hubs, as well as at events such as concerts, sporting events, and festivals. Dense crowds form when the available space is insufficient to accommodate the flow of pedestrians, leading people to gather in close proximity. However, in the absence of clear guidance on queueing, crowds are susceptible to unfair behaviors such as pushing by pedestrians eager to access exits quickly [2, 3]. Pushing behavior can take many forms, ranging from forceful and aggressive actions to mild and subtle movements. It is particularly common in scenarios where there is only one main entrance or exit, such as event entrance systems. Furthermore, pushing behavior is influenced by social context, including cultural norms and individual motivations. This complexity of factors can affect where and when pushing behavior occurs. Therefore, this paper aims to examine the spatial and temporal properties of pushing behavior in entrance scenarios, using an observation method and a motivational perspective that focuses on individual behavior for early access.

The importance of studying pushing behavior derives from the understanding that it poses a significant safety risk for the purpose of gaining early access in crowded environments. Pushing behavior can be particularly dangerous when it involves pushing others from behind, creating a dense environment [4, 5] that can be hazardous to those being pushed [6]. This can be particularly dangerous in extreme cases, where the felt pressure of the push could be fatal. Moreover, pushing behavior can intensify emergency situations, such as evacuations, where the priority is to get everyone out as quickly and safely as possible [7]. In these scenarios, confusion caused by pushing can hinder the evacuation process. Even in non-threatening situations, such as laboratory experiments with bottleneck setups, pushing behavior is often considered inappropriate and unfair [5]. It can also disrupt the overall speed of the crowd [8].

However, pushing behavior is not a static or consistently present behavior [1], and it can vary in strength, leading to different effects [9]. The likelihood of pushing may vary depending on the social context and norms at play [5]. In situations where the environment promotes unity and helping others, people may be less keen to push and more likely to walk together coherently [10, 11]. Furthermore, pushing behavior can change over time as the motivations of pedestrians shift. It can increase, decrease, disappear, or appear throughout the pursuit of a goal [1], as individual motivations are dynamic and constantly evolving. Therefore, pushing behavior is also a dynamic behavior that is influenced by the motivations of pedestrians.

Previous studies have shown that pushing behavior can be classified by rating individual behavior from crowd videos. Lügering et al. [1] developed a forward motion category system that includes the following categories: strong pushing, mild pushing, just walking, and falling behind. This system includes detailed definitions of pushing and forward motion, including the means by which the behavior is carried out, such as using elbows, protecting oneself, filling gaps, accelerating, and so on. This system allows researchers to rate individual pushing behavior (or the absence of it) from a starting point until the pursuit of a goal is completed. These ratings can be combined with pedestrian trajectories to see the individual effects throughout the sequence. Moreover, the spatial and temporal characteristics of individuals within crowds, as obtained from their trajectories, can be related to their forward motion aspects, allowing for a deeper exploration of their relationship with pushing categories.

The purpose of this paper is to utilize the forward motion category system developed by Lügering et al. [1] to investigate the relationship between pushing behavior and the spatial and temporal properties of the crowds. To achieve this objective, we analyze pushing occurrences from laboratory studies using trajectory data extended by pushing states and link them with crowd properties such as time and distance to the goal. By doing so, we aim to explore the motivational aspects of forward motion behavior, as well as individual pushing occurrences on a large scale, in order to identify collective patterns. While previous studies have shown that pushing behavior can increase the crowd density [4, 5], a more comprehensive investigation has not been conducted to explore the relationship between pushing behavior, pedestrian motivation, and physical crowd properties in detail. The utilization of the pushing category system as a tool will enable us to observe and measure the causal relationship between what pedestrians do to gain faster access and how the crowd changes, or vice versa. This understanding can subsequently be employed to inform the development of crowd management strategies and enhance safety in crowded environments.

2 Method

2.1 Empirical Material

Fourteen videos from laboratory studies ((Figure 1) investigating the movement in bottleneck platforms were selected for the current study from the Pedestrian Dynamics Data Archive [12]. These videos, along with the trajectory data of the pedestrians, were originally recorded for interdisciplinary experiments conducted at the University of Wuppertal [13, 5] and were stored in the Pedestrian Dynamics Data Archive for future research. Out of the original 24 videos available from this experiment series, 14 were selected based on a participant number threshold of n >40, following the approach of the original study [5]. Videos with fewer than 40 participants had shorter durations, which were considered unlikely to offer meaningful results. Additionally, below that participant threshold, only a few instances of pushing behavior were observed. Experimental run numbers and the order were opted to be maintained as they are due to convenience and consistency with the original research.

All experiments included motivational instructions for the participants to influence their behavior during the experiment. The high motivation instruction consisted of a concert context where participants were told they needed to reach the bottleneck quickly to get good seats. The low motivation instruction told

Figure 1: Exemplary screenshot from the experiments.

participants that they would have many good seats available, but it was still good to reach the bottleneck earlier. The selected videos were equally divided between these motivation priming conditions, with seven high motivation and seven low motivation videos.

The corridor width was another property taken into consideration. There were five different corridor widths, and it was thought that these different widths would produce different effects or be affected differently in terms of pushing behavior. The widths were as follows: 1.2 m., 2.3 m., 3.4 m., 4.5 m., and 5.6 m. There were two videos each for the 1.2 m., 2.3 m., and 3.4 m. widths, and four videos each for the 4.5 m. and 5.6 m. widths. The number of videos for each width was equal in terms of instructed motivation. Table 1 presents a summary of all experimental runs, providing relevant information.

2.2 Rating Procedure

The rating process was done using the PeTrack software [14]. The trajectories of each pedestrian were first captured using PeTrack during previous experiments, and these trajectories along with their corresponding videos were used in this study to rate the pedestrians' pushing behavior throughout their movement to the bottleneck. The rating was done at specific time points, using frame numbers (1 second is equal to 25 frames). When a participant was selected, their behavior was rated throughout the duration of the behavior. If the behavior changed, the rating was also changed and annotated at the corresponding time point using the software. This process was completed for each participant from the start

Run Number	Motivation	Corridor Width	Number of Pedestrians	Experiment Time	Flow Time	Crowd Time
030	High	5.6 m.	75	65 s.	0-3 s.	4-65 s.
040	Low	5.6 m.	75	66 s.	0-5 s.	6-66 s.
050	High	4.5 m.	42	38 s.	0-4 s.	5-38 s.
060	Low	4.5 m.	42	41 s.	0-7 s.	8-65 s.
110	High	1.2 m.	63	53 s.	-	0-53 s.
120	Low	1.2 m.	63	65 s.	-	0-65 s.
150	High	5.6 m.	57	57 s.	0-4 s.	5-57 s.
160	Low	5.6 m.	57	56 s.	0-5 s.	6-56 s.
230	High	2.3 m.	42	32 s.	0-5 s.	6-32 s.
240	Low	2.3 m.	42	38 s.	-	0-38 s.
250	High	4.5 m.	42	33 s.	0-3 s.	4-33 s.
260	Low	4.5 m.	42	39 s.	-	0-39 s.
270	High	3.4 m.	67	59 s.	0-7 s.	8-59 s.
280	Low	3.4 m.	67	67 s.	-	0-67 s.

Table 1: Experimental parameters across distinct runs are summarized along with their unique identification numbers

of the experiment until they reached the bottleneck. After the annotation was finished, a txt file containing all the ratings and the pedestrian coordinates was extracted from the software.

An ordinal four-stage category system developed by Lügering et al. [1] was used to annotate pedestrians in the bottleneck setup experiment videos. This system consists of four inclusive categories for annotating all the behaviors that can be seen throughout the experiments. There are two categories for pushing and two categories for non-pushing behaviors. The pushing categories consist of mild and strong pushing behaviors, with mild pushing including mostly active behaviors such as overtaking and filling gaps without excessive force, and strong pushing including intense pushing behavior. The non-pushing categories are going with the flow and falling behind from the crowd. The full category names are as follows: (1) falling behind, (2) just walking, (3) mild pushing, and (4) strong pushing. All the participants within all frames were rated with these four categories throughout the session of each experiment.

To account for momentary changes in behavior, as suggested by Lügering et al. [1], the two-to-three-second rule (50-to-75 frames) was adopted. If a behavior persists for two to three seconds, it is rated accordingly. However, if a behavior lasts for less time, it is considered unintentional or accidental, as the actor would need at least a couple of seconds to comprehend and act in relation to their environment. The rater's overall comprehension of behavior was also guided by the suggestions of Lügering et al. [1], and the minimum unit of measurement for complex behavior was set to one second (25 frames), instead of one frame, to ensure full comprehension by the rater.

Overall, two trained raters annotated the fourteen videos separately. These videos were then analyzed to assess the reliability assumption and to determine the level of agreement between the two raters. Joint ratings were then created based on the original files. The videos were watched again with a focus on disagreements, and a decision was made on which ratings should be used for the final data.

2.3 Measures

Spatial and temporal measures were employed to accurately capture the distribution of pushing behavior categories in bottleneck scenarios. The actual distance and time data (measured in meters and seconds) along with predefined divided areas were used to conduct the analyses. The category data within these areas were plotted accordingly.

Four different analysis methods were utilized:

1. Time and distance relationship of pushing categories for each experiment.

2. Showcase of pushing category data in semi-circle areas for each experiment.

3. Showcase of pushing category data in semi-circle areas for each category.

4. Showcase of pushing category data in small (25 cm. x 25 cm.) square areas for each experiment.

5. Number of category increases and decreases, along with the mean pushing category values for each second in all experiments.

These analyses will be presented in the results section, labeled as follows: Time-distance trajectories (1), distance bins (2), category charts (3), heat maps (4), and time analyses (5).

3 Results

3.1 Reliability Analysis

To ensure the reliability of the data, two trained raters independently assessed all 14 videos, which included a total of 776 participants. The data of one rater comprised 1,003,050 frames, equivalent to 40,122 units of measurement (seconds). Due to the manual input of ratings, small time slippages of one or two seconds were prone to occur, so timing corrections were performed up to three seconds between raters. To evaluate the inter-rater reliability, Krippendorf's alpha (KALPHA) was used, as it has been suggested as a suitable method for analyzing the inter-rater reliability of ordinal data [15, 1]. An SPSS macro, developed by Hayes and Krippendorf [16], was utilized to calculate the KALPHA value. The analysis revealed a 75.6 percent overlap between the raters and a KALPHA value of .65, indicating a moderate level of agreement between the raters.

De Swert [17] suggested that a good inter-rater reliability limit would be over .80, but for highly complex data, a minimum level of .60 would be sufficient. Our study involved an extensive dataset comprising an exceptionally high number of analysis units. The categories used in the analysis relied on small, context-dependent behaviors that could be challenging to discern from a limited top-down view. Furthermore, we took into account behavioral shifts over time, and the analysis units were interdependent. For instance, if one observer noticed a shift from a non-pushing category to a pushing category (and e.g., adjusted the rating from 2 to 3), while the other evaluator rated the behavior differently, the rating discrepancy would not be limited to a single second but would extend to multiple seconds. These factors increased the complexity of our rating system and the potential for disagreement between the raters. Due to these factors, we believe that a KALPHA value of .65 is justified in terms of agreement between the raters. Although this value is lower than the ideal value proposed by De Swert, the factors discussed above indicate that a moderate level of agreement was still achieved, supporting the reliability of our data and findings.

3.2 Category Analyses

3.2.1 Time-Distance Trajectories

The first type of analysis is referred to as time and distance trajectories, which illustrates the progression of agents through the bottleneck in terms of time and distance (introduced by Sieben et al. [18]). These plots are divided into four subplots representing different categories, including "strong pushing," "mild pushing," "just walking," and "falling behind," for each run individually.

However, the initial plot of each experimental run, referred to as the bulk plot, consisted of data for all pushing categories. These categories were visually distinguished using different colors: green for falling behind, yellow for just walking, orange for mild pushing (see Figure 2), and red for strong pushing. The subsequent plots illustrated individual pushing categories across all experimental runs (see A.1).

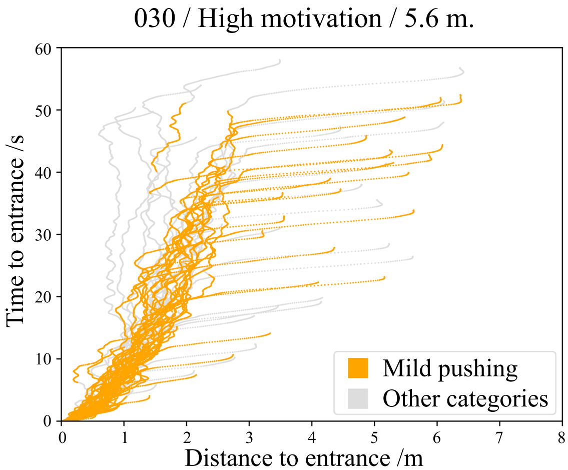

Figure 2: Exemplary time-distance plot for data in the "mild pushing" category. The mild pushing data is highlighted in orange, while the gray lines depict data from all other categories.

The bulk plots primarily showed that in high motivation runs, there were many participants who chose to engage in pushing behaviors, and these individuals were mostly successful in advancing forward, either by finding gaps or through pushing. This trend was particularly apparent during the initial phase of the experiments. The rapid progress in terms of distance without losing time was particularly evident in these plots for high motivation runs (see Figure 3a). On the other hand, participants with non-pushing behaviors tended to wait longer and make less progress. In low motivation videos, there were fewer instances of pushing behaviors, resulting in a smaller visible effect, although it was still present (see A.1).

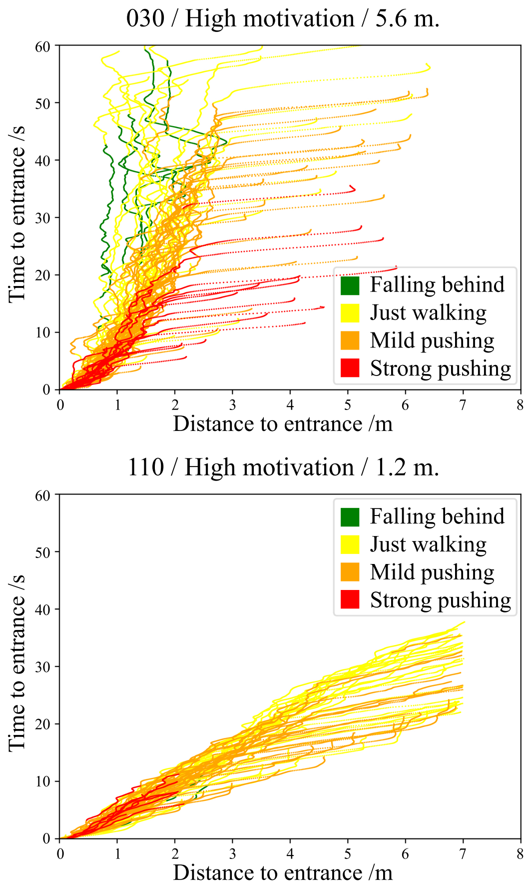

Figure 3: Exemplary plots of all pushing category data from wide and narrow width corridors.

Additionally, the width of the corridor appeared to have an impact on the overall flow. Wider corridors, such as those with widths of 5.6 m or 4.5 m, often experienced congestion and high density, resulting in a less smooth flow. Participants using pushing behaviors were able to make faster progress, while those not using pushing means experienced slower advancement. In contrast, corridors with a width of 1.2 m, despite exhibiting many instances of pushing behaviors, showed minimal additional waiting as the flow persisted. It was observed that pushing behavior did not have a prominent effect on gaining faster access in narrow corridors; participants in different categories had similar time and distance periods (see Figure 3b).

3.2.2 Distance Bins

The second type of analysis involved showcasing the category data within predefined areas located in front of the bottleneck. These areas were shaped as semi-circles, positioned at half-meter intervals from the entrance of the bottleneck (see Figure 4). However, the data from the experiment runs were collected without considering their temporal aspect. All the category data within each second was aggregated and added to the respective areas, without considering the specific frames or seconds in which it was generated. Additionally, some bins differed in size across experiments due to varying corridor widths.

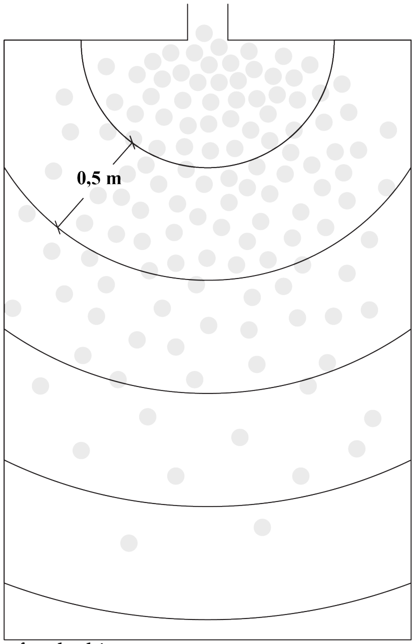

Figure 4: Predefined areas for the bins.

Initially, the objective was to analyze the spatial distribution of the four pushing categories within each bin using colored bars. However, due to the varying sizes of the bin spaces and the unidirectional movement of pedestrians (resulting in some bins containing more data than others, such as those closest to the bottleneck), the data distribution became imbalanced. Consequently, two different types of bin plots were generated to represent the same data: "absolute frequency" plots, which display the raw data without balancing, and "relative frequency" plots, which present the data as a percentage of the total within their respective bins.

Furthermore, we discovered that the relative frequency plots were unintentionally misleading for the bins located further away from the bottleneck, where only a few seconds of data were recorded. During those initial seconds, pedestrians quickly rushed through the bottleneck, creating a high-density environment. In the absolute frequency plots, these bins accurately reflected the insignificance of the data, but in the relative frequency plots, they appeared to contain substantial amounts of pushing or non-pushing data, which was misleading. Upon further investigation, we realized that these problematic bins in the relative frequency plots predominantly consisted of "flow" data rather than "crowd" data, hence they were fundamentally different from each other. In these time periods, pedestrians were free to move further without encountering any junctions or congestion, at least for a few seconds before the crowd formed. Therefore, we categorized these time periods as "flow" and "crowd" data in the plots. The "flow" data included only the first few seconds of the respective videos, spanning from 4 to 9 seconds.

Our time and distance plots, as showcased in Figure 2 and Figure 3, noticeably display the distinction between "flow" and "crowd" data. Initially, many pedestrians are able to progress rapidly in the first few seconds, representing the "flow" phase. Subsequently, pedestrians begin to advance in a less robust phase, primarily due to the dense environment caused by the intersecting pathways of all pedestrians toward the bottleneck. This later phase, referred to as the "crowd" phase, can be observed by the clustering of the trajectories after the conclusion of the flow phase.

Regarding the data itself, the flow phase, which represents the first few seconds before the crowd formation, showed a balanced distribution of pushing and non-pushing categories, although there was a tendency for more pushing categories among pedestrians in the first few meters rather than non-pushing categories. This presence of pushing categories was observed in almost half of the runs, with a balanced distribution between low and high motivation conditions, and between the different widths. However, because the data exhibits a balanced distribution among the categories and conditions, and considering that we have data for only the first few seconds of the experiments, we have opted not to present any additional plots for the flow phase.

The absolute frequency crowd data provides a clear picture of the presence of pushing categories as pedestrians get closer to the bottleneck, and this presence decreases as they move further away. However, due to the unequal spacing of the bins and the unidirectional flow of the crowd, there is more data in the largest semi-circle space when the crowd is formed, typically between 1 m and 2 m. The decrease between 0 m and 1 m is solely due to the smaller space of the first semi-circle. Percentage-wise, the increase in pushing categories is evident throughout the bottleneck, as seen in the relative frequency plots (see A.2). Mild pushing is the most prominent category, but strong pushing also shows a significant increase. The presence of just walking, along with the less visible falling behind, decreases as pedestrians approach the bottleneck area, particularly in the high motivation runs. In the low motivation runs, the same observations hold true if there are instances of pushing behavior. However, if there is little or no pushing behavior, an increase in non-pushing categories can be observed (from "falling behind" to "just walking"). These patterns hold true for the different corridor widths, and are clearly observable in almost all of the runs. Figure 5 aims to demonstrate the difference between absolute (Figure 5a) and relative (Figure 5b) frequency plots, along with the aforementioned observations. For clarity, the appendix section exclusively includes the relative frequency (crowd) plots, as they offer better interpretation (see A.2).

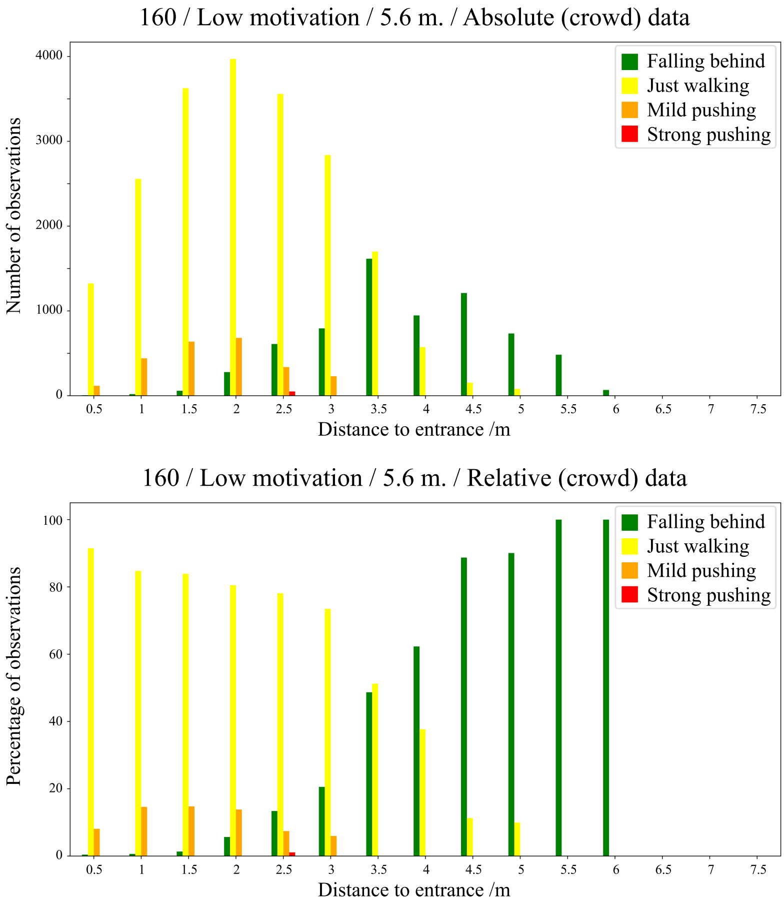

Figure 5: Exemplary absolute (a) and relative (b) frequency bin plots (crowd data). The X-axis of each plot represents ”distance to entrance” in meters (0 to 7.5 m., with each bin placed at 0.5 m. intervals), and the Y-axis represents the collected category data from all frames (a) and the percentage of category data (b) collected within each semi-circle, presented as bins. Each bin is color-coded according to category labels. Titles provide the necessary information about the experimental runs from which the data was selected.

3.2.3 Category Charts

The “crowd” data, which consists of the number of observed categories within each distance bin (absolute frequency), was also utilized in the category charts, but this time grouped by pushing categories. Although the addition of flow data wouldn’t lead to a misleading interpretation due to the use of absolute frequency data, it was opted not to be included to maintain consistency across the spatial analysis sections. The objective was to gain insights into the distance distribution to the bottleneck for each individual pushing category. Additionally, the runs were further divided into high motivation and low motivation categories to examine potential differences in the distance distribution for each pushing category between these two types of runs.

In all of the analyses, it is evident that the categories are predominantly clustered within the first three meters, which is likely the threshold where the crowd formation begins. Prior to reaching three meters, there is a slight increase in all categories across different runs, but this increase becomes more pronounced after the threshold is reached (see A.3).

In the first meter, which contains less data, there appears to be a decrease in all categories. However, it is important to note that this should not be interpreted as an actual decrease, as discussed earlier and disproved in the relative frequency distance bins. Additionally, it is worth mentioning that just like the pushing categories, the non-pushing categories also exhibit a significant increase in data as pedestrians move closer to the bottleneck. However, we need to interpret this with caution since their proportion decreases overall, as shown in the relative frequency distance plots. Nevertheless, the absolute frequency data of all categories demonstrates a similar trend across all cases.

Furthermore, in the high motivation runs, all categories exhibit a peak point that gradually approaches as the intensity of the pushing behavior increases. For instance, the peak point of "mild pushing" (see Figure 6a) is slightly further away from the peak point of "strong pushing" (potentially peaking at the first bin) (see Figure 6b), but still much closer compared to the peak point of non-pushing categories. On the other hand, the low motivation runs, which have fewer instances of pushing behavior, primarily show peak clusters for non-pushing categories. However, a gradual proximity for the active categories is still observable (see A.3 and Figure 13).

3.2.4 Heat Maps

For the next analysis, a heat map-like visualization was utilized to provide a clearer representation of the spatial distribution of the pushing categories. Instead of using semi-circles, the bottleneck platform was divided into equal square sections, with each cell measuring 25cm by 25cm. The category data was used as ordinal numbers, with a coding of 4 for strong pushing, 3 for mild pushing, 2 for just walking, and 1 for falling behind, as used during the actual rating process. The color of each square in the heat map was determined based on the mean values of the pushing category data within that cell, using a color scale ranging from 1 (falling behind) to 4 (strong pushing). Once again, the temporal aspect of the data was disregarded, and all the "crowd" phase data within each second or frame were collected for analysis.

The data presents a clear distribution pattern of the categories, with the pushing categories predominantly observed in the proximity of the bottleneck. This observation is consistent across all high motivation runs (see Figure 7a), as the closer cells tend to contain a higher concentration of pushing data. Similar results are observed in the low motivation runs (see Figure 7b), although

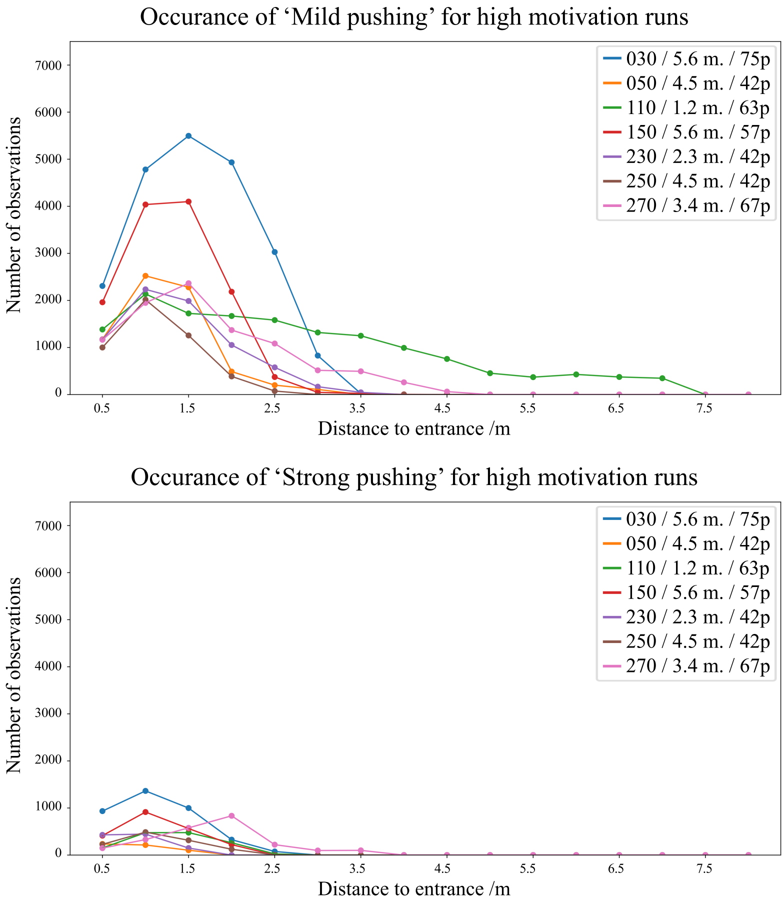

Figure 6: Category charts for the "mild pushing" (a) and "strong pushing" (b) categories (absolute frequency data) across all seven high motivation runs are presented. The X-axis of each plot represents "distance to entrance" in meters (ranging from 0 to 7.5 m., with each bin set at 0.5 m. intervals), while the Y-axis represents the collected category data from all frames within each semi-circle. Distinct colors correspond to various experimental runs. The labels provide insight into the experimental setups, detailing corridor width and pedestrian count for each run.

the visibility of this pattern varies due to the lower occurrence of pushing categories. However, there is still an increase within the non-pushing categories from "falling behind" to "just walking". Thus, regardless of whether it involves pushing or non-pushing behavior, there is an overall increase in the categories as pedestrians approach the bottleneck. Some anomalies can be observed in the distant cells, showing an increase in pushing; however, this occurrence is likely due to the smaller amount of data available for those cells. Figure 7 displays the general tendency of these observations in all the heat maps (see A.4 for all heat maps).

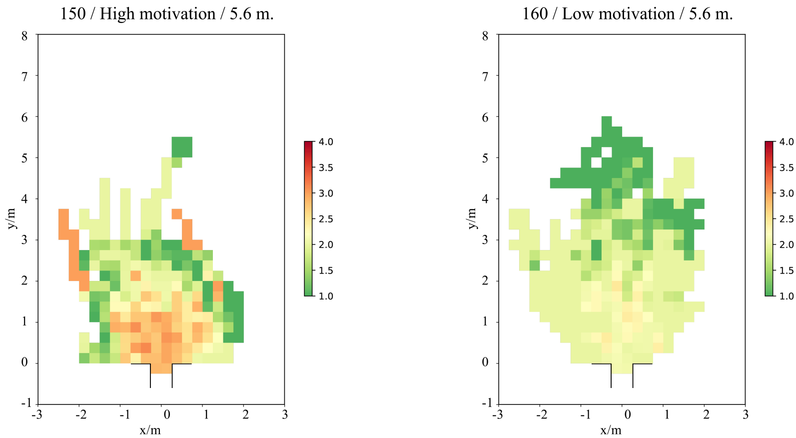

Figure 7: Exemplary heat maps from high motivation and low motivation runs. Figures illustrate the mean category value collected in 25 cm. to 25 cm. cells. The X-axis represents the width of a hypothetical bottleneck platform (-3 m. to 3 m., with a total width of 6 m.), while the Y-axis represents the length of the bottleneck platform (8 m.). The data flow, or pedestrian flow, is depicted from top to bottom. The collected data in each cell are color-coded based on the color scale derived from the category labels. Red represents "Strong pushing," orange represents "Mild pushing," yellow represents "Just walking," and green represents "Falling behind." Intermediate colors from the color scale are also used.

3.2.5 Time Analyses

Lastly, frequency-time analyses were conducted. These analyses primarily considered temporal aspects, disregarding spatial information, as the previous spatial analyses did not account for time. Two distinct types of plots were created for this analysis: Frequency charts illustrating category increases and decreases, and mean category value charts.

For the first plot type, all category increases (e.g., from 2 to 3: from just walking to mild pushing) and decreases were counted for each experiment individually, with consideration of the second at which they occurred. Spatial aspects, as well as the specific type of increase (e.g., from 1 to 2, 2 to 3, 2 to 4, etc.), were disregarded. Each increase and decrease was tallied and presented in a frequency chart over the course of the experiment period, with data aggregated in three-second intervals. The goal was to identify the time points at which these changes occurred and examine potential patterns that might correspond to psychological or social crowd dynamics. Figure 8 illustrates the variations in increase and decrease counts for selected high and low motivation runs (refer A.5 for all the plots).

In general, the figures reveal a tendency for an increase in the pushing category after the first three-second interval, corresponding to seconds between 3 and 6. This increase may be attributed to the previously mentioned distinction between the "flow" and "crowd" phases. During the "flow" phase, pedestrians move relatively quickly and freely, but as the initial seconds pass, they may have a tendency to increase their category as they seek to take advantage of the

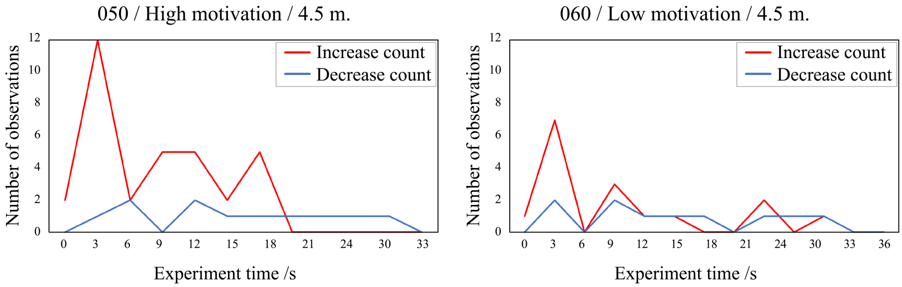

Figure 8: Exemplary time/frequency charts for pushing category increases and decreases in one high motivation (a) and one low motivation (b) run are displayed. These figures illustrate the category increases and decreases collected in each second, aggregated in three-second intervals. The X-axis of the plots represents the overall experiment time period in seconds, while the Y-axis represents the frequency of category increases (in red) and decreases (in blue).

situation. While this outcome was reasonable and expected, it's worth noting that this wasn't the only peak in category increases observed throughout the runs. For most runs, the second peak point in category increases occurred during later periods, often in the middle of the experiment, which hints at a pattern throughout the runs (see A.5, additionally, for a percentage-based version, refer to A.6).

Regarding the differences between categories, there was a general tendency for high motivation runs to exhibit higher frequency in category increases when compared to low motivation runs. Concerning decreases, on the other hand, while they were less frequent than increases, the main peak point for decreases also occurred in the earlier seconds, although not necessarily in the initial intervals. Lastly, corridor width does not appear to have a significant effect on category increases and decreases.

The second chart type involved tracking the mean category value throughout the experiments in three-second intervals. To accomplish this, all the category data were recorded for each second, the mean category value was calculated for each experiment individually, and then the results were combined into a single plot. The goal was to identify any patterns where the mean category value was higher or lower at specific time points, providing additional insights into temporal crowd dynamics. Figure 9 illustrates this analysis by combining results from both high motivation (a) and low motivation (b) scenarios.

The figures reveal that, in general, high motivation runs exhibited higher average pushing category numbers compared to low motivation runs, and there were no distinct differences between different corridor widths. Within high motivation runs, two distinct patterns emerge: firstly, a curved trend with an initial increase followed by a decrease, and secondly, a consistent slow decrease over time. However, it's notable that the category increases discussed previously did not substantially impact the overall mean value data. The averages peaked around 10 to 20 seconds, even though the most prominent category increases occurred between 3 to 6 seconds. However, it's important to consider that the overall pedestrian number gradually decreased in each second due to pedestri-

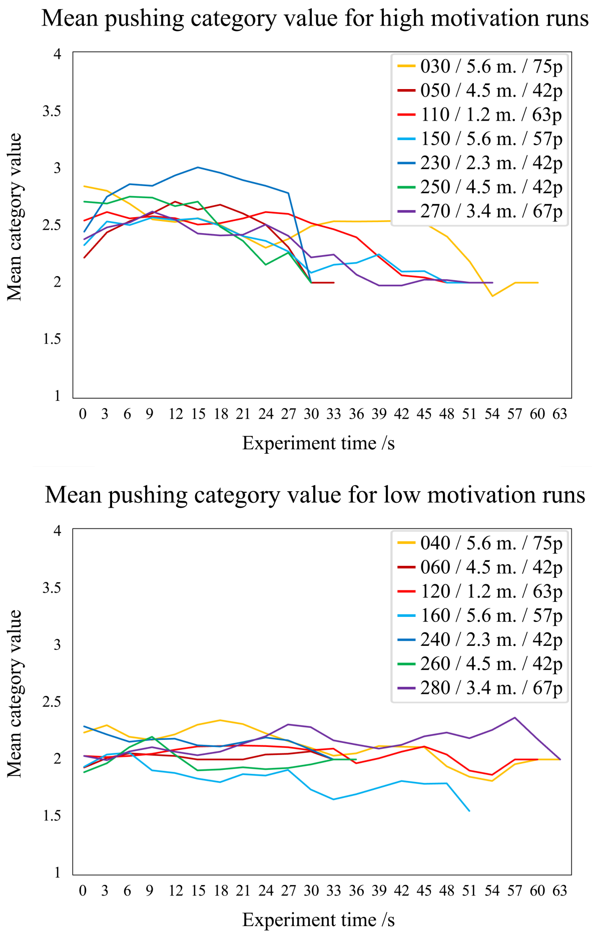

Figure 9: Mean category value charts for high motivation (a) and low motivation (b) runs, including all the experiments, are displayed. All average calculations were conducted for each second, and the results are presented in three-second intervals. The X-axis of the plots represents the overall experiment time period in seconds, while the Y-axis represents the total ordinal pushing category data, ranging from 1 to 4. Distinct colors correspond to various experimental runs. The labels offer insights into the experimental setups, providing information on corridor width and pedestrian count for each run.

ans exiting the bottleneck over time. It's possible that pedestrians with increased categories exited when they were near the bottleneck, leading to their data not being counted after they left. This interpretation aligns with the previous spatial analyses, which showed that the categories increased as pedestrians got closer to the bottleneck.

For both types of plots, the initial intention was to combine all the data from the experiments. However, this approach had to be revised because the experimental runs had varying durations and different numbers of pedestrians in each second. To address the issue of varying pedestrian counts, we created an alternative version of the category increase and decrease charts. This version includes ratios calculated from increase and decrease frequency divided by the total pedestrian count on the platform for that specific second, resulting in a percentage representation (e.g., if there are 40 pedestrians in a specific second with 10 increases and 5 decreases, it is represented as .25 increase and .12 decrease, as shown in A.6). However, due to the differences in experimental durations and fluctuations in the data, this plot type was presented individually for each experiment. In contrast, the mean category value charts were shown collectively since they demonstrate clear and continuous averages of the means. While we believe this shouldn't pose an issue for interpreting the plots, it's important to consider that mean category values are calculated from different numbers of pedestrians in each second (e.g., second 1 with 60 participants, second 40 with 10 participants), with variations across all experiments.

4 Discussion

The study at hand aims to investigate the different categories of pushing behavior in relation to the spatial and temporal properties of crowds. To obtain ratings for the pushing behavior categories, two trained raters independently annotated 14 videos of laboratory pedestrian experiments, ensuring a sufficient level of inter-rater reliability. Using this rating dataset, analyses were conducted to visualize the spatial dynamics, as well as certain aspects of the temporal dynamics of pushing behavior. These analyses facilitated the observation of how pushing behavior changes, forms clusters, increases, and decreases across different locations and time periods within the crowd.

There are several noteworthy findings from this research. Firstly, in almost every video, a clear pattern becomes apparent where the proportion of pushing behavior increases as individuals move closer to the bottleneck. Conversely, individuals further away from the bottleneck exhibit a lower frequency of pushing behavior and a higher proportion of non-pushing categories. This spatial division highlights the different behavioral dynamics among participants based on their position relative to the bottleneck. In a metaphorical manner, we refer to this observation as the "carrot effect," drawing from the English idiom "carrot and stick." This idiom, although more complex in its full context, signifies that a visible reward can increase an individual's motivation. In our case, pedestrians seem to be more engaged when they perceive the goal (the bottleneck) to be within closer reach. In the psychology and motivation literature, this phenomenon can be explained by the concept of "goal proximity", which suggests that as individuals get closer to their goals, the value and attractiveness of the task increase, subsequently enhancing their motivation [19, 20, 21]. Additionally, these findings are consistent with the expectancy and value concept of major motivation theories [22, 23, 24], as the expectancy of reaching the bottleneck continuously increases as individuals approach it, consequently amplifying their motivation. In light of these contextual factors, we interpret the observed increase in pushing behavior as a reflection of increased expectancy, goal valuation, and motivation.

Secondly, the category charts reveal that all categories show distinct peaks at specific distances, reflecting an orderly progression as the intensity of the category increases. This observation holds true for all categories in the high motivation instruction, and a similar observation also applies to non-pushing categories in low motivation instruction, as there is a gradual increase in those categories. This pattern is consistent with the previous finding, which showed an increased frequency of pushing categories as pedestrians approach the bottleneck entrance. Additionally, it indicates that behavior change of pedestrians shows a clear and organized sequence, increasing into more intensive categories as they approach the bottleneck.

Another pattern observed in the category charts is the presence of a starting threshold for mild pushing and strong pushing behaviors in terms of proximity to the bottleneck. It appears that for the high motivation instruction, mild pushing behavior starts to increase at approximately three meters before the bottleneck entrance. This finding is not surprising, considering that most crowd formations in the analyzed videos occurred within a three-meter reach of the bottleneck. However, there is also a threshold for strong pushing behavior, which is roughly two meters from the bottleneck. This suggests that intense pushing behavior begins either after the crowd has formed or when pedestrians are in close proximity to the bottleneck. While the increase in mild pushing at three meters could be attributed to a higher number of data points in that range, the two-meter threshold for the strong pushing category is a noteworthy finding.

Furthermore, the findings suggest that the notion that pushing leads to faster access is circumstantial and may not have a significant effect in terms of individual success. The width of the corridor emerges as a crucial factor in determining this particular flow dynamics. Narrower corridors tend to exhibit smoother flow, and among pedestrians rated with pushing categories, none of them demonstrated a visible advantage in narrow corridors. In fact, all pedestrians in narrow corridors, whether rated as pushers or non-pushers, reached the bottleneck in similar time and distance properties. However, in wider corridors where congestion and crowd formations occurred, there were instances where pushing pedestrians reached the bottleneck faster than their non-pushing counterparts. It is worth noting that this pattern was not explicitly consistent across all wide corridor runs; it was clearly evident in only one set of experiment data, while being hinted at in others.

Finally, our temporal analyses have revealed significant insights. The primary objective of these analyses was to investigate whether the observed pushing category results could be attributed to non-experimental factors, such as participants' prepositioning on the platform before the experiments began, particularly in front of the bottleneck due to the provided motivation instructions. We refer to this potential phenomenon as the "sorting effect," which suggests that motivation instructions might have strongly influenced the positioning of pedestrians even before the experiments started, with motivated participants placing themselves in front of the bottleneck and quickly exiting, rather than being evenly distributed across the platform. However, the category increase and mean category value analyses suggested that this effect was not a highly dominant factor. While there was a general tendency for category increases during the initial quarter of the experiments, we also observed multiple peak points for increases, most of which occurred after the first few seconds and in the middle of the experiment periods (or proportionally in the last quarter of the experiments). Similarly, the mean category values were typically highest during the middle stages of the experiments. Furthermore, we have strong confidence that our spatial findings were not significantly influenced by these potential issues, as all spatial results were derived from the experiment periods, excluding the initial five to seven seconds. However, this does not necessarily imply the absence of the "sorting effect," as the initial seconds still contained a substantial increase. Simultaneously, the presence of other effects, such as category increases and mean pushing category values peaking in the middle of the experiment periods, suggests the existence of other dynamics requiring further investigation, while also indicating a semi-homogeneous distribution of motivated pedestrians before the experiments began.

4.1 Limitations

It is important to note that the interpretations and discussions were based on artificial settings, which may limit their generalizability to real-world scenarios. It is crucial to apply the established category system in real-life situations and different experimental environments, such as evacuation scenarios, to ensure the relevance and replicability of the findings. Additionally, although we examined different corridor widths and motivations in bottleneck scenarios, other potential factors, such as bottleneck width or having multiple bottlenecks, were not thoroughly considered due to the limitation of having only one type and size in our study. It is necessary to verify the applicability of the findings in various settings, including wider or narrower bottleneck widths, as wider widths may lead to smoother crowd flow, potentially resulting in less utilization of pushing behavior.

Furthermore, the interpretations we made based on our findings, such as the idea that an increase in motivation leads to pushing as pedestrians get closer to the bottleneck, are somewhat speculative since we did not collect any subjective data from pedestrians regarding their underlying psychological mechanisms. While our interpretations align with existing motivation literature, they focus on one specific explanation, and it is important to acknowledge that there are other plausible explanations within different theories that may also hold true. For instance, competition theories or the propagation concept (see [25]) could also contribute to these results, aside from motivation. The lack of subjective data is a major limitation of this study, and despite our confidence in interpreting the events with motivation literature, we cannot disregard the fact that future studies should investigate this issue by focusing on the subjective psychological mechanisms to see the full picture.

4.2 Practical Implications

The present study has the potential to contribute valuable knowledge to crowd safety by examining the forward motion behaviors displayed in various circumstances, such as different corridor widths and instructed motivations. These behaviors have been observed to follow specific patterns, with excessive behaviors tending to occur in certain areas. Understanding where potentially dangerous behaviors may emerge can inform crowd managers and help them implement practical measures for prevention or mitigation. Additionally, researchers in the fields of pedestrian dynamics and crowd sciences can utilize the key findings of this study or build upon them to further investigate the link between pushing behavior, motivation, and general crowd behavior in terms of spatial and temporal dynamics.

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A Appendices

A.1 Time-Distance Trajectories

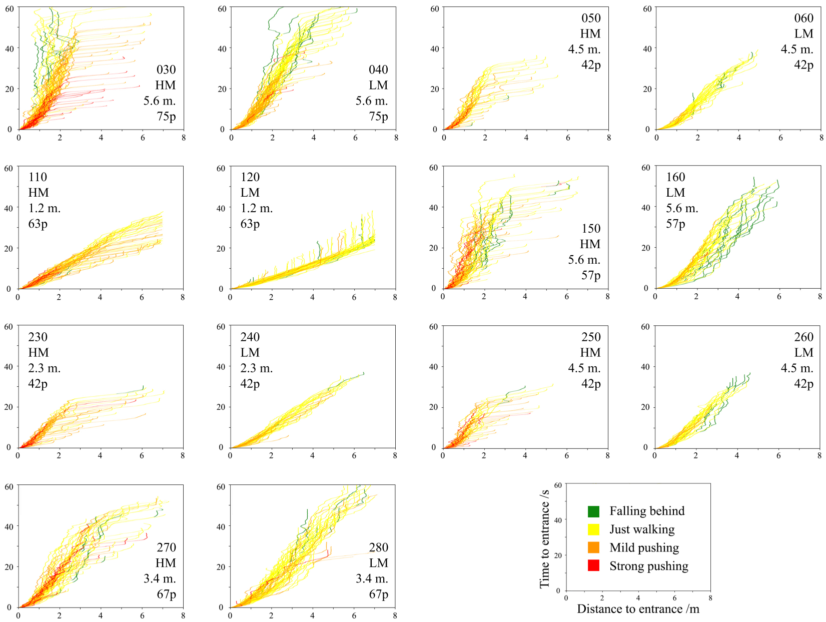

Figure 10: Complete time-distance analysis of the experimental runs is depicted in the figure. The X-axis of each plot represents "distance to entrance" in meters (0 to 8 m.), and the Y-axis represents "time to entrance" in seconds (0 to 60 seconds). Individual time and distance trajectories of pedestrians are color-coded according to category labels. Red indicates "Strong pushing," orange indicates "Mild pushing," yellow indicates "Just walking," and green indicates "Falling behind." Trajectories start from the initial position of each pedestrian and end when the pedestrian reaches the bottleneck. Side notes provide additional information, including the motivation level (HM = high motivation; LM = low motivation), corridor width (5.6 m.; 4.5 m.; 3.4 m.; 2.3 m.; 1.2 m.), and the number of pedestrians in each specific run. The order of the plots reflects the sequence of the conducted experiments.

A.2 Distance Bins (Relative Frequency)

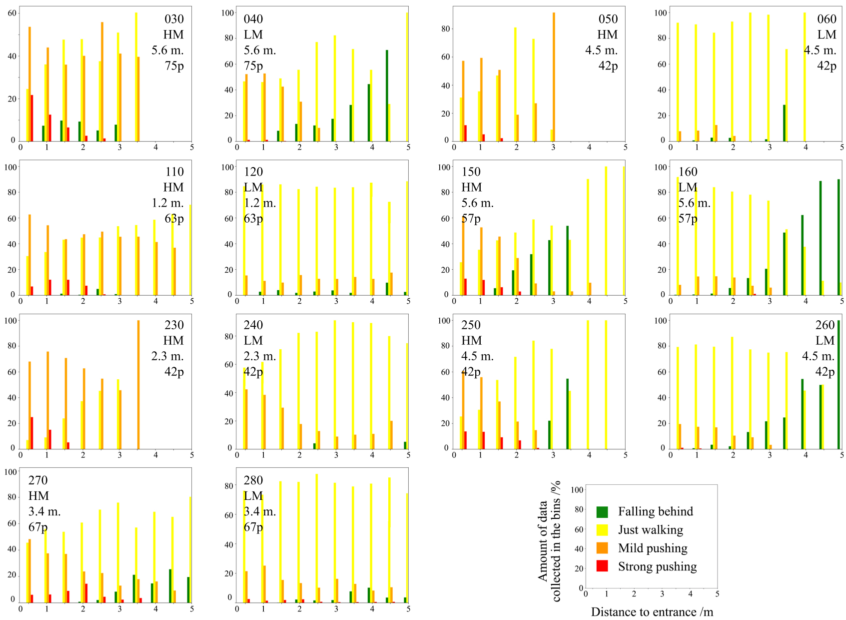

Figure 11: The figure depicts a complete (relative frequency) distance analysis of the experimental runs using bin columns. The X-axis of each plot represents "distance to entrance" in meters (0 to 5 m., with each bin placed at 0.5 m. intervals), and the Y-axis represents the percentage of category data collected within each semi-circle, presented as bins. The collected data in each bin are color-coded according to category labels. Red indicates "Strong pushing," orange indicates "Mild pushing," yellow indicates "Just walking," and green indicates "Falling behind." Side notes provide additional information, including the motivation level (HM = high motivation; LM = low motivation), corridor width (5.6 m.; 4.5 m.; 3.4 m.; 2.3 m.; 1.2 m.), and the number of pedestrians in each specific run. The order of the plots reflects the sequence of the conducted experiments.

A.3 Category Charts

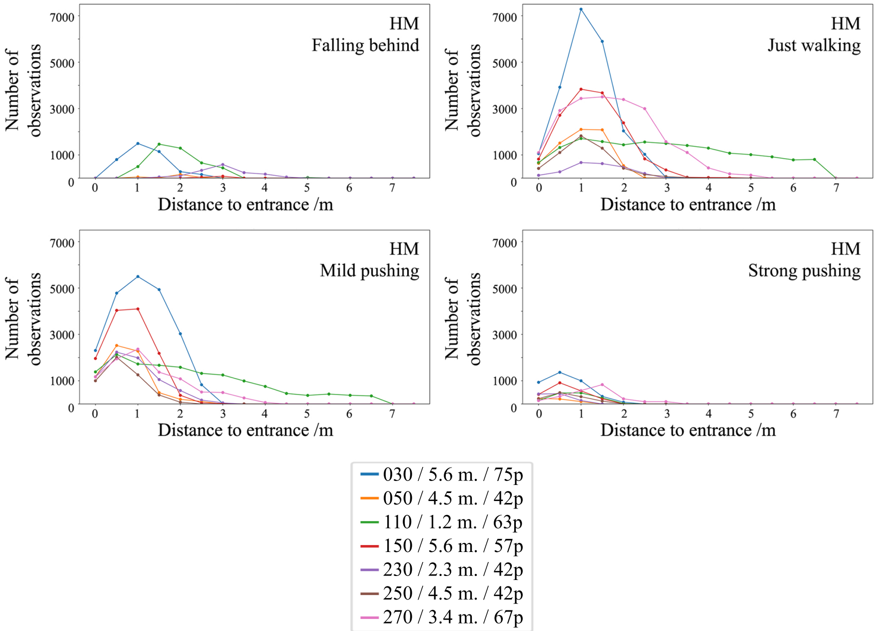

Figure 12: The figure illustrates a complete (absolute frequency) distance analysis of the pushing categories using coordinate points for high motivation runs. The X-axis of each plot represents "distance to entrance" in meters (0 to 7 m., with each point placed at 0.5 m. intervals), and the Y-axis represents the number of category data collected from all frames within each semi-circle. Colors represent the different experimental runs. Side notes provide additional information, including the motivation level (HM = high motivation) and the specific pushing categories being presented (falling behind, just walking, mild pushing, strong pushing).

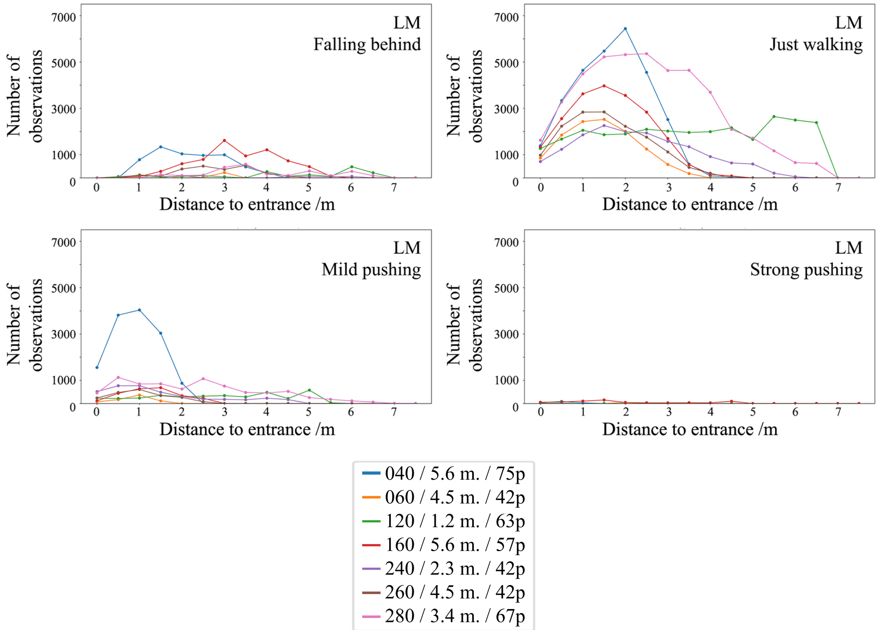

Figure 13: The figure illustrates a complete (absolute frequency) distance analysis of the pushing categories using coordinate points for low motivation runs. The X-axis of each plot represents "distance to entrance" in meters (0 to 7 m., with each point placed at 0.5 m. intervals), and the Y-axis represents the number of category data collected from all frames within each semi-circle. Colors represent the different experimental runs. Side notes provide additional information, including the motivation level (LM = low motivation) and the specific pushing categories being presented (falling behind, just walking, mild pushing, strong pushing).

A.4 Heat Maps

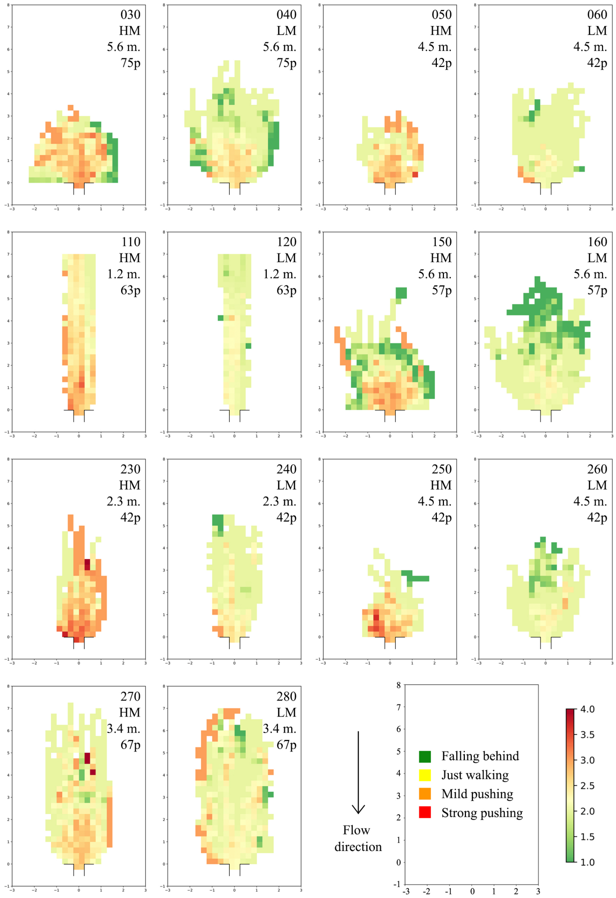

Figure 14: The figure illustrates the mean category data collected in 25cm to 25cm cells across all experimental runs. The X-axis represents the width of the bottleneck platform (-3 m. to 3 m., with a total width of 6 m.), while the Y-axis represents the length of the bottleneck platform (8 m.). The data flow, or pedestrian flow, is depicted from top to bottom. The collected data in each cell are color-coded based on the color scale derived from the category labels. Red represents "Strong pushing," orange represents "Mild pushing," yellow represents "Just walking," and green represents "Falling behind." Intermediate colors from the color scale are also used. The color scale is presented on the bottom-left of the figure. Side notes provide additional information, including the motivation level (HM = high motivation; LM = low motivation), corridor width (5.6 m., 4.5 m., 3.4 m., 2.3 m., 1.2 m.), and the number of pedestrians in each specific run. The order of the plots reflects the sequence of the conducted experiments.

A.5 Category Increase and Decrease Frequency

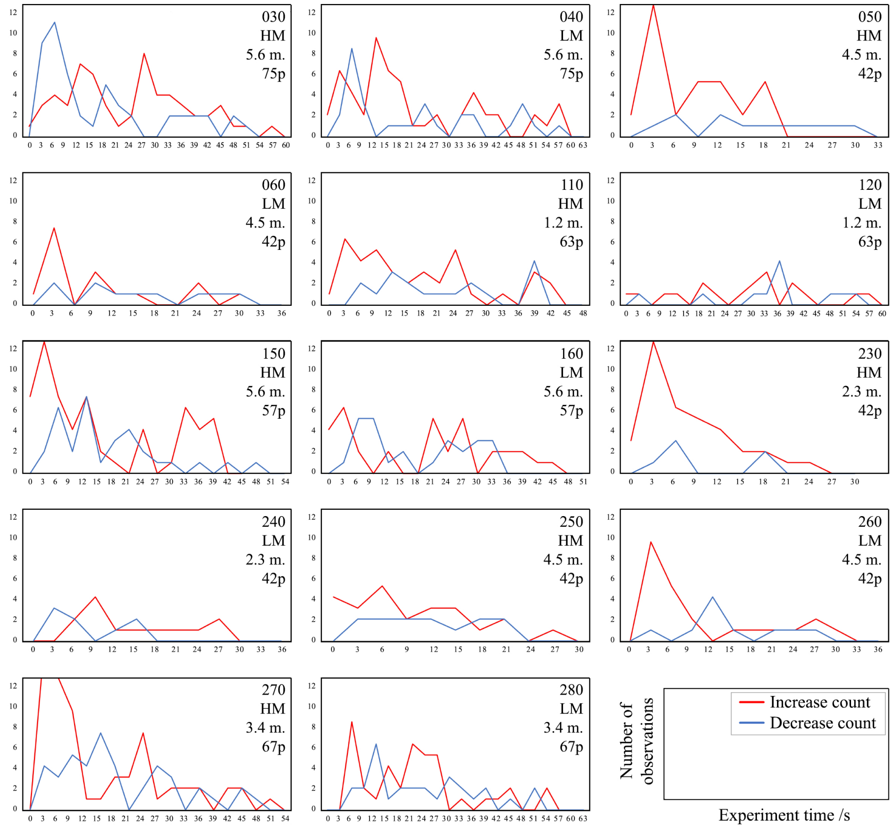

Figure 15: The figure illustrates time/frequency data for pushing category increases and decreases across all experimental runs. The category increases and decreases were collected in each second and aggregated in three-second intervals. The X-axis of the plots represents the overall experiment time period in seconds, while the Y-axis represents the frequency of category increases (in red) and decreases (in blue). Labels provide additional information, including the motivation level (HM = high motivation; LM = low motivation), corridor width (5.6 m., 4.5 m., 3.4 m., 2.3 m., 1.2 m.), and the number of pedestrians in each specific run. The order of the plots reflects the sequence of the conducted experiments.

A.6 Category Increase and Decrease Percentage

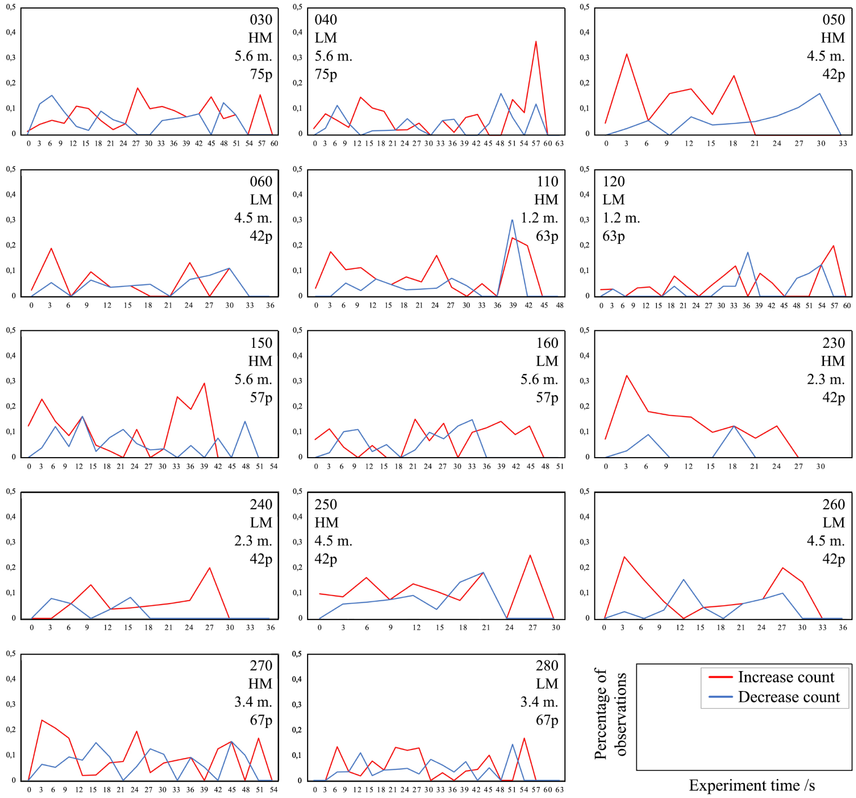

Figure 16: The figure illustrates the proportion of the time/frequency data for pushing category increases and decreases across all experimental runs. The category increases and decreases were collected in each second and aggregated in three-second intervals. The ratio is calculated from increase and decrease frequency divided by the total pedestrian count on the platform for that specific second. The X-axis of the plots represents the overall experiment time period in seconds, while the Y-axis represents the percentage of category increases (in red) and decreases (in blue) with a range of 0 to 50 percent. Titles provide additional information, including the motivation level (HM = high motivation; LM = low motivation), corridor width (5.6 m., 4.5 m., 3.4 m., 2.3 m., 1.2 m.), and the number of pedestrians in each specific run. The order of the plots reflects the sequence of the conducted experiments.

PUBLICATION IV

Towards Dynamic Motivation: Integrating Psychological Theories of Motivation in Pedestrian Modeling for Bottleneck Scenarios

Note: This article is ready to be submitted as Üsten, E., Cordes, J., Chraibi, M., Sieben, A., Seyfried, A. (2023). Towards Dynamic Motivation: Integrating Psychological Theories of Motivation in Pedestrian Modeling for Bottleneck Scenarios.

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Towards Dynamic Motivation: Integrating Psychological Theories of Motivation in Pedestrian Modeling for Bottleneck Scenarios

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Abstract

Modeling pedestrian entrance scenarios is a central focus in the field of pedestrian dynamics, yet existing models, rooted in physics, have limitations when it comes to incorporating psychological aspects of individual behavior. Despite prior efforts to integrate certain psychological concepts, this interdisciplinary perspective is relatively new, and there is room for further exploration. This study aims to initiate a discourse on the integration of motivation into pedestrian models. While previous approaches have often employed a simplified binary categorization of motivation, classifying agents as either highly motivated or lowly motivated, this simplification, while useful in some contexts, fails to capture the complexity of motivation, which is influenced by a multitude of intrinsic and environmental factors. We introduce two critical dimensions of motivation: heterogeneity (variations in individual motivation levels within the crowd) and dynamism (fluctuations in motivation levels during goal pursuit) to establish a foundation for modeling motivation in entrance scenarios. The manuscript includes a preliminary study that explores the spatial distribution of motivation within a crowd by dividing the bottleneck platform into three motivation areas consisting of high and low motivation groups, focusing solely on heterogeneity. This study employs a velocity-based model with parameters for desired speed (v^0) and time to close gaps between agents (T). The results reveal that the number of high motivation groups significantly impacts evacuation time, with more high motivation groups leading to faster evacuation. However, the specific placement of high motivation groups within the bottleneck platform does not significantly affect evacuation time. Additionally, a blueprint for the main study was presented, which outlines a comprehensive motivation model that incorporates both dynamism and heterogeneity in pedestrian behavior, aiming to move beyond the binary high and low motivation framework. This advanced model is intended to utilize psychological concepts such as expectancy, value, and competition, drawing from well-established expectancy and value theory of motivation in general psychology to provide a deeper understanding of crowd

behavior in entrance scenarios.

Keywords: Pedestrian modeling; Simulation; Motivation; Bottleneck; Crowd psychology; Social Psychology; Expectancy and value

1 Introduction

Crowd occurrences are complex yet very common in today's societies. As a result, scholars from various fields, including physics, computer modeling, and social sciences, have dedicated their efforts to studying pedestrian dynamics and crowd formations to better understand their characteristics and behavior. Computer modeling, in particular, has become an important tool for applying ideas and discovering the properties of pedestrian dynamics. These models aim to accurately represent crowd formations in simulation environments. Therefore, this field is fundamentally interdisciplinary, involving humans with complex psychological, social, and cultural characteristics, along with their particle-wise physical properties. The strategies and perspectives used are both micro and macro in nature, taking into account both individual and collective behaviors.

Unfortunately, up to this point, psychology (or general social sciences) has not played a prominent role in model creation within the study of pedestrian dynamics and crowd formations in entrance scenarios. Even in microscopic models where the movements of individuals are treated separately, the underlying human motives driving these different movements with varying speeds or accelerations have not been thoroughly explored with a strong theoretical foundation. However, to achieve a comprehensive representation of crowds, theories from psychology and sociology concerning crowds and individuals should be articulated, or at least partially integrated, in cases where these theories could not be represented mathematically. Nevertheless, they can at least aid in formulating the initial steps toward simulating crowd behavior.

It's worth noting that although this interdisciplinary perspective hasn't been extensively explored, there are some noteworthy examples. For instance, social identification has been used to model helping behavior in evacuation scenarios [1], and cognitive heuristics have been incorporated into pedestrian modeling to simulate simple decision-making processes such as collision avoidance or following behavior [2]. While the body of work in this area with an interdisciplinary focus is relatively limited, there is a growing belief that realistic and robust simulations can benefit greatly from the integration of social scientific theories [3].

The aim of this study shares a similar goal, as it seeks to initiate a discourse on incorporating motivation to move or reach a destination in entrance scenarios in pedestrian modeling. While motivation is a wide-ranging concept and has been the subject of numerous groundbreaking theories, many of which focus on long-term individual motivation (e.g., [4, 5, 6]), its relation to actions and behavior changes has also been extensively investigated. It has been shown that motivational changes can significantly impact behavior [7], and consequently, this concept can be readily adapted to pedestrian behavior. Pedestrians, driven by their motivations, can exhibit distinct behaviors, leading to diverse scenarios.

Motivation is believed to be one of the most apparent psychological drivers of movement behavior in pedestrian environments, capable of significantly influencing crowd dynamics.

Consequently, researchers in the field have used motivation in their studies to explore crowd dynamics. Pedestrian experiments, particularly those incorporating bottleneck scenarios, have provided valuable insights into the effects of motivation. Researchers have investigated various corridor shapes, widths, and scenarios while manipulating participants' motivation levels using a high versus low dichotomy [8, 9, 10, 11, 12, 13, 14]. Typically, motivation was primed through pre-instructions, where participants were asked to imagine scenarios artificially increasing their motivation (an exemplary instruction for high motivation being: 'Imagine you are on your way to a concert by your favorite artist...'). Not surprisingly, crowd dynamics such as density, flow, and acceleration exhibited different results between high and low motivation groups. Crowds instructed with high motivation tended to exhibit more active and assertive behavior, displaying a greater eagerness to reach the bottleneck quickly. Consequently, spatial and temporal crowd properties, such as density, exhibited greater increases in high motivation groups when compared to those receiving low motivation instructions.

In modeling, this dichotomous representation of motivation has also been used in certain scenarios [15]. Additionally, significant efforts have been made by Rzezonka et al. [16] to define parameters assigned to agents that correspond to high and low motivation instructions. Two parameters, namely desired speed and time to get close to neighboring agents, were utilized to replicate the density outcomes observed in selected high and low motivation experiments through simulation. While high and low motivation instructions typically influence more factors than just speed and gap closing in real-life experiments (e.g., attention, shoulder/arm position, social interactions) [17], in simpler terms, these parameters were successful in reproducing the density results within a computer modeling environment. The current study also aims to incorporate these parameters to simulate motivational effects, however, in a more detailed manner.

While simplifying motivation for simulations can be beneficial, it's important to note that in real-life scenarios or experiments, the distinction between high and low motivation in crowds is not always clear-cut. Unless explicit instructions are strongly imposed (e.g., as seen in military parades), individuals within a crowd do not necessarily exhibit the same behavior to the same extent. Furthermore, each person in the crowd is driven by different factors influencing their goal-reaching behavior. When analyzing video footage from the aforementioned studies, it becomes apparent that although the majority of the crowd moves at a similar speed (e.g., walking at 1.2 m/s), some individuals may move slower or faster due to factors such as their initial position on the platform, excitement within their social group, or simply a lack of interest. These observations, combined with decades of research in motivation concept in psychology [7], suggest that a complex interplay of individual psychological processes comes into play when pedestrians find themselves in such situations. Therefore, comprehending and modeling the nuanced effects of motivation on crowd behavior is a challenging task that demands a comprehensive approach, one that goes beyond simplistic categorizations of high and low motivation while also considering the dynamic and heterogeneous nature of human behavior in crowds.

Recent studies on the crowd behavior regarding heterogeneity have yielded similar findings. For instance, Lügering, Üsten, and Sieben [17] developed a rating system to measure the intensity of forward motion (e.g., pushing) in crowds and found that regardless of the initial motivation instruction, there is a wide range of actions taken by pedestrians. Although individuals in high motivation groups tend to exhibit more intense behavior, there are still some who do not show the same level of motivation, and vice versa in low motivation groups. These pushing behaviors also vary in intensity, with some categorized as "mild" and others as "strong" pushing. Moreover, individual behavior is found to be not static but ever-changing, as individuals' motivation and perspective may shift over time depending on potential internal and external factors. Üsten, Schumann, and Sieben [18] conducted a follow-up study that further demonstrated the influence of motivation on pedestrian behavior. The study revealed that as pedestrians approached the bottleneck, both in high motivation and low motivation scenarios, they exhibited a notable increase in pushing behavior. This spatial division highlighted the varying dynamics of behavior and motivation among participants based on their position relative to the bottleneck. This observation aligns with the concept of "goal proximity" in motivation literature, whereby individuals become more engaged and motivated when they perceive the reward or goal to be within closer reach. According to this concept, as individuals get closer to achieving their goals, the value and attractiveness of the task increase, resulting in enhanced motivation [19].

With guidance from existing knowledge and research on motivation-driven behavioral variety in crowds, this study aims to initiate a discourse on motivation within pedestrian modeling in entrance scenarios. Until now, all simulation models using a high and low motivation binary approach have been static, with parameters remaining constant throughout the simulation. Once these parameters are assigned to the agents, they move toward the entrance using these parameters until they exit from the bottleneck. In experiments, this may not hold true due to participants losing interest or becoming even more motivated during the experimental run. However, they are still treated as highly or lowly motivated because that was the initial instruction provided, as it allows for a convenient distinction between different motivation runs. Furthermore, in both scientific methods, the crowd, whether assigned parameters or instructed verbally, was treated as a homogeneous crowd, implying that all participants or agents either possess the same behavioral properties or actually exhibit the same behavior. In reality, experiments have shown that even when the entire crowd is instructed to behave the same, there tends to be variation, with some individuals highly motivated and others lacking interest. The discourse initiated in this paper incorporates the aspects of dynamism (motivational changes throughout goal pursuit) and heterogeneity (variations in motivation among individuals) within crowds, which arise from motivation-driven behavior, as the main objectives to be achieved within a simulation environment.

However, due to the complexity and extensive nature of incorporating dynamism and heterogeneity into simulations, this study has been divided into two stages. The initial approach focuses solely on the heterogeneity aspect, disregarding dynamism and the changing motivation over time. In this preliminary stage, high and low motivation are still used as two categories, and they remain constant over time. However, the crowd is divided into agents assigned with low motivation parameters and others assigned with high motivation parameters. The first step serves as an exploratory approach that aims to demonstrate the potential of the idea and establish a foundation for the next (main) study.

2 Spatially Distributed Motivation – Preliminary Model

This preliminary model presented here serves as an exploratory approach, and as previously mentioned, it employs a high vs. low motivation dichotomy. However, what sets our preliminary model apart from other models that incorporate high and low motivation parameters is that the bottleneck platform is divided into three motivation areas, each assigning different motivational parameters to the agents based on their initial placement. The objective was to investigate how evacuation time and time/distance trajectories of agents change when different motivation groups (either high or low) are positioned in different areas. Figure 1 illustrates the main borders of these areas.

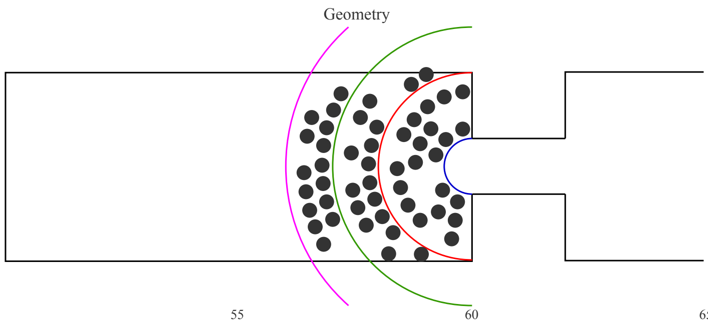

Figure 1: Three predefined motivation areas distributed spatially. The bottleneck is located on the right, and the flow direction is towards the right. The semi-circle lines represent the borders between different motivation groups, which can be assigned by either high or low motivation parameters.

The rationale behind this approach was rooted in observations from previous experiments that utilized high and low motivation conditions. Specifically, it has been shown that pedestrians initially positioned at the back tend to exhibit less intense behavior and often lack interest, regardless of their instructed motivation [18], as opposed to individuals initially placed in the front or middle sections of the platform. While motivation in real-world crowd environments is not precisely outlined, we believe that exploring area-wise motivation effects in pedestrian dynamics presents a promising starting point. Therefore, we assigned different motivation inputs (either high or low) to all predefined areas to explore all possible scenarios. The aim is to present a simple movement model using a fixed set of parameters to indirectly demonstrate the influence of motivation on pedestrian movement.

2.1 Definition

The preliminary model used to simulate pedestrian dynamics in selected entrance scenarios is based on a velocity-based model with basic agent interactions, as proposed by, Tordeux, Chraibi, and Seyfried [20]. The simulation is conducted using the JuPedSim platform [21]. In this model, two parameters, namely desired speed and the slope factor (representing the time to get close to neighboring agents), are employed to characterize the movement of pedestrians. These parameter choices have been previously used to model high and low motivation [16]. These parameters align with the fundamental concept of motivation in pedestrian dynamics, where pedestrians increase their speed when their motivation levels are high and decrease it when their motivation is low. Additionally, the slope factor reflects the rate at which pedestrians close gaps with neighboring agents and is associated with motivation and pushing behavior [17].

The desired speed (v^0) is set as a constant, representing the average walking speed of 1.2 m/s, and is assigned to all agents, regardless of their initial position or the motivation area they are placed in. The slope factor (T) is set to 0.1 second for agents exhibiting high motivation, while agents with low motivation are assigned a value of T = 1.3 second. These values reflect how quickly the agents would close gaps with neighboring agents situated in front of them. These parameter choices are intended to capture differences in agent behavior based on their initial motivation levels.

To comprehensively evaluate the outcomes of the simulation, eight different scenarios were conducted, each specifically designed to test a unique combination of motivation levels. These scenarios are denoted by binary values, where “1” represents high motivation and “0” represents low motivation. The groups were arranged in order, from the group closest to the bottleneck to the group farthest from it. The tested scenarios are listed in Table 1. The "full high motivation" scenario (1, 1, 1) and the "full low motivation" scenario (0, 0, 0) serve as reference points, reflecting existing knowledge on motivation from the literature, which has been extensively investigated in previous research studies [10, 12, 16].

The simulations were conducted separately for 34, 52, and 72 agents, with each simulation repeated ten times to ensure the robustness of the results. For each scenario, the averaged evacuation times were computed to assess the impact of different motivation levels on pedestrian flow. Additionally, we analyzed time-distance data to investigate potential effects of motivation groups on pedestrian flow. For example, we examined how having a high motivation group at the back and low motivation groups at the front (0, 0, 1) influenced the time (in seconds) and distance (in meters) flow of agents in the first two low motivation groups.

Group 1	Group 2	Group 3
1	1	1
1	1	0
1	0	1
1	0	0
0	1	1
0	1	0
0	0	1
0	0	0

Table 1: Table of motivation groups: Assigned motivation levels (0 = Low motivation, 1 = High motivation). Groups are arranged in sequential order, from the group closest to the bottleneck (Group 1) to the group farthest from it (Group 3)

2.2 Numerical Results

The results of the simulations revealed a clear relationship between the proportion of high and low motivation groups and overall evacuation time. As the number of high motivation groups increased, the evacuation time decreased (as shown in Figure 2). Interestingly, however, the placement of high motivation groups within the bottleneck platform did not significantly impact evacuation time. For instance, scenarios with one high motivation and two low motivation groups ([1, 0, 0], [0, 1, 0], [0, 0, 1]), irrespective of their spatial distribution, exhibited similar evacuation times This outcome was consistent across all simulations with varying total pedestrian numbers. Additionally, repeating the simulations did not result in significant differences within each scenario, with the standard deviation always being less than 3 seconds.

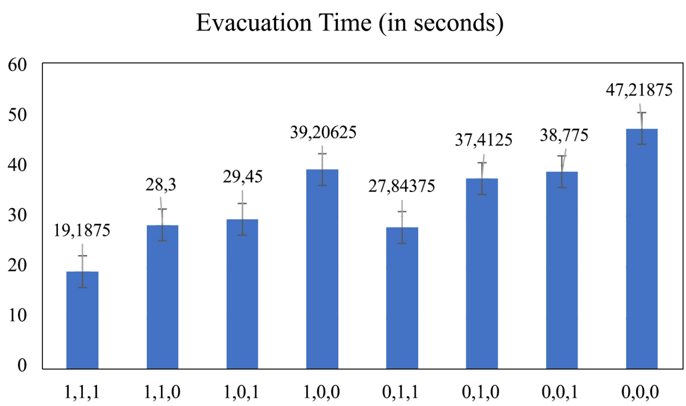

Figure 2: Evacuation time of different motivation scenarios (N = 52).

Analysis of the time-distance plots in individual simulations revealed notable variations in pedestrian movement within simulations featuring the same number of motivation groups (e.g., two high motivation groups, one low motivation group: [1, 1, 0], [1, 0, 1], [0, 1, 1]). The placement of high motivation groups appeared to impact the pedestrian flow pattern. When high motivation groups were positioned at the front of the bottleneck, the resulting pedestrian flow appeared to be more fluid and uniform (see Figure 3). In contrast, simulations with high motivation groups at the back of the platform led to slower movement for low motivation groups in the front, as highly motivated pedestrians attempted to overtake their slower counterparts (see Figure 4). However, it is important to note that while this potential overtaking behavior may appear to affect crowd flow, the overall evacuation time remained consistent across all scenarios with the same number of motivation groups.

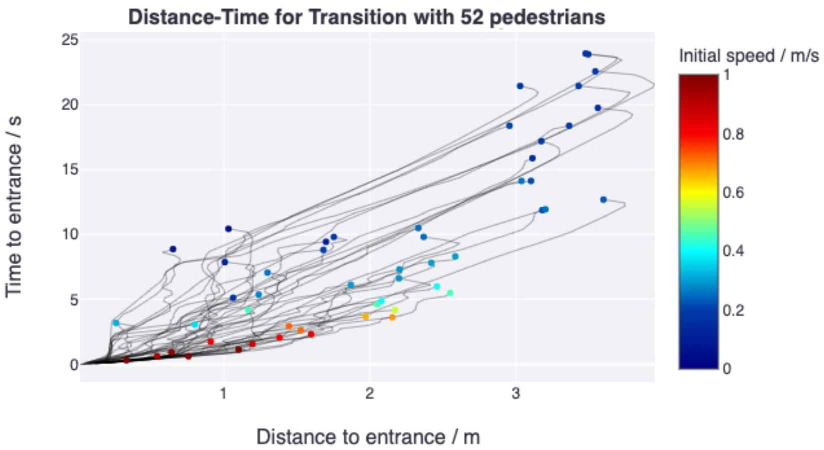

Figure 3: Time-distance plot of an exemplary simulation with two high motivation and one low motivation groups (1, 1, 0) (N = 52).

2.3 Discussion

The preliminary model showed clear outcomes, primarily concerning how different motivational parameters affect the overall evacuation time. While the goal was to examine and explore the spatial distribution of motivation parameters, the model had limitations in terms of dynamism (the change of behavior over time), and heterogeneity was represented by only three divisions. Nevertheless, within this constrained approach, we believe that a foundational framework has been initiated, which future research could potentially benefit from, given the distinct results obtained through a basic representation of heterogeneity based on spatial distribution.

Among the results, it was initially observed that the number of high motivation groups had a significant impact on the overall evacuation time. While extensive research has explored the 'faster-is-slower' effect, suggesting that fast-moving particles can lead to clogs and consequently slower overall evacuation

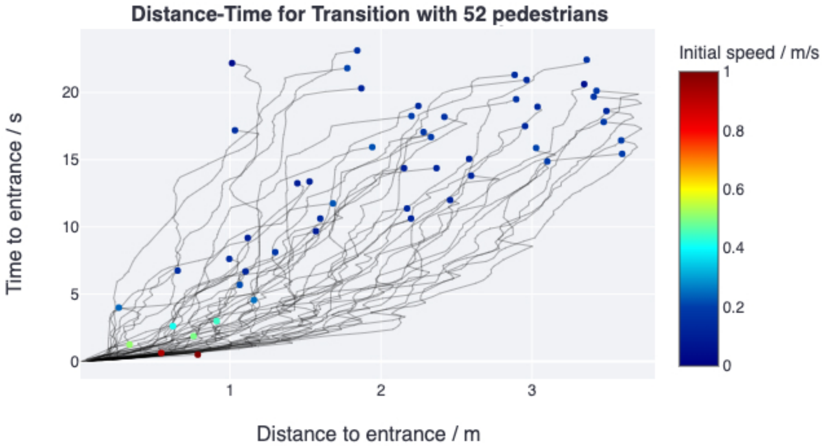

Figure 4: Time-distance plot of an exemplary simulation with two high motivation and one low motivation groups (0, 1, 1) (N = 52).

times [22, 23], the simulations for spatially distributed motivation parameters yielded results indicating that having faster agents resulted in faster evacuation times, as shown under certain conditions [24, 25]. Although the speed parameter (v^0) in the simulations remained constant for all agents regardless of their assigned motivation, the T parameter (the slope factor), representing the time taken to close gaps with neighboring agents, could be viewed as complementary to speed due to its role in rapidly closing gaps with neighboring agents in front. The results showed that the presence of highly motivated groups on the bottleneck platform resulted in faster evacuation times, while reducing the number of highly motivated groups led to slower evacuation times. This effect displayed an orderly pattern, with more high motivation groups resulting in faster evacuation, and decreasing the number of high motivation groups leading to slower evacuation times.

However, concerning the placement of different motivational groups, the results did not reveal significant differences in terms of evacuation time. While the overall flow patterns in terms of time and distance trajectories indicated that the number and location of these groups could influence the flow's smoothness, the resulting evacuation times were quite similar when the compositions of high and low motivation groups were the same. This consistent effect was also observed across repetition runs, with a low degree of variance between the simulations. This outcome was unexpected; for example, it was initially thought that high motivation groups might obstruct overall flow through simulation representations of "pushing," especially when they were located at the back of the platform. However, the results showed that this was not the case. On the other hand, this expectation did not arise from observations in real-life experiments, instead, it was presented as an initial idea for exploring different combinations. In real-life experiments, highly motivated individuals were rarely found at the back of the crowd, and even when they were, they were not typically observed as a group of highly motivated agents; they were more often isolated cases. However, simulations indicated that even when high motivation groups were located at the back, it did influence the overall flow's smoothness, but this flow smoothness did not have a significant impact on the evacuation time.

3 General Discussion and Future Directions

The preliminary model presented in this study served as the initial stage toward creating a comprehensive representation of motivation-driven behavior in entrance simulations. To achieve this, one of the main aspects of motivation in crowds, namely heterogeneity, was utilized in a limited manner to model crowd behavior and yielded promising results. The other aspect, dynamism, which involves the changing motivation over time, was not incorporated. However, while the current outcomes are sufficient for starting this discourse, it is important to note that in order to achieve a realistic representation of crowds in simulations, both aspects—heterogeneity and dynamism—must be fully integrated to develop an extensive model of crowds that focuses on motivation-driven behavior. We will discuss ideas on how to achieve this integration in the following paragraphs.

The main model, currently under development, aims to completely move away from the high and low motivation dichotomy. Instead, it focuses entirely on individual differences plus dynamic changes. This approach inherently incorporates the aspect of heterogeneity, with agents having varying degrees of motivation on a linear scale. Furthermore, it incorporates the ability for agents to change their motivation over time. These concepts are rooted in the observations from crowd experiments, as discussed extensively in previous sections. It is evident that regardless of the initial motivation instructions, participants tend to change their behavior over time or may have different behaviors to begin with. They may lose interest or become more motivated, even though they were initially categorized as either "highly motivated" or "lowly motivated" pedestrians. Additionally, the parameters used in the preliminary study, speed (v^0) and the time to close gaps (the slope factor, T), are also intended to be integrated as primary parameters. On the other hand, for the main model, instead of assigning the parameters on our own, we aim to present several psychological concepts from the motivation literature that will be defined in the model and used to produce these parameters accordingly.

However, many existing approaches to motivation in the psychology literature primarily focus on long-term academic achievement, such as the desire to perform well in school or the motivation to attain a degree [5]. In the context of crowds, our concern shifts to motivation operating on a shorter time scale. In a crowd setting, motivation can impact an individual's position and actions, and it can also be rapidly influenced by the environment, such as the pedestrian's current location.

One approach to understanding motivation in short-term contexts like crowds is the expectancy and value definition [5, 6]. This definition posits that motivation is a function of an individual's expectations of success and the value they place on achieving the desired outcome. In the context of crowds, these expectations and values may be related to the individual's desire to exit the crowd safely and effectively. The expectancy and value definition of motivation could be well-suited to explaining motivation in short-term environments because it considers both the individual's expectations (the likelihood of reaching the bottleneck earlier) and the value they place on achieving their goals (the importance of reaching the bottleneck earlier). Moreover, this definition lends itself well to computer modeling, as both expectancy and value concepts can be numerically represented on a scale from 0 to 1 (ranging from no expectancy to maximal strength expectancy) [6, 26].

Extending these concepts further, the expectancy concept refers to the degree to which a person believes a particular goal is probable [6]. In simpler terms, it reflects an individual's momentary assumption regarding the likelihood of achieving a specific goal. The greater the perceived likelihood of success, the higher the motivation of the individual. In a bottleneck situation, the initial perceived likelihood of success is primarily determined by an individual's initial position within the crowd. As a person gets closer to the exit, their perceived likelihood of success increases. Since an individual's position is constantly changing, this likelihood also fluctuates based on their proximity to the exit and the information regarding how much of the crowd has already exited the bottleneck. On the other hand, the value concept relates to the desirability or attractiveness of the potential outcome that can be achieved through individual behavior [6, 26]. This concept can be thought of as the reward that an individual aims to attain. In the context of crowds or bottlenecks in real-life scenarios, the value typically related to reaching the bottleneck quickly. However, the perceived value may vary among pedestrians depending on the urgency of their need to leave the bottleneck. For instance, in real-life scenarios, some pedestrians may be in a rush to reach their destination for their later inquiries. In simulations, we can manipulate the value concept by assigning a multiplier to pedestrians, either with the same or different values relative to the simulation's objective. This multiplier can then interact with the pedestrian's expectancy level in real-time, affecting their motivation parameters together.

Additionally, we assert that competition should be considered as one of the primary factors determining the motivation of an agent to simulate a realistic crowd scenario. Conventionally, competition is recognized as a key influencer of expectancy [6]. However, in a crowd setting, competition could be viewed as separate from the expectancy concept for two reasons. Firstly, bottleneck settings are intrinsically competitive, as individuals strive to "win" rather than "lose" based on given instructions (such as finding good seats at a concert). Secondly, we have limited the expectancy factor solely to spatial parameters (distance to the bottleneck). In a typical crowd entrance scenario (e.g., concert entrance), individuals positioned in the front tend to compete with their immediate peers, while those in the middle face broader competition as they contend with both their immediate peers and those in front of them. This dynamic situation changes in real-time as individuals continually adjust their positions while competing with one another. By incorporating the competition factor into our simulation model, we can address the potential issue of unrealistic behavior among individuals who are already in front of the bottleneck but exhibit excessive motivation. If the competition factor is set to zero, their motivation will be adjusted accordingly in the simulation.

When combined, all these concepts (expectancy, value, and competition) are considered to collectively indicate an individual's motivation in entrance scenarios. These concepts would be dynamic, meaning they are subject to change, and the resulting parameters would be distributed heterogeneously across the crowd, with the aim of achieving the grand objective of the current study. While the results from the initial model were promising, it lacked many essential perspectives (such as dynamism) that needed to be integrated into the discourse. As the final phase of our staged approach, the comprehensive motivation model incorporating "expectancy," "value," and "competition" is intended to be integrated and presented in a future publication.

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