

Analysis of “Faster is Slower” Effect on Panic Evacuation with Anthropometric Measurements

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Abstract: Panic evacuation, also known as mass panic or stampede, refers to a situation in which a large group of people react with fear and rush to escape a perceived threat, often resulting in chaos, injuries and sometimes death. The "faster is slower" effect is a phenomenon related to the fact that acting quickly in a panic will have slower consequences. It is used to explain the negative consequences of uncoordinated action by a panicking crowd. This makes crowd evacuation inefficient. Calm and controlled movements can ensure a safe exit. Anthropometry is the science that deals with the measurement and dimensions of the human body, and this information can provide insight into people's mobility and behavior in crowded places or emergency situations. The force generated by each individual in these situations is different. Therefore, it can be studied separately. In this study, the relationship between anthropometric characteristics of humans and the "fast is slower" effect was investigated. 19% difference in evacuation time was found between simulation experiments with and without anthropometric characteristics. These results are important for understanding human behavior in emergency situations and developing effective response strategies in these situations. In addition, these findings can contribute to practical applications to understand how anthropometric factors affect certain skills and to create more effective building evacuation plans considering individual differences.

Keywords: Anthropometry; Crowd dynamics; Faster is slower; Panic evacuation; Social force model.

1. INTRODUCTION

The development of urbanization and rapid population growth has led to an increase in the number of large centers with complex structures and dense crowds. This makes people more prone to panic in emergency situations than in open spaces. The resulting extreme tension can cause panic groups to behave in confusion. Evacuees, especially those with high levels of panic psychology, may be prone to extreme emotions, which can lead to chaotic and disorganized evacuation processes [1]. The desire to move quickly can lead to a tendency to move carelessly and uncoordinatedly towards environmental obstacles and other people. This can lead to a chaotic environment, injuries and even fatalities [2]. In recent years, there has been a great deal of research into building models to better understand the behavior of large crowds. The understanding that these models seek to provide is essential for designing safer buildings, events, and evacuation plans. These models have three main areas of application. The first area focuses on the calculation of time spent in evacuation. This area takes a general view of pedestrians as a crowd and considers crowd characteristics (speed, density, and capacity) at an aggregate level. The second area is crowd movement research, which focuses on factors such as obstacles in the room, the width of exit doors and the speed of pedestrians, examining how they affect the behavior of pedestrians during evacuation. This area considers a relatively high computational burden while developing lifelike models. The third application is the practical area where the infrastructure arrangement needs to be assessed before and during a major event. This requires a relatively accurate but fast model [3]. Problems in pedestrian crowds are often caused by opposing flows, bottlenecks, or intersecting flows. Entrances and exits, decompression and diversion in dense crowds are also important issues [4]. In emergencies, it is vital to effectively guide large numbers of people to safety. Preventing mass panic is essential to minimize damage. Evacuation poses a challenge because individuals lack general knowledge. They do not know where to go or which areas to avoid. Static plans also ignore the distribution of evacuees within buildings and potential choke points [5].

Anthropometry is a technique for numerically expressing the shape of the human body and is used to determine its physical and morphological characteristics. Anthropometry aims to determine the hardware, tools and landscaping required by the user for the system or space to be designed, taking into account body measurements with scientific measurement methods [6]. Anthropometric data ensures that designs are suitable and compatible for people. For this reason, it is of great importance to

determine the size differences of societies in the field of architecture and design and to design and produce according to these differences [7].

The "faster is slower" effect (FIS) is a phenomenon of pedestrian dynamics where a crowd moving at a higher speed can paradoxically increase the evacuation time required to escape from an exit. This phenomenon has been extensively studied and experimentally verified in various systems involving discrete particles flowing towards a central exit [8]. There are many studies in literature on the "faster is slower" effect. This effect has been investigated in manned and unmanned experiments and the results have been analyzed. In [8], experiments on the escape behavior of rats under panic showed that evacuation times increased significantly as warning levels increased, suggesting that humans moving faster in emergencies may increase competition with other humans, leading to slower evacuation. According to Gershenson and Helbing's study [9], this impact is observable in many areas such as pedestrian movements, vehicular traffic, logistics, public transportation, social dynamics and ecological systems. The authors also identified the characteristics of the impact as the presence of bottlenecks, the importance of coordination and cooperation between components, the existence of feedback loops, and the need for a balance between individual and collective performance. The authors in [10] studied this effect using human subjects. They helped to distinguish between situations where faster is likely to be faster/slower and to identify the factors that change the direction of this effect. The authors in [11] experimentally investigated this phenomenon in relation to pedestrian flows at junctions, a common geometric feature of crowd exits. They observed that there are clear dependencies between the evacuation speed and the physical layout of the junction. They also examined the relationship between crossings according to the size of pedestrians. Similarly [12], in manned experiments, they demonstrated the existence of the faster is slower effect, based on temporary but prolonged flow stoppages caused by intermittent blockages, proposed alternative designs of emergency exits, and described the conditions necessary to observe this effect. In [13], authors investigated the faster is slower effect by simulation. They showed that the effect occurs when clusters of blockages dominate the scene, a structure that can connect to the walls of the exit and temporarily block the exit, realizing medium and long duration blockage delays. They observed short delays during evacuation. The authors in [14] conducted experiments to demonstrate that the high pressures generated by pedestrian crowding change the dynamics in the blocking cluster and therefore change the statistics of time delays during the escape process. They examined their contribution to the overall evacuation performance and compared their results.

The studies compared in the literature collectively contribute to the understanding of the "faster is slower" effect in different contexts, from animal behavior to simulations and physical experiments involving human subjects. By highlighting the factors that influence evacuation dynamics, they provide insights into improving evacuation processes and designing more efficient systems, especially in emergency scenarios. However, the data were taken with fixed body sizes in the simulations. In real life, each individual has a different body size, and this results in different forces.

In this study, we used the anthropometric characteristics of people to examine the "faster is slower" effect. Using people's physical characteristics, we aimed to examine the impact of this effect on the design of exits and escape areas. Anthropometric data was used as a tool to understand how escape routes can be designed according to factors such as people's size, mobility, and physical characteristics. In this context, the study highlights that anthropometry, the measurement and analysis of the human body, can be an important tool to help understand and minimize the "faster is slower" effect in areas such as building design and emergency evacuations. It is thought that people's physical characteristics can help to develop more effective designs for escape routes and safe egress strategies.

The main contributions of the present study are as follows:

- Exploring the "faster is slower" effect and its impact on crowd evacuation in panic situations.
- Highlighting the importance of calm and controlled movements in ensuring safe evacuation.
- Examining the role of anthropometry in understanding human mobility and behavior in emergency situations.
- Providing insights into improving evacuation processes and designing more efficient systems, especially in emergency scenarios.
- Using anthropometric data as a tool to understand how escape routes can be designed according to factors such as people's size, mobility, and physical characteristics.
- Demonstrating the existence of the "faster is slower" effect through simulations and physical experiments involving human subjects.
- Emphasizing the importance of preventing mass panic to minimize damage in emergency situations.

Information about the literature is given in the introduction. The social force model, anthropometry and the fast is slower effect are presented in Chapter 2. The results obtained and discussions are given in Chapter 3. Chapter 4 contains the conclusion.

2. MATERIAL AND METHODS

When studying the dynamics of crowds, different models are used to describe the movement of pedestrians. In the literature, these are divided into macroscopic and microscopic models. Macroscopic models usually model large crowds. Microscopic models perform calculations at the individual level and help to find more efficient results. Queueing theory approaches are approaches that model many collective behaviors, such as fluid dynamics, gas-kinetics, cellular automata, multi-agent approaches and social force modelling [15]–[17]. After 20 years of development, the social force model has become one of the most widely used models due to its simple mathematical formulas and its ability to describe the movement process well [18]. In this study, the social force model is used to describe the movement of pedestrians and this model is described in the following section.

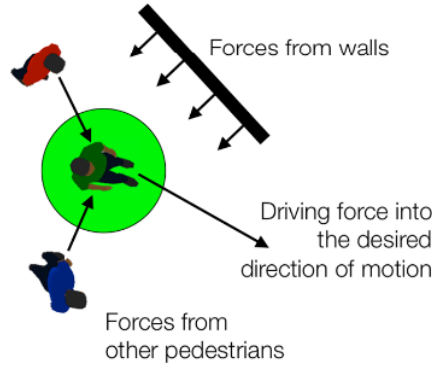


Figure 1. Forces acting on a pedestrian [23].

2.1 Social Force Model

The notion of social force is one that responds to human behavior in a somewhat "chaotic" and unpredictable manner. These "forces" are not directly imposed by the immediate environment of pedestrians, but rather reflect the inner drive of individuals to engage in specific actions or movements [19]. Equation (1) delineates pedestrian behavior within the equation of motion. Here, the interplay between the pedestrian and their surroundings is encapsulated by various forces [20].

$$m_i \frac{dv_i}{dt} = m_i \frac{v_i^0 e_i^0 - v_i(t)}{\tau} + \sum_{j \neq i} f_{ij} + \sum_W f_{ij} \quad (1)$$

The right-hand side of the equation contains a speed correction term that guides a pedestrian towards the target point. The desired speed of pedestrian i is denoted v_i^0 . e_i^0 is the desired direction of pedestrian i . τ is the time in seconds it takes for a pedestrian to accelerate to the desired speed v_i^0 . The last two terms, represented as sums, account for the total force exerted on pedestrian i originating from all adjacent pedestrians j and all neighboring walls W [21], [22]. Figure 1 shows a representation of the forces surrounding pedestrians. The interaction forces between pedestrian i and pedestrian j can be described by Equation (2).

$$f_{ij} = \{A_i \exp [(r_{ij} - d_{ij})/B_i] + kg(r_{ij} - d_{ij})\} n_{ij} + \kappa g(r_{ij} - d_{ij}) \Delta v_{ji}^t t_{ij} \quad (2)$$

Equation (2) is the formula for the interaction forces between pedestrians. The interaction forces f_{ij} consist of the repulsive interaction force and the sliding friction force. A_i , B_i and k are constants. A_i is the intensity of the repulsive interaction between pedestrians. B_i is the minimum distance at which the repulsive interaction force occurs. r_{ij} is the sum of the radii of pedestrians i and j . d_{ij} is the distance between the centers of pedestrians i and j . $g(x)$ represents a function that takes the value 0 when the pedestrians cannot touch each other ($r_{ij} < d_{ij}$) and x otherwise. The values of the parameters used are $A_i = 2000$ N, $B_i = 0.08$ m, $k = 1.2 \times 10^5$ kg/s². Equation (3) shows the calculation of obstacles (wall) forces for pedestrians i and j .

$$f_{iw} = \{A_i \exp [(r_i - d_{iw})/B_i] + kg(r_i - d_{iw})\} n_{iw} - \kappa g(r_i - d_{iw}) (v_i \cdot t_{iw}) t_{iw} \quad (3)$$

The interaction forces f_{iw} consist of the repulsive interaction force and the sliding friction force. r_i is the radius of pedestrian i . d_{iw} is the distance between pedestrian i and the edge of the obstacle; n_{iw} represents the vector normalized from the edge of the obstacle to pedestrian i . v_i represents the actual velocity of pedestrian i and t_{iw} represents the tangential direction between pedestrian i and the edge of the obstacle [24]. Many models of pedestrian behavior have been proposed to unravel the mechanism underlying real-life crowd movement. One of the best-known models of crowd dynamics, the social force model, is based on Newtonian mechanics and successfully explains a number of self-organization phenomena found in empirical observations [25].

2.2 Anthropometry

Anthropometry, a specialized branch of anthropology, delves into the comparative measurements of the human body, encompassing its various components and the influential factors shaping these metrics. This field scrutinizes both the genotypic and phenotypic frequencies within individuals and populations, shedding light on the distinctive anthropometric traits specific to different groups. Consequently, conducting anthropometric field studies holds paramount importance for nations worldwide. The precision of anthropometric data bears immense significance for a multitude of professionals, particularly those engaged in disciplines closely tied to human attributes, such as design, engineering, and health. Hence, ensuring accurate anthropometric measurements is indispensable for the seamless operation of these domains. [26]. Anthropometric data ensures that designs are suitable and compatible for people. It has been determined that the products produced vary for the use of people in different countries. For this reason, it is very important to determine the size differences of societies in the field of architecture and design and to design and produce according to these differences [7].

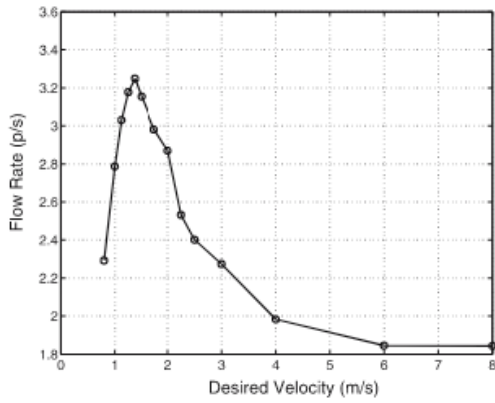


Figure 2. Relationship between running speed and evacuation flow [30].

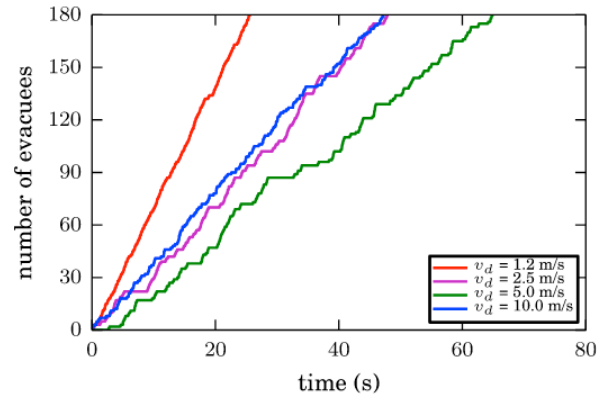


Figure 3. Flow rate of the evacuation [13].

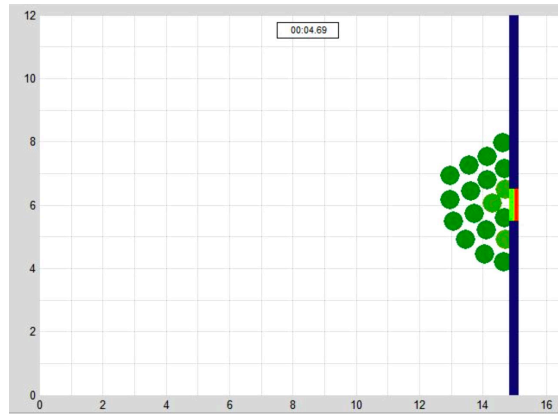


Figure 4. Fast is slower effect on evacuation.

2.3 The Fast is Slower Effect

The "faster is slower" effect describes a phenomenon in which the increased pace of individuals within a crowd paradoxically leads to a reduction in overall movement speed and evacuation efficiency. This phenomenon is commonly observed in pedestrian dynamics and is closely tied to the dynamics of competition and congestion that arise in densely populated areas, particularly during emergency situations. Interestingly, as individuals attempt to move more rapidly, they inadvertently hinder each other's progress, ultimately causing delays in the collective evacuation process. This effect holds crucial implications for crowd safety protocols and the strategic planning of emergency evacuation procedures [27]. For desired velocities above the critical velocity, the greater the velocity, the slower the evacuation process. This effect has recently been experimentally verified for many different systems [28].

When trying to evacuate quickly, the movement of people can slow down the evacuation process and increase the risk of injury or death. This effect has been observed in simulations and anecdotal evidence from human stampedes and other disasters. Therefore, taking into account the desired speed of pedestrians when planning evacuation is crucial to avoid this phenomenon [29]. Under normal walking conditions, the time for 200 pedestrians to evacuate the room decreases as the desired speeds increase. However, desired speeds higher than 1.5 m/s reduce the separation efficiency and this effect is particularly pronounced when the exit is divided by the desired speed. This is because the thrust causes additional frictional effects [21]. Figure 2 shows the relationship between running speed and evacuation flow.

Figure 3 shows a useful visualization of the relationship between desired velocity v_d and evacuation time, and how different behavioral regimes can emerge depending on the underlying dynamics of the crowd. The social force model was used to conduct the experiments. There are many models that examine pedestrian movement in crowd evacuations. This study utilizes the social force model. In the social force model, the effect of the change in the area covered by pedestrians on evacuation is investigated. Anthropometric data were taken at different values in the scenarios. Thus, the behavior of people with different body sizes on the fast is slower effect is simulated.

3. RESULT AND DISCUSSION

The "panic simulator" tool for MATLAB was used to perform the experiments. The purpose of the Panic Simulator is to simulate the characteristics of human escape panic in crowded environments with only one exit [31]. Therefore, the modeling of pedestrian behavior was inspired by the model used by Helbing et al. [21]. Figure 4 shows the operation of the panic simulator. The experiments were completed with 4 scenarios. The parameters in the simulation were used with standard defined values. For each scenario, 25 experiments were run. The room used for evacuation is 12x15 meters and the door width is 1 meter.

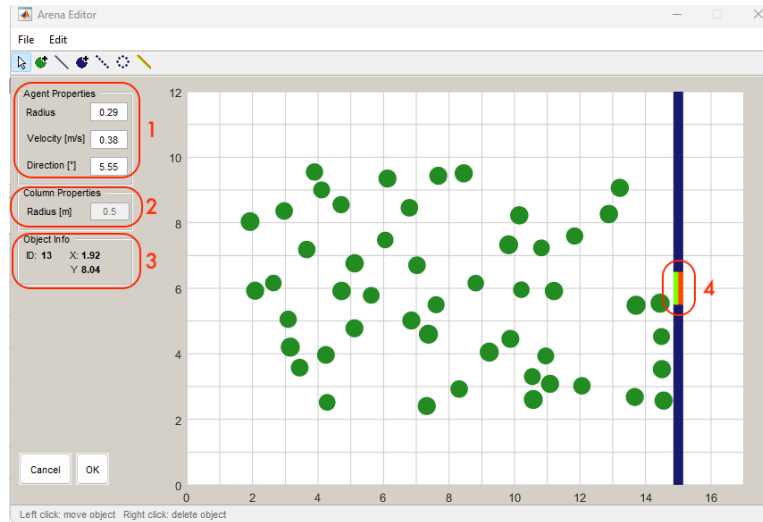


Figure 5. Arena editor interface.

Table 1. Arena editor interface parameters [31].

Number	Parameters	Explanation	
1	Radius	Pedestrian radius	
	Velocity(m/s)	Pedestrian speed	
	Direction	Direction of the agent's velocity, angle of 0° corresponds to the positive x -direction (right) and goes counter-clockwise, 90° positive y -direction (up), 180° negative x -direction (left), 270° negative y -direction (down)	
2	Column properties	Radius (m)	Radius of the selected column
3	Object info	ID	Identification number of the selected object
		X, Y	Spatial position of the object in x -direction and y -direction
4	Exit door		

Table 2. Parameters for different scenarios.

	Anthropometric values		Running speed (m/s)
Scenario 1	Constant	0.30 m^2	1.5
Scenario 2	Variable	$0.21 \text{ m}^2 - 0.33 \text{ m}^2$	1.5
Scenario 3	Constant	0.30 m^2	4.0
Scenario 4	Variable	$0.21 \text{ m}^2 - 0.33 \text{ m}^2$	4.0

The comparisons of the scenarios are as follows: fixed body sizes and constant running speeds, and variable body sizes and constant running speeds were measured and observed. The other comparison situation is variable body sizes and high running speeds, and fixed body sizes and high running speeds. In this study, the effect of body size on "faster is slower" was investigated. According to [8-14], the "faster is slower" effect is a phenomenon observed during panic flight. While observing this phenomenon with simulations, only the speed data were changed, and the results were obtained. Body sizes are given constant for each individual. Since the anthropometric data of each individual is different, it was predicted that this situation would also have an effect on escape and the experiments were conducted accordingly. To show the effects of body sizes, different body sizes were entered using the Arena Editor in the Panic simulator. With this interface, we randomly assigned body sizes between 0.21 m^2 and 0.33 m^2 . Figure 5 shows the interface where different values can be entered. The body size of the pedestrians can be adjusted with the radius parameter in the "Agent Properties" field in this interface. Table 1 describes the parameters.

For Scenario 1, constant velocity (1.5 m/s) and constant body size (0.30 m^2) parameters were used. For Scenario 2, speed (1.5 m/s) and variable body size parameters were used. This was inspired by the anthropometric measurements of humans and randomly assigned values between 0.21 m^2 and 0.33 m^2 radius. Thus, the effect of anthropometric characteristics on "faster is slower" was investigated. For Scenario 3, high running speed (4 m/s) and constant body size (0.30 m^2) parameters were used. For Scenario 4, high running speed (4 m/s) and variable body size were used as parameters. In addition, the coordinates in each scenario were recorded for pedestrian placement. By recording the coordinates, all pedestrians were placed at the same points and the relationship between running speed and body size was investigated. Table 2 describes the situations used within the scenarios.

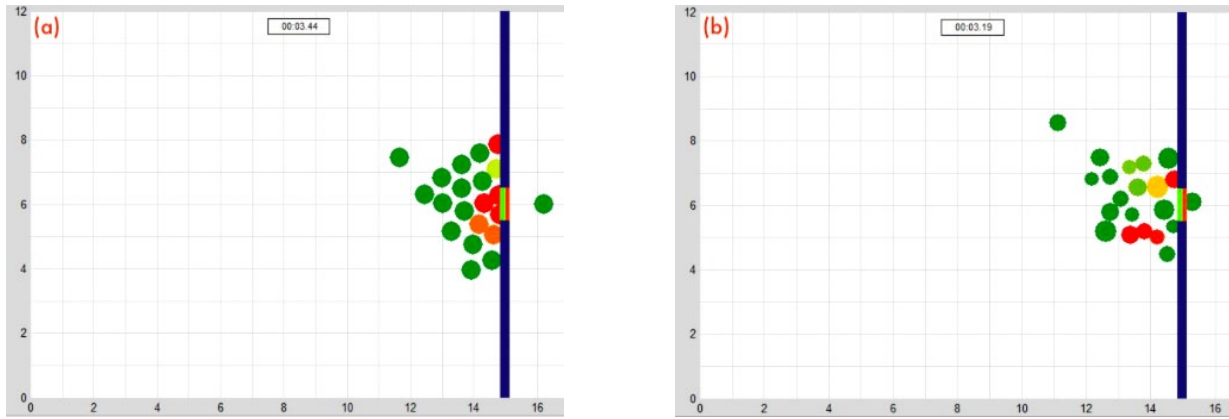


Figure 6. Working example (a) Scenario 1, (b) Scenario 2.

Table 3. Evacuation times for each scenario.

Exp No	S1 (s)	S2 (s)	S3 (s)	S4 (s)	Exp No	S1 (s)	S2 (s)	S3 (s)	S4 (s)
1	15.43	14.13	18.24	14.76	14	14.36	12.46	18.67	14.52
2	16.86	12.89	17.80	13.62	15	15.70	13.23	16.74	14.89
3	16.65	12.57	16.22	13.57	16	16.10	12.09	16.46	14.12
4	17.36	12.52	17.21	13.00	17	16.01	12.71	18.08	13.89
5	16.27	11.41	16.93	12.16	18	17.88	14.59	18.55	15.63
6	16.23	12.29	17.00	12.92	19	13.95	13.04	17.91	13.72
7	16.06	10.93	18.73	15.30	20	15.20	13.86	17.44	14.70
8	19.08	12.05	19.48	13.10	21	18.60	13.83	17.74	14.85
9	16.50	13.39	19.72	13.78	22	16.82	14.67	15.22	15.82
10	17.01	13.46	18.06	13.90	23	13.72	13.98	18.17	14.16
11	15.98	13.51	17.41	15.81	24	16.77	12.95	18.60	14.33
12	15.58	15.97	16.86	16.87	25	19.90	13.12	20.45	14.37
13	15.26	13.81	16.91	14.61	AVG	16.37	13.19	17.78	14.34

The aim of the experiments was to first examine the “faster is slower” effect and then add anthropometric features to observe the difference between the two. Figure 6(a) shows Scenario 1 in action and Figure 6(b) shows Scenario 2 in action. The force exerted by pedestrians on each other during evacuation is depicted as intensifying from green to red. Within the simulation, areas displaying red hues signify locations subjected to heightened pedestrian force. For every scenario, a set of 25 experiments was conducted, and the corresponding evacuation times were documented. Table 3 provides a comprehensive overview of the evacuation times across all cases. Upon conclusion of all trials, the average evacuation time is computed and appended to the final row (S1: Scenario 1, S2: Scenario 2, S3: Scenario 3, S4: Scenario 4).

After the completion of each experiment, the average evacuation time for Scenario 1 was 16.37 seconds. In Scenario 3, this time was 17.78 seconds. These results show that the 'faster is slower' effect was observed in the simulation. The body size of the pedestrians heading towards the door was kept constant, but the walking speed was determined to be 4 m/s in Scenario 3, while it was 1.5 m/s in Scenario 1. This shows that at speeds above the optimum escape velocity, congestion in areas with intense pedestrian movement increases the evacuation time. The evacuation time was 13.19 seconds in Scenario 2 and 14.34 seconds in Scenario 4. The running speed of pedestrians is 1.5 m/s in Scenario 2 and 4 m/s in Scenario 4. When we compare these two scenarios, again, the evacuation time was prolonged due to congestion in case of exceeding the optimum running speed. Panic evacuation shows the situations necessary to safely move people from one place to another in emergency and disaster scenarios. This process is of great importance in terms of saving lives and minimizing injuries. Today, research on panic evacuation continues to increase. It is extremely important to understand the dynamics of crowds and to gain safe living spaces.

This study examines the relationship between high running speed and crowd evacuation in terms of the “faster is slower” effect. The “faster is slower” effect describes the phenomenon that in crowded or congested areas, as people try to move faster, they move slower. A comparison of all scenarios is shown in Figure 7. Comparing Scenarios 1-3 and 2-4, a 9% increase in evacuation time is observed due to the 'faster is slower' effect. These comparative results can be seen in Table 4. A side-by-side examination of the graphs shows that with constant body size parameters and if pedestrians run at 4 m/s, the evacuation time increases.

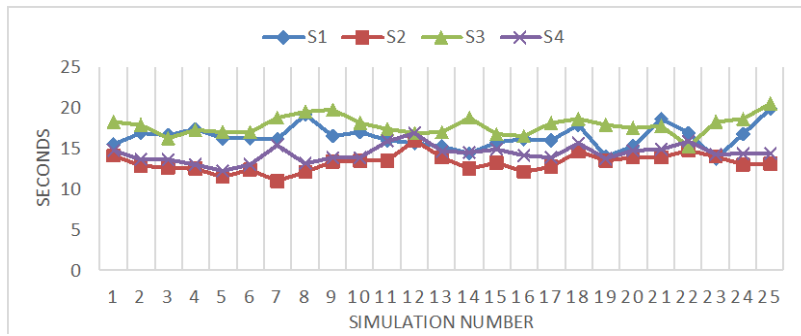


Figure 7. Results of all scenarios.

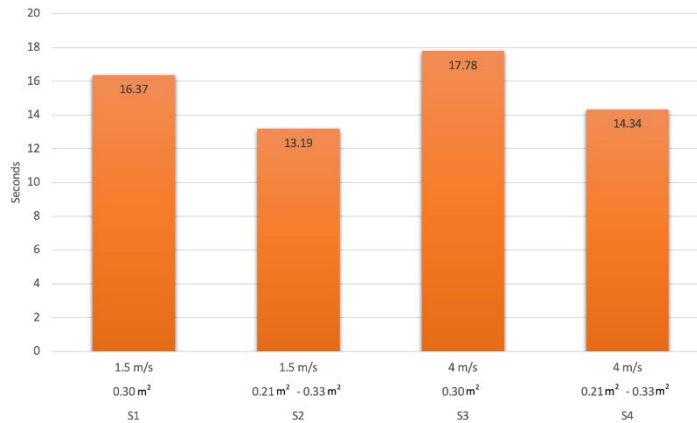


Figure 8. Average evaluation time for all scenarios.

Table 4. Comparing scenarios S1-S3 and S2-S4.

	Results			
	S1	S3	S2	S4
Anthropometric values (m ²)	0.30	0.30	0.21- 0.33	0.21- 0.33
Running speed (m/s)	1.5	4	1.5	4
AVG (second)	16.37	17.78	13.19	14.34
Difference (%)	9%		9%	

Table 5. Comparing scenarios S1-S2 and S3-S4.

	Results			
	S1	S2	S3	S4
Anthropometric values (m ²)	0.30	0.21 – 0.33	0.30	0.21 – 0.33
Running speed (m/s)	1.5	1.5	4	4
AVG (second)	16.37	13.19	17.78	14.34
Difference (%)	19%		19%	

When paying attention to anthropometric data, positive results are obtained. Comparing Scenarios 1-2, a 19% reduction in evacuation time is observed at the optimum running speed (1.5 m/s). Likewise, a reduction in evacuation time is also observed when comparing Scenarios 3-4. Details of these comparisons are presented in Table 5. Figure 8 shows the results and comparisons graphically. It is clear from this data that the optimal situation is the one calculated in Scenario 2. In Scenario 2, the shortest evacuation time can be achieved with the optimum running speed and anthropometric data.

4. CONCLUSION

The efficiency of evacuations in panic situations is an important issue due to the complexity and urgency of human behavior. Research shows that optimal running speeds have a decreasing effect on evacuation time. However, anthropometric data should also be used to obtain results closer to real-world conditions. Anthropometric data provides important information about the physical characteristics of individuals and analyzing this information accurately will help to predict evacuation times more precisely. The "faster is slower" effect can have a significant impact on evacuation time, even in less crowded areas than expected. This effect requires a more in-depth analysis to understand the complexity of individuals' panicked behavior and evacuation times. Therefore, future studies could highlight the importance of not only rapid escape but also planned evacuation to optimize evacuation time. Anthropometric data need to be used as a valuable tool to improve evacuation times. The height, weight and other bodily characteristics of individuals have an important role for the management of the evacuation process and for more effective prediction of evacuation times. Therefore, it is of paramount importance that anthropometric data are considered and used accurately in future evacuation planning. This will be a critical step to shorten evacuation times and improve emergency management.

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DECLARATION OF CONFLICTING INTERESTS

The authors declare no potential conflicts of interest with respect to the research and publication of this article.

REFERENCES

- [1] M. Zhang, Y. Wan-Jun, H. -L. Zhao, Y. Tian, J. -Y. Tang and M. Zhang, Emergency evacuation model of panic group based on big data, *5th International Conference on Intelligent Informatics and Biomedical Sciences (ICIIBMS)*, Okinawa, Japan, 2020, 107-110.
- [2] M. Haghani, E. Cristiani, N. W. F. Bode, M. Boltes and A. Corbetta, Panic, irrationality, and herding: Three ambiguous terms in crowd dynamics research, *Journal of Advanced Transportation*, 2019, 9267643.
- [3] N. A. Thio, *Pedestrian Crowd Evacuation Under Panic*, Master Thesis, School of Mathematics and Statistics, The University of Melbourne, Australia, 2019.
- [4] D. Helbing, L. Buzna, A. Johansson and T. Werner, Self-organized pedestrian crowd dynamics: Experiments, simulations, and design solutions, *Transportation Science*, 39(1), 2005, 1-24.
- [5] S. Merkel, S. Mostaghim, D. Blum and H. Schmeck, Distributed swarm evacuation planning, *IEEE Symposium on Swarm Intelligence (SIS)*, Singapore, 2013, 276-283.
- [6] A. Kılıç, *Development of A New Pattern Preparation Method for Skirt and Ladies Trousers by Utilizing Anthropometric Measurement System*, PhD Thesis, Graduate School of Natural and Applied Sciences, Ege University, İzmir, Turkey, 2011.
- [7] S. Sipahi and Ş. Ertaş, A perspective to setting up anthropometric data bank for field of architecture in Turkey: Caesar project, *Art-e*, 12(23), 2019, 167-184.
- [8] J. M. Chen, P. Lin, F. Y. Wu, D. L. Gao and G. Y. Wang, Revisit the faster-is-slower effect for an exit at a corner, *Journal of Statistical Mechanics: Theory and Experiment*, 2018, 023404.
- [9] C. Gershenson and D. Helbing, When slower is faster, *Complexity*, 21(2), 2015, 9-15.
- [10] M. Haghani, M. Sarvi and Z. Shahhoseini, When "push" does not come to "shove": Revisiting "faster is slower" in collective egress of human crowds, *Transportation Research Part A: Policy and Practice*, 122, 2019, 51-69.
- [11] Z. Shahhoseini, M. Sarvi and M. Saberi, Pedestrian crowd dynamics in merging sections: Revisiting the "faster-is-slower" phenomenon, *Physica A: Statistical Mechanics and its Applications*, 491, 2018, 101-111.
- [12] J. M. Pastor *et al.*, Experimental proof of faster-is-slower in systems of frictional particles flowing through constrictions, *Physical Review E*, 92(6), 2015, 062817.
- [13] F. E. Cornes, G. A. Frank and C. O. Dorso, Microscopic dynamics of the evacuation phenomena in the context of the social force model, *Physica A: Statistical Mechanics and its Applications*, 568, 2021, 125744.
- [14] I. M. Sticco, F. E. Cornes, G. A. Frank and C. O. Dorso, Beyond the faster-is-slower effect, *Physical Review E*, 96(5), 2017, 052303.
- [15] T. Yu, J. Wang and Z. Zhao, Evacuation entropy particle swarms optimization (e-PSO) evacuation model considering panic factors, *IEEE 4th International Conference on Control Science and Systems Engineering (ICCSSE)*, Wuhan, China, 2018, 538-544.
- [16] L. Jiang, J. Li, C. Shen, S. Yang and Z. Han, Obstacle optimization for panic flow - reducing the tangential momentum increases the escape speed, *PLoS ONE*, 9(12), 2914, e115463.
- [17] J. Zhonghua and C. Yanyun, Research on evacuation of panic people based on optimal control, *37th Chinese Control Conference (CCC)*, Wuhan, China, 2018, 2161-2166.
- [18] X. Chen, M. Treiber, V. Kanagaraj and H. Li, Social force models for pedestrian traffic – state of the art, *Transport Reviews*, 38(5), 2018, 625-653.
- [19] H. Sharbini, R. Sallehuddin and H. Haron, An analysis of a modified social force model in crowd emergency evacuation simulation, *Applications of Modelling and Simulation*, 3(3), 2019, 135-144.

- [20] A. Verma, Crowd management - social force model, *International Journal of Engineering Research & Technology*, 10(05), 2021, 887-898.
- [21] D. Helbing, I. Farkas and T. Vicsek, Simulating dynamical features of escape panic, *Nature*, 407(6803), 2000, 487-490.
- [22] E. Leijonmarck and T. Olergård, *Modelling of Panicking Pedestrians During Emergency Evacuation*, Bachelor Thesis, Department of Optimization and System Theory, Royal Institute of Technology, Sweden, 2013.
- [23] B. Kabalan, *Crowd Dynamics: Modeling Pedestrian Movement and Associated Generated Forces*, Master Thesis, Université Paris-Est, France, 2016.
- [24] Y. Zhao *et al.*, Optimal layout design of obstacles for panic evacuation using differential evolution, *Physica A: Statistical Mechanics and its Applications*, 465, 2017, 175-194.
- [25] W. Wu, M. Chen, J. Li, B. Liu, X. Wang and X. Zheng, Visual information based social force model for crowd evacuation, *Tsinghua Science and Technology*, 27(3), 2022, 619-629.
- [26] I. Erkan, A system proposal for rapid detecting of anthropometric data and affecting design strategies, *Journal of Engineering, Design and Technology*, 18(6), 2020, 1793-1822.
- [27] P. Lin, J. Ma, T. Liu, T. Ran, Y. Si and T. Li, An experimental study of the “faster-is-slower” effect using mice under panic, *Physica A: Statistical Mechanics and its Applications*, 452, 2016, 157-166.
- [28] V. Dossetti, S. Bouzat and M. N. Kuperman, Behavioral effects in room evacuation models, *Physica A: Statistical Mechanics and its Applications*, 479, 2017, 193-202.
- [29] A. Garcimartín, I. Zuriguel, J. M. Pastor, C. Martín-Gómez and D. R. Parisi, Experimental evidence of the “faster is slower” effect, *Transportation Research Procedia*, 2, 2014, 760-767.
- [30] D. R. Parisi and C. O. Dorso, Why “faster is slower” in evacuation process, *Pedestrian and Evacuation Dynamics 2005*, N. Waldau, P. Gattermann, H. Knoflacher, and M. Schreckenberg, Eds., Berlin, Heidelberg: Springer Berlin Heidelberg, 2007, 341-346.
- [31] Panic Simulator, <https://www.mathworks.com/matlabcentral/fileexchange/46849-panic-simulator> (Accessed 30.08.2023).