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The Effect of Amplitude, Event, and Duration of Electrical Stimulation on the Evacuation Velocity of Rodents: An Evacuation Experiment

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설치류 대피 실험에서의 전기 자극의 크기, 횟수, 지속시간의 대피 속도에 대한 영향

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ABSTRACT

Despite advances in technology, crushing accidents still occur during emergency evacuations of crowded public spaces. To prevent crushing accidents, it is necessary to understand the flow of pedestrians during evacuation scenarios through experiments. Since experiments with humans can generate real accidents, we performed experiments on rodents to approximate human behavior. To trigger an emergency evacuation response, we applied electrical stimulation to the feet of the rodents. Although electrical stimulation has been applied to mice in many experiments, studies on the intensity and pattern of electric stimulation required to evoke a rapid evacuation response in mice is still lacking. In this study, we experimentally investigated how the evacuation flow of mice changes according to the amplitude, event, and duration of electric stimulation.

Key Words : Evacuation Flow(대피 유동), Crowd Flow(군중 유동), Pedestrian Bottleneck(보행자 병목현상), Electric Shock(전기 충격), Rodent Experiment(설치류 실험)

1. Introduction

As culture advances, people tend to cluster together more and more. Good examples include large markets, movie theaters, concert halls, and stadiums. Within such places, people create pedestrian flows by moving around. However, when many people try to leave such places with limited access, i.e., entrance and exit, all at once, a bottleneck can be created for pedestrians, possibly causing a crushing incident. For example, in Sangju city, Gyeongbuk Province, South Korea, on

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October 3rd, there was a crushing incident with a large audience entering the civic stadium to attend an music concert hosted as part of the Sangju Bicycle Festival. There were 11 deaths and about 100 casualties[1]. On March 26th, 2006, a crushing incident also occurred with 16 casualties suffering serious injuries on the opening day of Lotte World amusement park, to which about 30,000 people had flocked[2]. Crushing accidents as above can always occur anytime in overly crowded places. The likelihood of crushing incidents increases amidst emergency or panic situations, as in fires or disasters.

Devastating crushing incidents may be prevented by predicting the pedestrian evacuation flow during panic situations through experiments and simulations. For simulation, experimentation is required to determine simulation parameters with which a crushing incident is reproducible. Due to the actual risk of deaths and casualties involved in the experiments dealing with people, simulation experiments can use rodents, assuming that they react similarly to panic situations [3].

Experiments using rodents have long been conducted. For several decades, rodents have been commonly used in medical experiments for genetic mutations, hormonal changes, and disease identification. These days, they are increasingly used for behavioral research. In rodent's brains, there are amygdala and hippocampus responsible for fear and excitement status in the same way as in humans, so rodents are seen to show reactions similar to human reactions in fear excitement status. Therefore, rodents can be used to predict human patterns of mental and behavioral disorders[4]. Assuming that the rodent's reactions are similar to human reactions in pedestrian evacuation flow in panic situations, we conducted a simulation experiment using rodents. The freezing response is one of the reactions to a panic situation that rodents show but humans do not. In freezing response, rodents cannot move and stay frozen. We adjusted experimental conditions appropriately to prevent the freezing response from occurring and excluded the experiment results from the occurrence of freezing[5].

Experiments that cause rodents to panic include the Morris water maze (MWM)[6] and Saloma's experiment[7]. In MWM, rodents swim, perceive space, and search for a hidden foothold in the water, depending on their memory. This experiment evaluates the functions of the hippocampus, responsible for memories, in rodents' brains by checking for abnormalities in the brain structure and functions. In Saloma's experiment[7], rodent's panic is induced based on the fact that they hate water. This experiment evaluates rodent's perception capability, although stimulation using water may be inadequate for creating the type bottleneck phenomenon present in evacuation flow during emergencies for observation of rapid movements.

Other experiments regarding the evacuation flow of rodents include the scent candle experiment[8], in which scent and smoke from the candle stimulate the rodents to escape through an exit. However, stimulation using a scented candle lacks reproducibility, and controlling the stimulation is a challenge. Electrical stimulation is regarded as the best choice for rodent evacuation experiments, as it can provide identical stimulations that rodents react to instantaneously at every moment during an evacuation.

In the present study, we applied the electric foot shock to cause fear and excitement in rodents[9~10]. Early-stage rodent experiments using electrical stimulus were merely used to determine the response to stimulations[11] and investigate behavioral changes following electrical stimulation[5]. Recently, electrical stimulation has been used for experiments to study human diseases such as anxiety, depression, and post-traumatic stress disorder (PTSD)[4]. Electrical stimulation is increasingly used in various experiments because rodents do not get accustomed to electrical stimulus, unlike other stressors hated by them, such as a loud noise, bright light, and extreme temperatures, whereas its control can be relatively straightforward[12]. Many previous studies used electrical stimulation to create fear, punishment, and stress in experimental animals. Examples include the determination of how stress affects immune functions in mice[13], identification of hormonal changes in the liver of mice under stress[14], and acquired helplessness toward aversive stimulus[15].

2. Experiment

2.1 Backgrounds

Many previous studies have used electrical stimulation to place rodents in a stressful situation, but there has been a lack of studies investigating how the changes in electrical stimulus affect rodents' evacuation patterns in experiments inducing the rodents to escape. Rodents' evacuation time in an emergency is as short as 10–60 seconds per meter, which is significantly different from the electrical stimulation with more extended time intervals used in other studies[5],[13],[14]. Therefore, in this study, we conducted a detailed analysis of rodents' evacuation patterns, including the average and instantaneous evacuation velocities, for the frequency, time, and intensity of an electrical stimulus during a second.

Active avoidance test was used to evaluate rodents' evacuation flow subject to electrical stimulus[9,10,16]. After applying electrical stimuli to the rodents in a specific cycle to cause movements, they evacuated to a safety zone with no electricity. Rodents learn to evacuate to escape from the fearful situation after a few training sessions. In this study, we used electrical stimulation to create fear and panic and analyzed mouse's evacuation velocities subject to different electrical stimulation patterns.

2.2 Selection and management of animals

All experiments were conducted using 9 ~ 14 mice, depending on the experiments, whose reactions to the panic situation are similar to humans. The C57BL/6N Cr SLc species, with a small genetic difference between individuals, was used. We prevented stress for the mice by providing purified water and adequate feeds and creating a pleasant environment for them. Males and females were separated to prevent breeding and other environmental changes. Additionally, mice were divided into two experimental groups, Group 1 (younger mice) and Group 2 (older mice), to determine the age-dependency of changes in evacuation patterns. (IACUC, authorized No.UNISTIACUC-20-27)

2.3 Device and equipment

The device system for the experiment, as shown in Fig. 1, consisted of three sections: waiting section, measurement section, and safety section. Waiting and measurement sections were made of acryl and stainless steel rod, whose floor was made of 2-mm stainless steel rod for the electricity to conduct. If the gap between the stainless steel rods is too narrow, mic manure can cause a short circuit. If the gap is too wide, the mice's leg may get caught in it. A 1-cm gap between the rods was used to prevent the problems mentioned above. A partition exists between the waiting section and measurement section. An exit of 5 × 5 cm is between the measurement section and safety section. Considering that an adult mouse's abdomen is 2 - 3 cm in length, 5 cm is barely enough for two mice

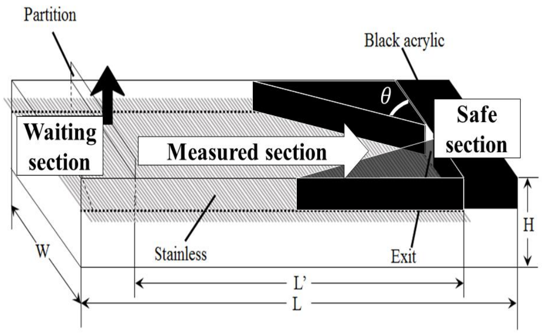


Fig. 1 Schematic of experimental equipment(W = 40 cm, L = 170 cm, H = 11 cm, L' = 100 cm, θ = 75°)

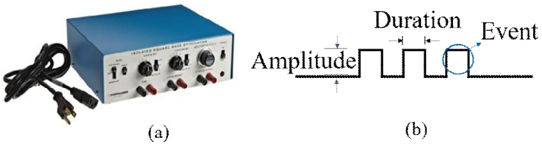


Fig. 2 Experimental equipment and stimulation concept: (a) Isolated square wave stimulator; (b) Conceptual electrical stimulation

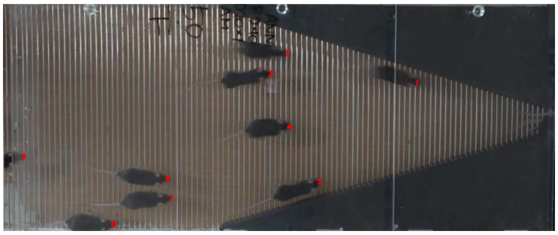


Fig. 3 Example of video analysis by MouseTracker program

to pass through. At the exit, a 75° ramp is installed. Since mice may get on each other's backs to avoid the electrical stimuli, its height is adjusted to allow a maximum of 1~2 mice to ride. Additionally, mice prefer dark places, so the safety section had a black sheet covering the acryl for mice to find stability.

To provide electrical stimuli, the isolated square wave stimulator (PHIPPS&BIRD, NO. 7092-611/120) was used (Fig. 2(a)). There are a total of three control parameters for electrical stimulation in this device: amplitude (V), duration (ms), and event (s^{-1}). As shown in Fig. 2(b), these refer to the applied voltage magnitude, duration time of an electrical stimulus, and frequency of electrical stimuli per second, respectively. We used an FDR-AX700(SONY) camcorder to record the experimental procedure. For analysis, MouseTracker software, an in-house development, was used (Fig. 3). In MouseTracker, mouse movement can be transferred to XY-pixel values for each frame, allowing the analysis of the mouse's instantaneous velocity, average velocity, and location.

Table 1 Experimental conditions; (Unit: Amplitude(V), Event(s^{-1}), Duration(ms))

Amplitude Experiments	Amplitude(Varied: 30, 35, 40, 45, 50, 55), Event(Fixed: 20), Duration(Fixed: 20)
Event Experiments	Amplitude(Fixed: 45), Event(Varied: 50, 100, 200, 300, 400, 600, 800), Duration(Fixed: 1)
Duration Experiments	Amplitude(Fixed: 45), Event(Fixed: 20), Duration(Varied: 1, 5, 10, 20, 30, 40)

2.4 Experimental methods

First, all the experimental mice were placed upon the waiting section, where stainless steel rod and isolated square wave stimulator are connected in parallel to make the electric current conduct on the floor. As the mice start getting affected by the electric current, the partition is opened for them to evacuate to the safety section, passing by the measurement section. One experiment session is completed right after the last mouse escapes. A video is created using a camcorder when the first mouse evacuates from the waiting section until the last mouse reaches the safety section. The video file is moved onto a computer station and analyzed for instantaneous and average velocity using MouseTracker software.

Experiments were conducted for three different parameters, as shown in Table 1. A preliminary experiment was conducted to determine the experimental conditions for three parameters: amplitude, event, and duration. Mice did not feel the electrical stimulus for amplitude ranging from 10 to 25 V; minor body twitches were observed starting at 30 V. The electrical voltage was increased by 5 V. Mice started squeaking more loudly, and velocity increased significantly at 55 V. The voltage greater than 55 V may be too much for the mice, causing shocks and freezing. Freezing is a severe reaction that mice show to fearful

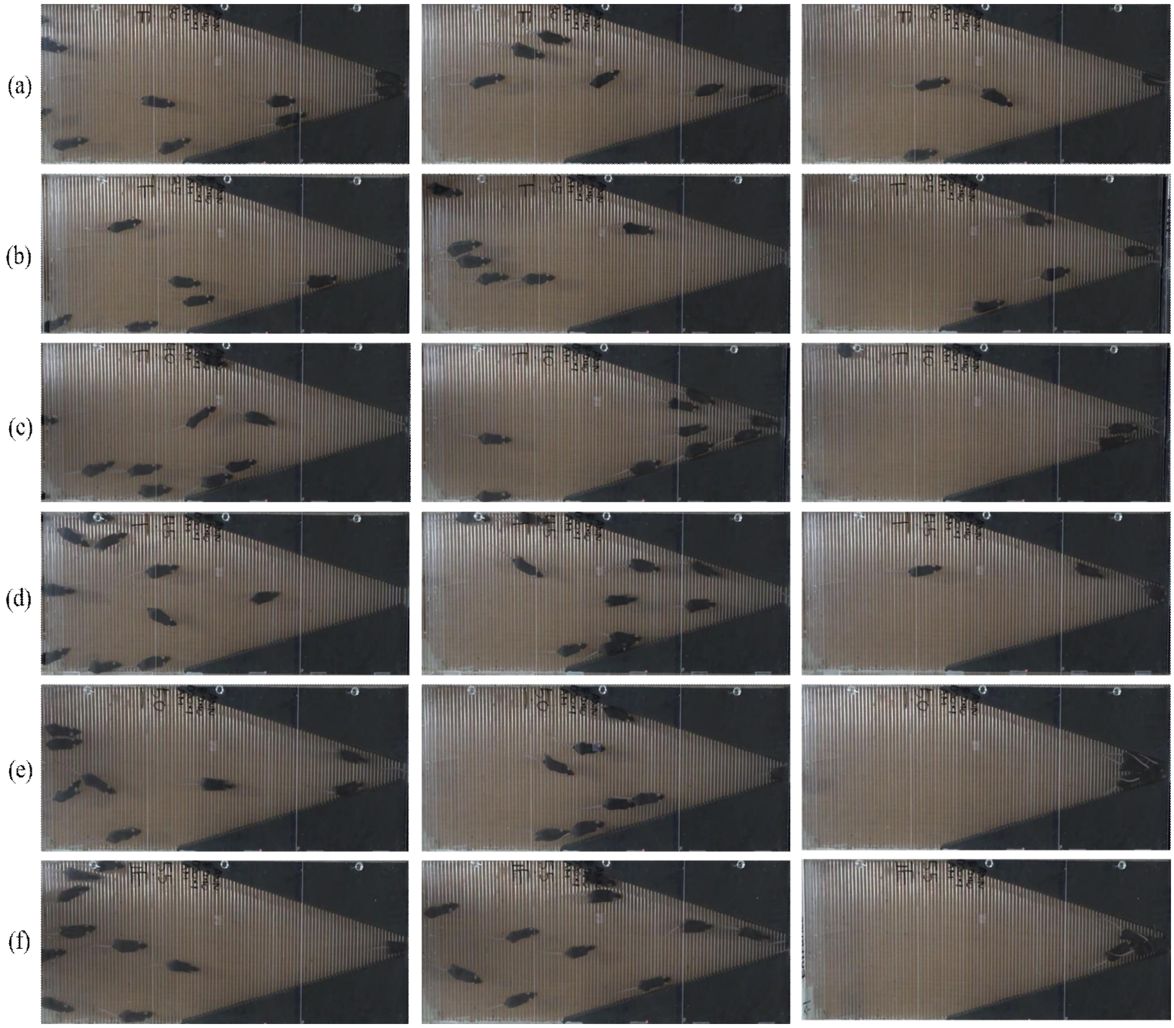


Fig. 4 Snapshots of mice experiments for amplitude change. From left to right, early evacuation, mid-term evacuation, late evacuation, and captured every 10 frames from early evacuation snapshot: (a) 30 V (b) 35 V (c) 40 V (d) 45 V (e) 50 V (f) 55 V

situations[5], which is uniquely observed in rodents but not humans. Thus, the maximum amplitude values allowed was set to be 55 V to prevent a freezing response. Fig. 4 presents snapshots showing the process of mice evacuation by time as the amplitude was increased from 30V (Fig. 4(a)) to 55 V (Fig. 4(f)) by 5-V increments. From left column to right column, early, mid, and late-phase of evacuation are shown; pictures were taken at ten-frame intervals starting from the early phase. The pictures from the third column are of the late evacuation phase, a snapshot of when evacuation is almost complete. In (a) and (b), with relatively small amplitude values, mice are seen still evacuating, whereas in (e) and (f), with larger amplitude values, most mice are seen to have succeeded with the evacuation.

If the multiplication of event and duration values reach 1000 (s^{-1}×ms), current starts conducting continuously. Mice do not feel the continuous current as a stimulus, so the velocity decreases rapidly to zero stimulus level. Because the current will be continuously conducting under the condition, event 1000 (s^{-1}) and 1-ms duration, experiments for duration were conducted from 50 (s^{-1}) to 800 (s^{-1}). Similarly, the current conduct continuously for duration 50 ms in duration experiment with 20 (s^{-1}) event, so experimental conditions were set between 1 ms and 40 ms. Unlike in the amplitude experiment, optimal condition did not exist for mice not to feel the stimuli at all or to feel it as too much stimuli in the event and duration experiments; thus, we contol the conditions between the minimal and maximal values.

3. Results

In Group 1, amplitude experiments were conducted 40 times, event experiments 25 times, and duration experiments 15 times. In Group 2, amplitude experiments were conducted 23 times, event experiments 21 times, and duration experiments 11 times. There were fewer duration experiments than others because duration not affecting the evacuation velocity was clear.

3.1 Amplitude experiment

Fig. 5 shows the results from the amplitude experiment; evacuation velocity for mice increases with amplitude increase. The velocity increase is not visible for amplitude values 30 - 40 V but is seen to be linearly increasing for 45 - 55 V. Evacuation velocity has increased two-fold from 30 - 55 V, increasing amplitude value. The evacuation velocity increase was in both the groups, with Groups 1 1.5-fold greater than Group 2. The same trend of the increase can be confirmed by looking at the error bar's minimal and maximal points.

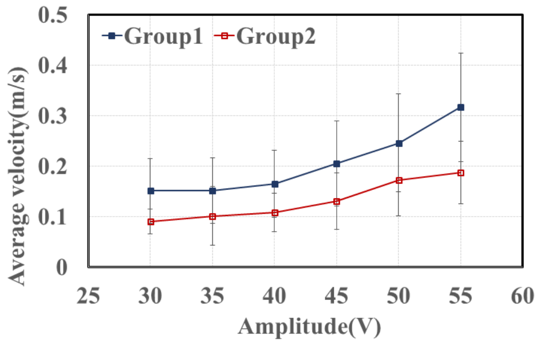


Fig. 5 Average velocity depending on amplitude

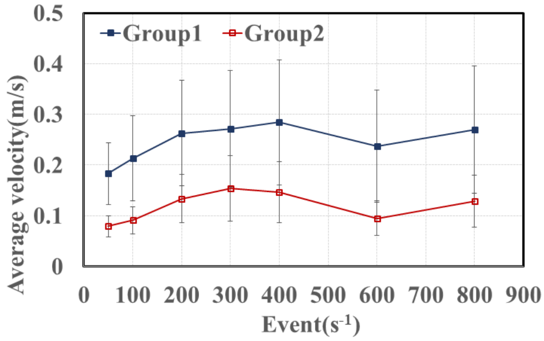


Fig. 6 Average velocity depending on event number

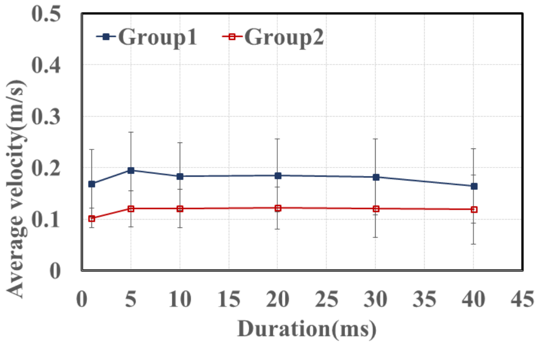
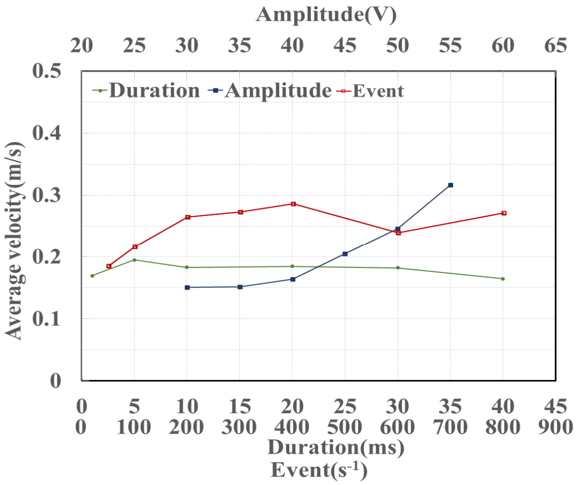


Fig. 7 Average velocity depending on duration

3.2 Event experiment

Fig. 6 shows the results of the event experiment. An event is defined as the number of electrical stimuli per



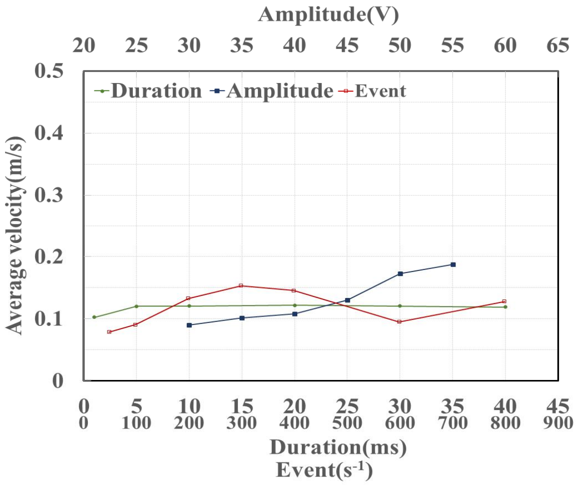


Fig. 8 Comparing with Group1 and Group2 for amplitude, event and duration

second, so an increased evacuation velocity was expected to be proportionate to a greater event value (i.e., more stimuli per second). The experiment results, however, show that evacuation time tends to increase beginning at the event value 50 (s^{-1}) and 400 (s^{-1}) for Group 1 and Group 2, respectively; it starts to decrease at 600 (s^{-1}) and increases again at 800 (s^{-1}) at a slightly lower than maximum velocity for both groups. These results indicate that the average velocity increases proportionate to event values up to 300 (s^{-1}) and then saturates. Group 1 and 2 showed the same evacuation trend, with Group 1 two-fold greater than Group 2. The trend can also be confirmed in the minimal and maximal points of error bars.

3.3 Duration experiment

Fig. 7 shows the results from the duration experiment. Compared to the amplitude and event experiments, the duration experiment results do not show unique characteristics but show overall constant value. Additionally, errors in evacuation velocity in the control group are not significantly large; no significant tendency is noticeable in the error bar plot. Therefore, duration did not significantly affect the evacuation patterns of mice. Evacuation velocity is seen to be 1.5-fold greater in Group 1 than in Group 2.

3.4 Group comparison

In Fig. 8, the results from Group 1 (younger mice) and Group 2 (older mice) are compared. The increase in velocity was 1.5-fold in the amplitude experiment and duration experiment, whereas it was 2-fold in the event experiment. For the amplitude experiment, a larger amplitude value was expected to result in an increase in the evacuation velocity, as amplitude relates to voltage intensity. Experimental results revealed that evacuation velocity was not necessarily higher for a higher event value. Finally, it was found that mouse age affects the velocity but not the patterns of evacuation.

4. Conclusion

The present study conducted experiments to predict the evacuation flow to prevent crush incidents that can occur in crowded places during emergencies. Electrical stimulation was applied in the experiment after the rodents were divided into two groups based on their age: Group 1 (younger mice) and Group 2 (older mice). The experimental parameters selected were amplitude, event (i.e., frequency), and the duration of the electrical stimulus. The average velocity was shown to have increased continuously for amplitudes ranging from 30 to 50V; the average velocity was highest for events of 300–400 (s^{-1}); the average velocity was almost the same for different durations. These patterns were consistent regardless of the rodent's age, although the magnitude of the average velocity varied between age groups.

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