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Experimental Attempt on Walking Behavior and Stress Assessment in a Completely Darkened Tunnel

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Abstract: In case of massive fire incidents in tunnels, ceiling lights are covered by dense smoke, and pedestrians must evacuate in the dark tunnel with almost zero visibility. Nonetheless, the walking behavior in a completely darkened tunnel has not been clarified. In this study, we experimentally attempted to investigate the evacuation loci and assess the stress of evacuees by measuring oxytocin and cortisol concentrations in saliva, heart rates, blood pressures, and responses in a survey questionnaire for a full-scale tunnel. Results indicated few differences in both one- and two-dimensional walking speed. In terms of stress, the group of subjects who felt stress demonstrated a walking speed that is 0.17 m/s slower than the group that did not feel it. In the questionnaire survey, most of the subjects answered that the wall was the most helpful item, followed by the unevenness (bumps) on the white lines on the road. One of the subjects became lost, stating that she could not find the unevenness (bumps) on the white lines. These two factors can be rational guides in a dense smoke environment or a completely dark tunnel scenario.

Keywords: tunnel; fire; smoke; evacuation; stress assessment; human behavior; risk analysis

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1. Introduction

The typically long and enclosed geometry of tunnel spaces contributes to difficulties in the evacuation, rescue, and firefighting operations in tunnels, given that even the slightest of incidents produce possible significant losses, e.g., human casualties or economic slowdowns, as demonstrated by tunnel fire incidents in the past. In case of a massive fire, the ceiling lights are covered by dense smoke, thereby reducing the effective visibility for an evacuation. An evacuee's mobility or walking speed in a less visible environment is not only influenced by insufficient lighting but also by stratified dense smoke covering the lighting that may induce forced evacuation in the dark. Togawa [1] approximated that the walking speed in a dark architecture was 0.3 m/s, which was within the walking speed of 0.24–0.88 (average 0.49) m/s that Seike et al. [2] have reported, whereas walking behavior in a dark tunnel has not been clarified. Evacuees during the Sekisho tunnel fire accident in Japan [3] were reported to have used their mobile phones' light, but the mobile light function effect was little due to the dense smoke. Without regarding the influence of dense smoke and toxic gas on the human body, the walking speed in a dark tunnel may be considered as the slowest evacuation speed. In addition, evacuees tend to become lost while searching for fire exits. If the evacuees' behavior and the reason for such a tendency of becoming lost in a completely darkened tunnel could be clarified, then we would be able to develop a performance-based design for emergency facilities.

Seike et al. [2] reported the literature review relating to our study, so we referenced their report as follows:

Togawa [1] simulated blackouts by investigating the fundamental walking speeds of participants with and without blindfolds in various environments, including underground corridors, hotels, and department stores. Participants who were familiar and unfamiliar with their surroundings were considered. A tunnel environment was not considered.

Jin and Yamada [4] investigated the influence of visibility by measuring the walking speeds of 10 participants in a smoke-filled 20 m long corridor. The participants were directed to walk along the side of the corridor until they saw an emergency board placed in front of the wall. The smoke was produced by burning wood (irritant) or crude oil (nonirritant). The tests were not conducted in a tunnel but were intended for disaster prevention in Japanese road tunnel fires because they used real smoke. The results have been widely referenced in the literature on building safety.

In the Frantzich and Nillson [5,6] study, the walking speed was measured in a 37 m long tunnel filled with artificial glycerol (irritant) smoke and acetic acid (nonirritant), with real vehicles placed as obstacles throughout. The experiments were performed in dense smoke (with an extinction coefficient of greater than 1.9 m^{-1}). Their target was to clarify the function of guide lights in tunnel fires, but the real tunnel-evacuation experiments, especially in the significantly a dense smoke (greater than 2 m^{-1}) situation, were few; hence, we chose their experiments for comparison.

Fridolf et al. [7] experimented in a 200 m long road tunnel. They used glycerol-based artificial smoke with (irritant case) and without (nonirritant case) acetic acid. Participants watched a video of a situation in which a passenger train stopped, and the passengers were instructed to seek the emergency facilities for evacuation. Four crossing points were established from the starting point to the endpoint, and the participants were instructed to walk diagonally from one wall to another. Emergency lights were installed at intervals of 8 m. The mean illuminance of the emergency lights was only approximately 1 lux, meaning the experiments were conducted in an almost dark scenario. Their experimental situation differed from ours, especially in terms of the guide lights, but real tunnel-evacuation experiments in a dense smoke (greater than 1 m^{-1}) situation were not so many; hence, we chose their experiments for comparison.

Fridolf et al. [8] and Ronchi et al. [9] reported experiments in a 400 m long road tunnel. Participants watched a video of a situation in which a passenger train stopped, and the passengers were instructed to seek the emergency exits for evacuation. Emergency lights were installed at 8 m intervals. The illuminance of the ceiling lights ranged from approximately 70 to 110 lux. The experimental situation was identical to that of Frantzich and Nilsson [5,6] and Fridolf et al. [7].

Seike et al. [10,11] experimentally investigated evacuation speed in a 700 m long full-scale smoke-filled tunnel of which 400 m was used and clarified the relationship between the extinction coefficient (up to 1.6 m^{-1}) and normal walking speed under lightened and darkened conditions, respectively. They conducted their evacuation experiment in a full-scale smoke-filled tunnel to clarify the relationship between smoke density up to the extinction coefficient = 1.6 m^{-1} (which includes extinction coefficient = 0.4 m^{-1} as the Japanese road tunnel fire-prevention standard) and evacuation speed.

Seike et al. [2] reported that age and gender were confirmed to have an insignificant influence on walking speed. The results clarified that participants' walking speeds were approximately lognormally distributed within a 95% interval (using the 2.5th and 97.5th percentiles of the distribution as endpoints, which were, respectively, 0.24 and 0.88 m/s with a mean value of 0.49 m/s). Some female participants became lost and gave up trying to evacuate, which generated a cancelation rate of 0.6% of the total number of evacuees.

Seike et al. [12] experimentally investigated evacuation speed distribution. The results of the statistical analysis were used for determining the relationship between emergency evacuation speed and an extinction coefficient of up to extinction coefficient = 2.2 m^{-1} through a set of formulations, which agree that the evacuation speed decreases with greater extinction coefficient values. Based on the comparison between our experimental results and that of the Swedish group, it was considered that the evacuation speed decreased rapidly around extinction coefficient = 4 m^{-1}, after which it approached Seike et al.'s [2] values asymptotically.

These past experiments did not investigate the relationship between evacuation behavior and psychological stress in evacuation. In their experiments, they supposed that participants were always calm. However, Leach [13] reported that during disasters, around 10–15% of those affected embrace themselves, 70–75% feel frozen, and 10–20% cry or scream. A rise in stress levels and anxiety increase an evacuee's heart rate and result in respiratory distress, even after evacuation starting and the smooth evacuation action difficult. Panic follows and induces unexpected occurrences, thus requiring stress assessment among the evacuees.

Regarding the past psychological stress assessment, Jin [14] only investigated the relationships between psychic unrest levels, walking speed, and smoke density in an architectural space, whereas Frantzich and Nilsson [5,6], Fridolf et al. [7,8], Ronchi et al. [9], and our group [2,10–12] reported the walking speed in a smoke-filled tunnel without clarifying the relationships between the walking speed in a completely darkened tunnel and under stress. Therefore, in this study, our aim is to show a new evaluation method proposal of stress evaluation from saliva, heart rate, and blood pressure measurement and we attempted to investigate of the relationship with movement speed. The present study's state-of-the-art is a challenge to evaluate the stress and connect to the human behavior in the tunnel evacuation. To the best of our knowledge, this study is the first to evaluate the stress and connect to the human behavior in evacuation. Our investigation could be useful for innovate the stress assessment. Additionally, our study assumption is significantly rare in the field of endocrinological data. We measured the walking locus, speed, and stress in a darkened full-scale tunnel to investigate the fundamental characteristics during tunnel fires. The study subjects wore an eye mask, assuming a middle-to-late evacuation environment. We did not use smoke.

Stress levels by heart rate, blood pressure, and oxytocin and cortisol concentrations from saliva are assessed before and after the experiments, followed by a questionnaire survey. Typically, oxytocin is released during feelings of stress and fear and has an anxiolytic effect [15]. Recent works [16,17] have shown that the released oxytocin related to stress is detectable from human saliva.

2. Experimental Setup

2.1. Experimental Tunnel

We conducted experiments in an obsolete full-scale tunnel, the ex-Tonokuchi tunnel in Fukui. The horseshoe-shaped tunnel was 488 m long, 6.6 m wide, and 5.4 m high. The region allocated to the experiment (longitudinal interval and transverse section) is shown in Figure 1. The longitudinal and wide directions were indicated by x and y, respectively, and the origin was set at the width center point o.

2.2. Subjects

Nine subjects participated in the experiments (six males, three females; 20.6 years old on average), because we would like to avoid the influence of age and prevent the injured. The subjects were instructed to wear a safety vest, a mask, and a helmet. The group effect is fundamental in tunnel fire scenarios; however, before the group evacuation investigation, it was necessary to consider the individual behavior characteristics investigation. Hence, we focused on the individual behavior and stress and would focus on the grouping effect in the future topic.

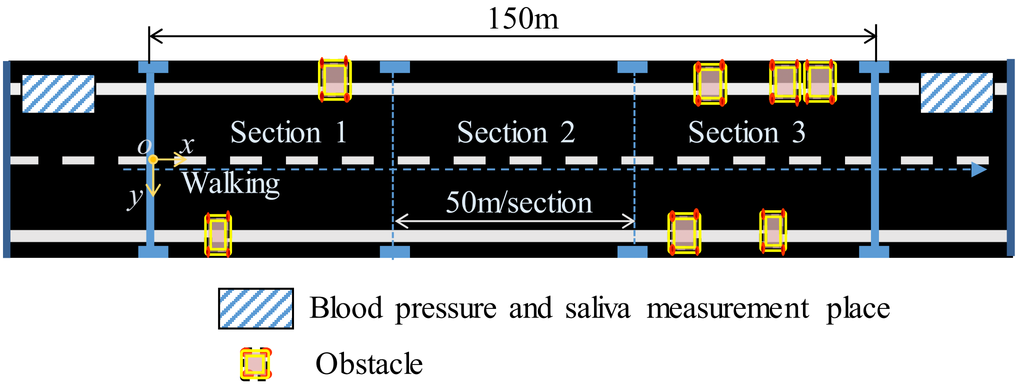


Figure 1. Evacuation route and section.

2.3. Explanation

We investigated the fundamental characteristics for risk analysis in tunnel fires by measuring the walking speed in a tunnel with no visibility. Subjects wore an eye mask and were given these instructions:

"Please walk in the tunnel as you would normally walk."

The subjects walked the 150 m long lanes consisting of several sections with or without obstacles. Three obstacles were installed on the measuring route (Figure 1). Four obstacles (sorts of a tent) were set at a fixed location. Before the experiments, subjects were reminded to walk with caution relative to these obstacles.

2.4. Measurement of Walking Speed

The walking speed of the subjects was derived from their longitudinal and transverse locations where their experimental attendant left numbered cards every 5 s (see Figure 2). Notably, the subjects were blindfolded.

Figure 2. A scene during the evacuation experiment.

A subject was blindfolded while the locus was measured by another subject.

Two walking speed types were addressed herein as follows:

The mean walking speed v_m = one section (50 m)/the passing time in one section (see Figure 1).

Topical walking speed $v_t = \frac{\sqrt{\Delta x^2 + \Delta y^2}}{\Delta t}$,
where Δx and Δy are longitudinal and transverse displacement during Δt (5 s).

2.5. Stress Assessment

We assessed the stress of the subjects by measuring their heart rate before, during, and after the experiments, their blood pressure, and their oxytocin and cortisol concentrations from saliva before and after the experiments, as well as completing a questionnaire survey after the experiments. This research ethics were approved by Toyama Prefectural University (corresponding author's (M. Seike) former affiliation) and Kanazawa University.

2.5.1. Oxytocin Concentration in Saliva

A study shows that oxytocin, a substance involved in an anxiolytic effect, is released upon feelings of stress or fear [15]. As stress biomarkers, oxytocin and cortisol were measured before and after the experiments. After gargling, the subjects' saliva was collected by exhaling into a polystyrene centrifuge tube (15 mL, Figure 3) through which approximately 1 mL saliva was passed directly. After centrifugation at 3000 rpm for 12 min at 4 °C, the supernatant was collected and transferred to an Eppendorf tube. Oxytocin and cortisol concentrations were immediately measured from the saliva using EIA: Enzo kit.

Figure 3. Saliva collection test tube.

A 50 µL oxytocin blue conjugate and 50 µL yellow antibody were added to 100 µL of the sample. The antigen–antibody reaction was then performed overnight at 4 °C. After washing with a wash buffer the next day, a pNpp substrate (200 µL) was added and kept at room temperature. Moreover, after a stop solution (50 µL) was added, the corresponding absorbance at 405 nm was read with a plate reader (made by BioRad). A calibration curve was prepared each time, and the oxytocin concentration was calculated.

2.5.2. Heart Rate and Blood Pressure

Selye [18] reported that an increase in body stress results in hypotension, such as a shock layer, and then transitions to the antishock phase, accompanied by an increase in blood pressure. Accordingly, Jin [14] used heart rates to measure psychic unrest levels. In this study, we measured both blood pressures and heart rates using TrikerFIT WahooWF124 (see Figure 4(i)). We measured the blood pressures and heart rates before and after the experiments using Omron HEM-6324T (see Figure 4(ii)). The subjects' blood pressures were measured along with measuring time. We applied this time to investigate the heart rates of the subjects in the experiments.

(i) Heart rate (ii) Blood pressure

Figure 4. Measuring equipment.

2.6. Questionnaire Survey

Upon completion of the experiments, we asked the subjects to answer a questionnaire. We picked up the anxiety factors at the time of evacuation as follows and investigated what the subjects were anxious about. The reason for adopting a 5-point evaluation was determined from the classification based on S.S. Stevens [19], focusing on the interval scale by the question about the attitude in this study.

(A) Anxiety Factors

(1) Nobody around the subject;
(2) Touching or colliding with the obstacles;
(3) No sound;
(4) Sound (someone collision something);
(5) Sound (someone's voice);
(6) Sound (wind);
(7) Sound outside the tunnel;
(8) Temperature;
(9) Wall (dirty);
(10) Unevenness of the road;
(11) Do not know if going in the right direction;
(12) Do not know how to reach the destination;
(13) Do not know the place where he/she was.

We picked up the elements that were useful at the time of evacuation as follows and investigated what the subjects depended on. The reason for adopting the 5-point evaluation was the same as the anxiety factors.

(B) Helpful item

(1) Wall;
(2) Obstacle;
(3) Unevenness of the white line *. * There is unevenness (bumps) on the white lines to alert the drivers in the tunnel.

We prepared two sets of questionnaires: one assessing anxiety factors and the other asking the helpful item for walking by score (yes: 2 points, probably yes: 1 point, neither yes and no: 0 points, probably no: −1 point, and no: −2 point).

3. Results and Discussion

3.1. Walking Speed

Figure 5 shows the mean walking speed v_m in each 50 m section. The blue columns represent Section 1 in Figure 1, the orange ones represent Section 2, and the gray ones represent Section 3. The dotted bars are the mean value of each subject. The dotted line in Figure 5 shows the total mean value. Apparently, Subject #3 returned to the starting point by touching the wall or obstacles after becoming lost in the direction and after retrying three times. Thus, we decided to assign a speed of 0 m/s to her, which indicates that she gave up. The walking speed v_m was from 0.47 m/s (Subject #8) to 1.27 m/s (Subject #1), whereas the mean value of all subject walking speeds was 0.78 m/s. The fastest mean walking speed was 1.08 m/s, whereas the slowest was 0.56 m/s, excluding that of Subject #3. The walking speed v_m in Section 2 had the fastest mean value of 0.87 m/s, whereas those of Sections 1 and 3 were 0.75 and 0.74 m/s, respectively, as there was no obstacle in Section 2. The mean speed of males was 0.93m/s, and that of females was 0.74 m/s. (excluding Subject #3). However, in a previous study [2], we investigated the gender and age bracket influence on the walking speed and clarified that the influence was insignificant. In addition to that and since our present results' sample number was small, we did not discuss gender influence.

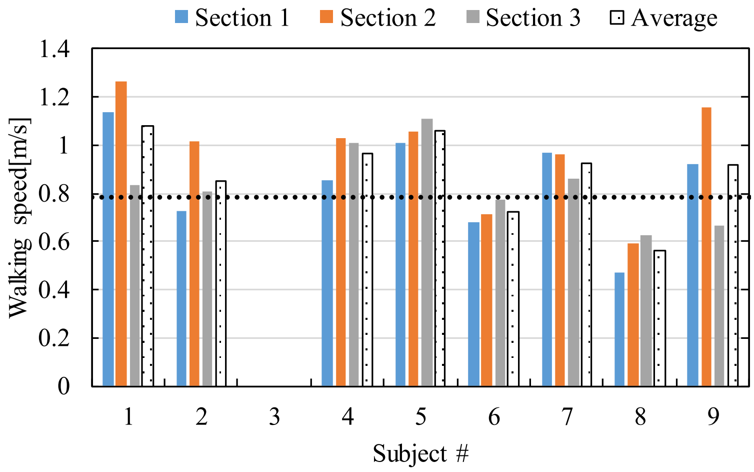


Figure 5. The mean walking speed v_m in each 50 m section.

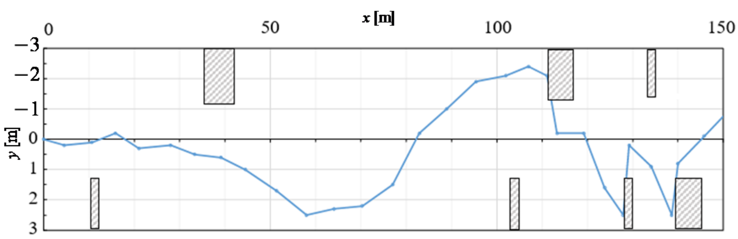
3.2. Locus

In this section, we investigated the evacuation behavior of the subjects by their locus, including subjects who gave up. Figure 6(i)–(iv) show the maximum walking speed subject locus (Subject #1) closing-in to the mean walking speed subject locus (Subject #9), the minimum walking speed subject locus excluding giving up person (Subject #8), and the locus of the subject who gave up (Section #3), respectively. All loci were measured individually every 5 s.

In Figure 6(i), Subject #1 walked by not touching the wall until x = 58 m but touching the wall first (x = 58 m, y = 2.5 m) went to the opposite side and touched the obstacle (x = 111 m, y = −2.1 m), went to the opposite side (x = 127.9 m and y = 2.5 m), avoiding the obstacle and touching the wall (x = 138.6 m, y = 2.5 m), before finally arriving at the goal. He was to walk straight confidently, but he was surprised by touching or colliding the wall and obstacles. His walking speed was the fastest in the results.

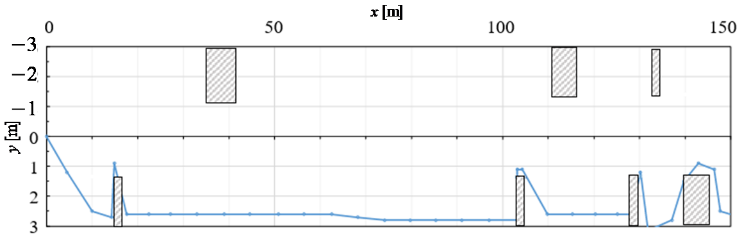
In Figure 6(ii), Subject #9 walked toward the obstacle, followed to the obstacle, after that she walked by touching the wall.

In Figure 6(iii), Subject #8 walked, touching the wall and following the obstacles, but she walked without touching anything from around x = 80 m and y = 2 m. During this time, the walking distance was longer than that of touching the wall, but she touched the obstacle, went to the wall, and walked touching the wall and following the obstacle finally. In these subjects' locus, the wall could be one of the functions of the guide, but the walking speed might decrease from that of not touching the wall.

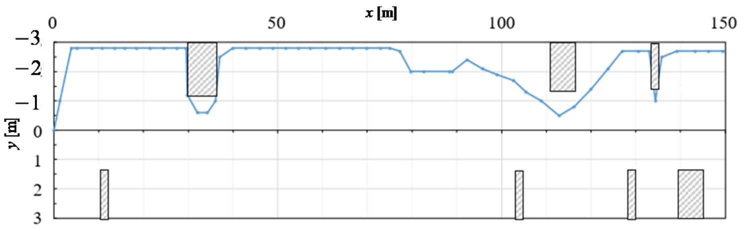


(i) Maximum walking speed subject locus (Subject #1).

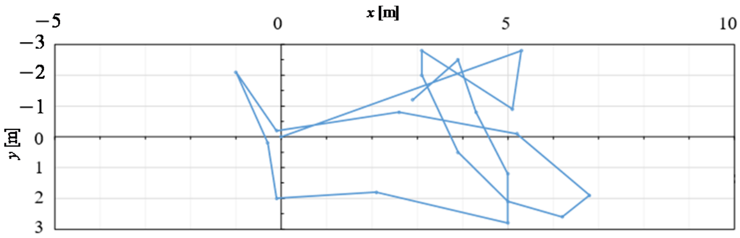
Figure 6. *Cont.*



(ii) Closing-in to the mean walking speed subject locus (Subject #9).



(iii) Minimum walking speed subject locus excluding giving up (Subject #8).



(iv) The locus of the subject who gave up (Subject #3).

Figure 6. A representative subject locus (maximum, mean, and minimum, excluding the subject who gave up).

Table 1 shows the topical walking speed v_t from a certain distance in each 5 s. The topical average value was calculated from the first location (origin point in Figure 7) to the final location in Figure 7 with time. Subject #1's walking speed was the fastest. In addition, the minimum walking speed of Subject #1 at 0.44 m/s was close to Subject #3's mean walking speed. Subjects #9 and #8's maximum and minimum walking speed differences were 0.1 m/s; however, these differences were integrated so that the averaged walking speed was 0.3 m/s differences. Moreover, Subject #3's walking speed was almost the slowest, except for the minimum walking speed; she moved with a slow speed of 0.45 m/s but became lost around the starting point.

Table 1. Topical walking speed v_t (Subjects #1, #9, #8, and #3).

Subjects #	1	9	8	3
Max $v_{t,\max}$	1.40	1.26	1.14	1.04
Min $v_{t,\min}$	0.44	0.22	0.12	0.18
Average v_{ta}	1.07	0.91	0.58	0.45

The topical mean walking speeds v_{tm} of Subjects #1, #9, and #8 were shown on the linear regression line with distance as the dependent variable using the least-squares method (see Figure 7). The topical mean walking speed v_{tm} (inclination of the linear regression line) of Subject #1 was 1.12 m/s (R^2 = 0.99, blue), whereas that of Subject #9 was 0.96 m/s (R^2 = 0.99, gray). In addition, that of Subject #8 was 0.56 m/s (R^2 = 0.99, orange). We had calculated the integral absolute wide movement distance, which was 21.4 m

(Subject #1, 14%), 17 m (Subject #9, 11%), and 17.1 m (Subject #8, 11%), or approximately less than 11–14% as compared with the longitudinal distance.

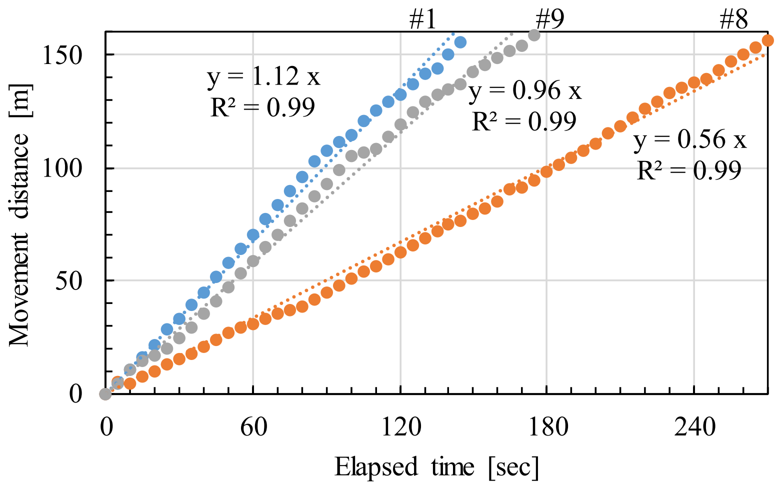


Figure 7. Topical mean walking speed v_{tm} time profile.

3.3. Stress Assessment

Each subject's stress level was assessed based on the amount of oxytocin concentration in the saliva, heart rate, blood pressure, and the answers to the survey questionnaire.

3.3.1. Oxytocin and Cortisol Concentrations

Figure 8 shows the rate of oxytocin (blue) and cortisol (orange) variation in each subject's saliva before and after the experiments. We noticed an increase in the concentration of both substances. Particularly, an increase in both concentrations was observed in four subjects; in addition, we noticed an increase in either of the two in eight subjects. We focused on the concentration of oxytocin and calculated the mean walking speed in the six subjects in which the substance increased, and in three subjects in which it decreased (Table 2). The first group had a mean walking speed of 0.73 m/s in the case that included the subject who gave up, whereas the second group had 0.90 m/s, such that the first group (who were stressed out) was 0.17 m/s slower than the second group (those who did not feel stress). Table 2 also shows that the maximum and minimum walking speed of the subjects who felt stress was 0.16 and 0.2 m/s, respectively, slower than those who did not feel it. Salivary cortisol concentration may fluctuate two to three times in the context of psychological stress test, although number 5 appears to be higher than in previous studies [16,17]. However, since no study has measured the variability of salivary cortisol concentration in an experimental system like ours and we still need further research to assess the fluctuation range of cortisol concentration, we did not treat number 5 data as outliers in this study.

Table 2. Mean walking speed v_m of groups with steady and increased oxytocin.

	Steady (Not Stressed)	**Increased (Stressed out)**
Max	1.27	1.11
Min	0.67	0.47
Average	0.90	0.72 *

* Including the subject who gave up—walking speed (0 m/s).

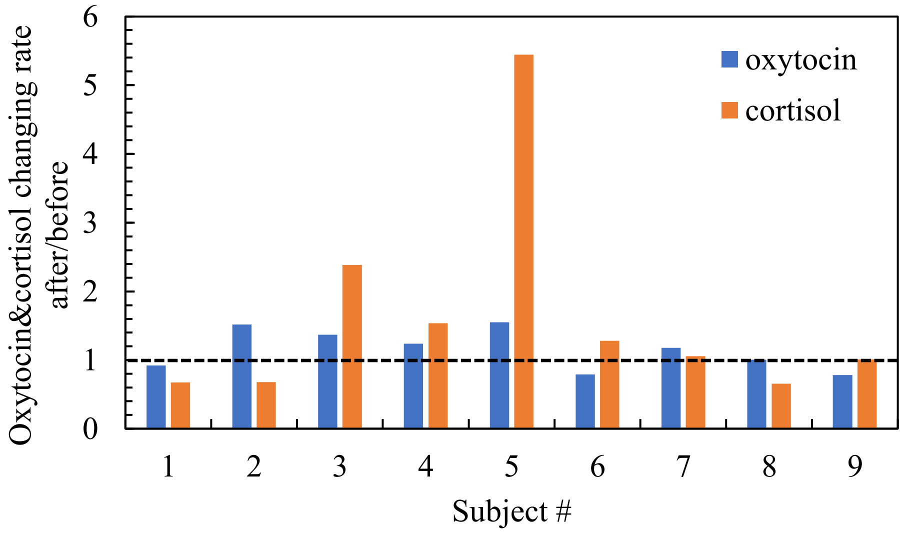


Figure 8. Rate of variation in oxytocin and cortisol concentration (before/after experiments).

3.3.2. Blood Pressure and Heart Rate

Figure 9 shows the systolic (blue) and diastolic (orange) blood pressure and heart rate (gray) of the subjects before and after the experiments.

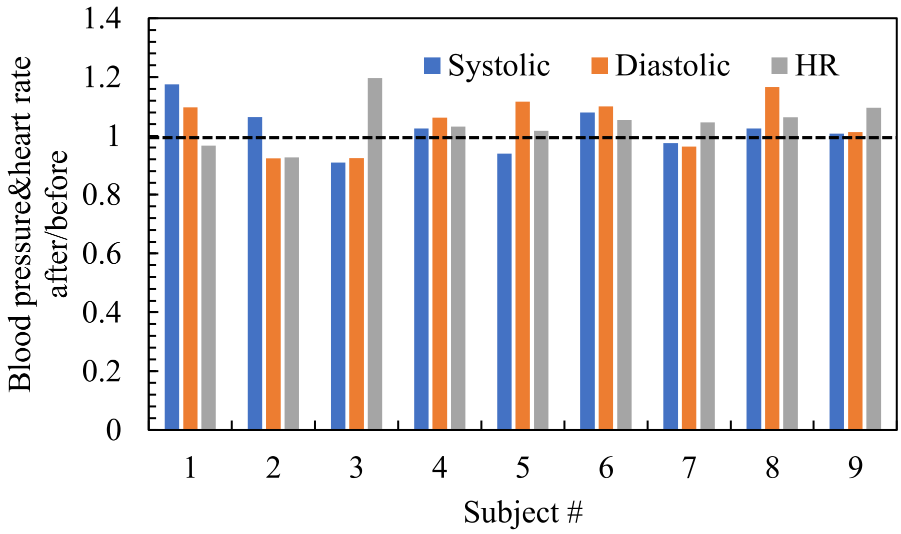


Figure 9. Rate of change in subjects' blood pressure and heart rate (before and after experiments).

As in the blood pressure, the lines in the figure are regression lines for the heart rate calculated using the least-squares method. Apparently, the heart rate of seven subjects and the oxytocin concentration of six subjects increased at a maximum rate of 1.2 times than before the experiments were performed. Similarly, as with the oxytocin concentration investigation, we calculated the mean walking speed in six subjects whose blood pressure and heart rate increased, and three subjects in which these decreased, as shown in Figure 10. The mean walking speed of the group with increased systolic blood pressure was 0.85 m/s (including the subject who gave up), whereas the group in which this was steady was 0.99 m/s. Thus, subjects who felt stress were 0.14 m/s slower than those who did not feel it. Similarly, the mean walking speed of the group with increased diastolic blood pressure was 0.88 m/s (including the subject that gave up), whereas the group in which this was steady had 0.89 m/s; thus, the speed was almost the same. The mean walking speed of the group with an increased heart rate was 0.86 m/s (including the subject who gave up), whereas the group whose heart rate was steady walked at 0.96 m/s, indicating that those who felt stress were 0.1 m/s slower than those who did not. From these results, we could see the relationships between systolic blood pressure, heart rate, and walking speed. Nonetheless, it is necessary to analyze such relationships to obtain further evidence.

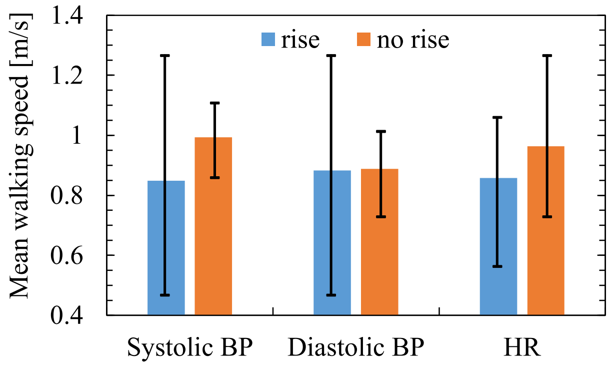


Figure 10. Mean walking speed v_m of groups with steady and increased blood pressure (BP) and heart rate (HR), the black lines mean the range between maximum and minimum values.

Table 3 summarizes the oxytocin concentration, systolic and diastolic blood pressure, and heart rate of the subjects. The term "yes" in the column means that these parameters increased after the experiments. Notably, at least one of these elements increased after the experiments. Moreover, all items in Subjects #4 and #8 increased. Subject #3 (who gave up from the experiments) also showed increased oxytocin concentration and heart rate. Afterward, she walked to around 150 m without the blindfold and had her blood pressure and heart rate measured. Thus, her heart rate and blood pressure decreased after walking but increased before the experiments. Her heart rate, blood pressure, and oxytocin concentration should have increased after the experiments, if these were measured at the moment she gave up, to display a significant change in these elements. Essentially, Table 3 demonstrates that all subjects had increased heart rate and oxytocin concentration, and Subjects #4 and #8 showed an increase in blood pressure, along with heart rate and oxytocin, possibly indicating a relationship between the latter two parameters.

Table 3. Summary of increase in oxytocin concentration, systolic and diastolic blood pressure, and heart rate. The bold is all item Yes.

Subject#	Oxytocin	Systolic BP	Diastolic BP	HR	Sum
1		Yes	Yes		2
2	Yes	Yes			2
3	Yes			Yes	2
4	**Yes**	**Yes**	**Yes**	**Yes**	**All**
5	Yes		Yes	Yes	3
6		Yes	Yes	Yes	3
7	Yes			Yes	2
8	**Yes**	**Yes**	**Yes**	**Yes**	**All**
9		Yes	Yes	Yes	3
Sum	6	6	6	7	

3.3.3. Questionnaire Survey

Figure 11 shows the results of the survey questionnaire. The horizontal axis representing the ratio of the answered score to the total point. In particular, Figure 11(i) depicts that touching or colliding with obstacles was the most anxious feeling, with a reply of 14 pt. The most helpful item for walking was the wall (13 pt), followed by unevenness (bumps) of the white lines (12 pt). The bumps were originally used as signals for drivers to step on the white line, and it turned out that bumps help evacuees. The subjects, including Subject #3, replied the wall was the helpful function. In addition, the subjects, excluding Subject

#3, replied the bumps were helpful for walking. Therefore, when paving the road, it can be said that installing bumps around 1 cm from the road surface was effective for not only drivers but also evacuees for helping the evacuation. Remarkably, Subject #3 became lost, and she told us that she could not find the unevenness (bumps) of the road. Thus, she moved by touching the walls or obstacles but became lost in her direction. The walls and obstacles did not guide her well, which was a different scenario from the other subjects who moved to the walls and were aided by the bumps of the white lines.

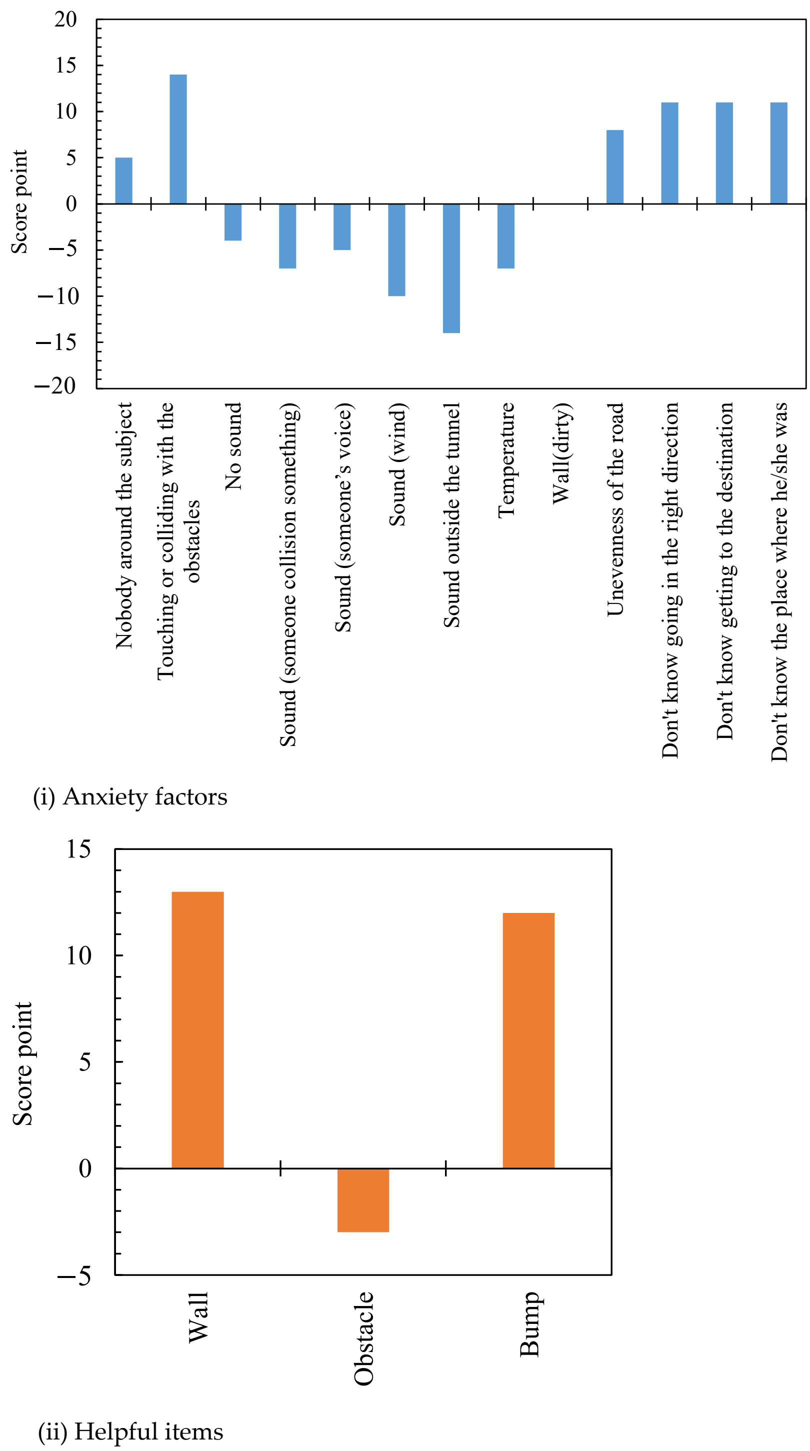


Figure 11. Questionnaire survey results.

Five subjects pointed out that the obstacles were unhelpful for walking, and that they could have become lost by walking with the obstacles. We could see in the experiments that the subject who became lost (including those who gave up) determined the appropriate direction by touching with two hands. By contrast, the subjects who found the right direction used a single hand to touch the wall or obstacles first and then walked to the direction with one hand touching the wall and raising the other hand toward the correct direction, in addition to feeling the bumps of the white line. These two factors may be acceptable guides in finding the right direction within a dense smoke environment or a completely dark tunnel situation.

4. Conclusions

We experimentally attempted to investigate the evacuation loci and stress levels of subjects by measuring the oxytocin concentration in their saliva, their heart rate, blood pressure, and results of a survey questionnaire for a full-scale tunnel scenario. These are the generalized results:

- The mean walking speed v_m was 0.47 m/s (Subject #8) to 1.27 m/s (Subject #1), with a mean value of 0.78 m/s for all subjects. The mean walking speed in Section 2 was the fastest (0.87 m/s), and those in Sections 1 and 3 were 0.75 and 0.74 m/s, respectively, which was because there was no obstacle in Section 2. The moving distance of the subjects to the width was approximately less than 11–14%.
- The heart rate of all subjects increased with oxytocin concentration. Two subjects (Subjects #4 and #8) had increased blood pressure, heart rate, and oxytocin. Thus, heart rate and oxytocin concentration may have some relationships. For stress assessment, the group who felt stress demonstrated a walking speed of 0.17 m/s, slower than that of the group that did not feel stress. Increases in heart rate and blood pressure due to stress also affected their motor function and inevitable slow down. Therefore, how to reduce stress and evacuate was paramount.
- The subjects answered the tunnel wall as the most helpful item (chosen by eight subjects including those who gave up), followed by the unevenness (bumps) on the white lines on the road (chosen by the subjects other than those who gave up). One of the subjects became lost, saying that she could not find the unevenness (bumps) on the white lines on the road. However, the bumps can be acceptable guides in a dense smoke environment or completely dark tunnel scenario. It is significantly crucial to choose what to rely on for evacuation.

In this study, we could only collect nine samples; thus, the data were small. This study was limited by its small number of participants with fewer exclusion criteria. Hence the future tasks with large sample sizes and including both males and females should be required to provide meaningful data regarding our investigation's potential usefulness. The ultimate goal of the program is to assess the stress and connect to the human behavior in evacuation. To the best of our knowledge, this study is the first to evaluate the stress and connect to the human behavior in evacuation. Our investigation could be useful for innovate the stress assessment. Additionally, our study assumption is significantly rare in the field of endocrinological data. To elucidate the walking speed behavior and stress, we would investigate the age of an individual, initial psychophysical conditions of an individual, respiratory volume (exposure to toxic gas concentrations), awareness of the subject who is taking a test, and detection and reaction time (the premovement time) as future tasks after overcoming COVID-19.

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