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Analysis of Walking-speed of Cruise Ship Passenger for Effective Evacuation in Emergency

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ABSTRACT

In Korea, people are paying growing attention to leisure activities on ships as they grow wealthy, and as a result, the volume of passenger ships and the number of passengers are on the rise. In case of emergency such as fire, evacuation on a cruise ship is different from other buildings due to unique spatial characteristics(e.g. evacuation route) and other factors(e.g. the ship's movement). For this reason, a special evacuation plan is needed in consideration of passengers' walking on a ship. Passengers of a cruise ship without an experience of on-board life participated in the experiment for comparative analysis of walking speed along the corridors(horizontal walking) and stairs(vertical walking) that are used as evacuation path in case of a marine emergency. For the experiment, the participants' movements along the designated horizontal and vertical routes were recorded by several CCTVs, and recorded videos were analysed to calculate walking speed based on the distance between two baselines and the time it took to cross them. For horizontal walking, walking speed dropped by 13.5% when the ship was sailing than when at berth; particularly, in sections that are partly narrowed with obstacles, walking speed fell sharply by 20~25%. For vertical walking, the ship's movements had less impact on walking speed, and downward walking was faster than upward walking by 20% for both when the ship was at sea and at berth. By age, participants ages 60 and over walked slowest for both horizontal and vertical walking. When the ship was sailing, its movements affected walking speed by age less for horizontal walking than for vertical walking. By gender, speed difference was relatively smaller when the ship was at sea, and men's walking speed was more affected by the ship's movements. Further research is needed on evacuation speed in a simulation of an actual marine emergency such as fire, as well as research on pre-evacuation time in consideration of sleeping facilities within a ship.

Keywords: *Cruise Ship, Walking Speed, Evacuation Safety, Human-behavior, Full-scale Test*

Introduction

People are paying growing attention to leisure activities that involve ship as their wealth increases. Accordingly, traveling by passenger ships and cruise ships is increasing. In Korea, the share of domestic travel is high for cruise tours, and for overseas cruise tours, destinations are concentrated in the Asian region. In terms of cruise ship passengers, 65.3% of passengers are 60 years old or older, and women account for 58.1%[1)]. Since most cruise ships are built for traveling, and to accommodate long-term passengers, they have various convenience, entertainment and sleeping facilities. In case of emergencies such as fire, fire fighters cannot be called from the outside, and fire should be extinguished within the ship. Particularly, many obstacles are onboard that obstruct effective evacuation in case of marine emergencies, including closed and narrow paths, and difficulty of walking due to movements of the ship. And, the last point of evacuation is on the sea that people face

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secondary risks in many cases. Further, unlike crew members, passengers lack knowledge and evacuation training regarding marine accidents that it is hard to make voluntary and reliable decision on paths of evacuation in case of an emergency. Moreover, evacuation on a ship is different from other buildings because ships' movements are affected by waves and other weather elements. Thus, techniques need to be developed to improve evacuation skills of passengers unfamiliar with on-board life to be prepared for marine emergencies.

Literature Review

Walking is the basic skill in evacuation, which can be measured in three dimensions: speed(m/s, in/min, km/hr), stride(m, cm), and the number of steps(step/s, steps/min). Among them, speed is most important in evacuation. Walking speed is usually studied in actual walking experiments, and it varies by a person's features(e.g. age, gender), spatial characteristics(e.g. horizontal, vertical, large space, corridors)[2),3)]. IMO(International Maritime Organization) presented standard walking speed by passengers' age groups and moving paths to assess evacuation capacity and effectiveness on a particular ship[4)]. Hwang(2013) conducted research on walking speed on ship for people in their 20s who are not familiar with onboard life, in terms of horizontal and vertical moving, as well as moving in a group. He argued that walking speed changed by 27.2% by a ship's movement, and in a group moving, the speed difference between a front group and a back group was 50% due to intervention[5)]. Yoshida(2001) conducted research on the impact of a ship's rolling and pitching on walking speed, and reported that the shorter the cycle of these movements, the slower the walking speed[6)].

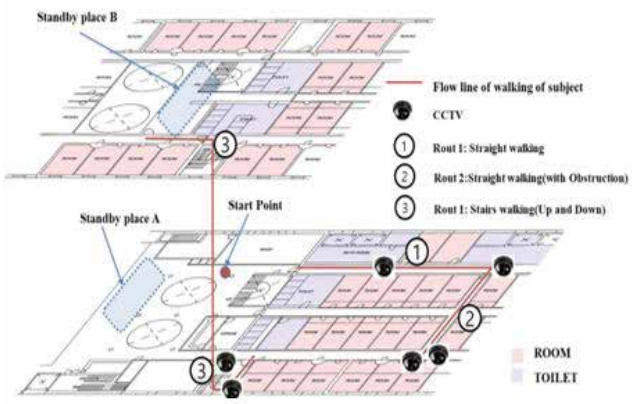
Materials and Method

Overview of cruise ship and experiment conditions: For this research, a 21,535 ton Ro-Pax cruise ship was examined that can accommodate 681 passengers. And weight of this cruise ship is GRT: 9,690ton and DWT: 4,249 ton. Volume of ship is 160m×25m×13.5m. The cruise ship harbors various lodging facilities, performance halls, convenience stores, bathing facilities, singing lounges, restaurants, lounges, and souvenir shops; programs include various performances and firework show. Accordingly there is a heavy traffic along the paths of the ship, and bottlenecks are observed at narrow paths and entrances at certain hours.

To assess the ship's movement, its rolling and pitching was measured at the horizontal plane of the ship's central part where it can be observed. The mean ship-motion of the experiment was Yawing(X): 286.19[degree], Pitching(Y):3.91[degree] and Rolling(Z):2.27[degree]. During the operation of the ship, the pitching and rolling fluctuation angles excluding the midnight time zone were measured as ± 1 ° and the fluctuation period was 5 to 15 seconds. And the weather was clear and the average wind conditions were 5 ~ 6m/s and the wave height was 1 ~ 1.5m.

Overview of experiment participants: Cruise ship passengers participated in the experiment to measure walking speed of people unfamiliar with onboard life, and crew members were not included. A total of 79 passengers participated(22 males, 57 females). The composition of the participants reflected the characteristics of Korean ship use. In Korea, there are many older users, and the percentage of women is high. Therefore, the participants in this experiment consisted of 15 people in their 60s, 20 people in their 50s, 20 people in their 40s, 16 people in their 20s and 30s, and 8 people in their teens. They did not participate in more than one experiment. And participants are not a crew members and they are inexperienced in shipboard life on a passenger ship.

Method and scope of experiment: This study is a preliminary experiment to improve evacuation capacity of ship passengers unaccustomed to onboard life, and main paths of a cruise ship were examined, which are used for evacuation in case of an emergency.



Route ① **Route ②** **Route ③**

Figure 1: Passenger moving route and CCTV installation location

Passengers' walking speed was measured for horizontal and vertical (both upward and downward) movements when the ship was sailing and staying at berth. The participants were asked to walk along the horizontal section and vertical section of the three routes(①, ②, ③), and their movements were recorded by CCTV at various points(Figure 1).

The participants move one by one after measuring the body size at the standby place A. After one participant left and spent 5 minutes, was sending the next participant. Subjects who completed horizontal walking and vertical upward movement waited at standby place B. The experiment was completed by moving vertically downward again when all the subjects were in standby place B. The recorded videos were analyzed to calculate walking speed based on the distance between two baselines and the time it took to cross them. In Figure 1, Route ① indicates a horizontal section for straight walking, Route ② indicates a horizontal section with obstacles, and Route ③ indicates a vertical section for climbing up and down the stairs. Route ① is an open-ended section for horizontal walking and the participants will move horizontally in a straight line. The total distance of Route ① is 20.35 m, and the effective width is 1.18m in the movable space. Route ② is a section for horizontal walking, where it is partly narrowed due to obstacles. The total distance of the route 2 is 10m, and the effective width is 1.18m in the movable space. However, for the route 2, the distance where it is partly narrowed due to obstacles is 3m and effective width of reduced due to an obstacle is 0.8m. Route ③ is a vertical section for climbing up and down the stairs. The movement distance at the stairs is 4.98 m, and the effective width of the stairs is 1.19 m. The participants can use the handrails in stairs. Participants in the experiment started one by one to measure the individual move time and started the next participant after a sufficient time after departure. After walking on the horizontal movement section, the participant passes through the horizontal movement section with the obstacle, and the vertical upward movement is performed through the staircase. After all the participants completed the vertical upward movement, they were moved vertically downward one by one in the waiting place.

Results and Analysis

Horizontal Walking: Horizontal walking was examined when the cruise ship was at berth and at navigation. Figure 2 shows average walking speed, frequency and normal distribution for Route ①.

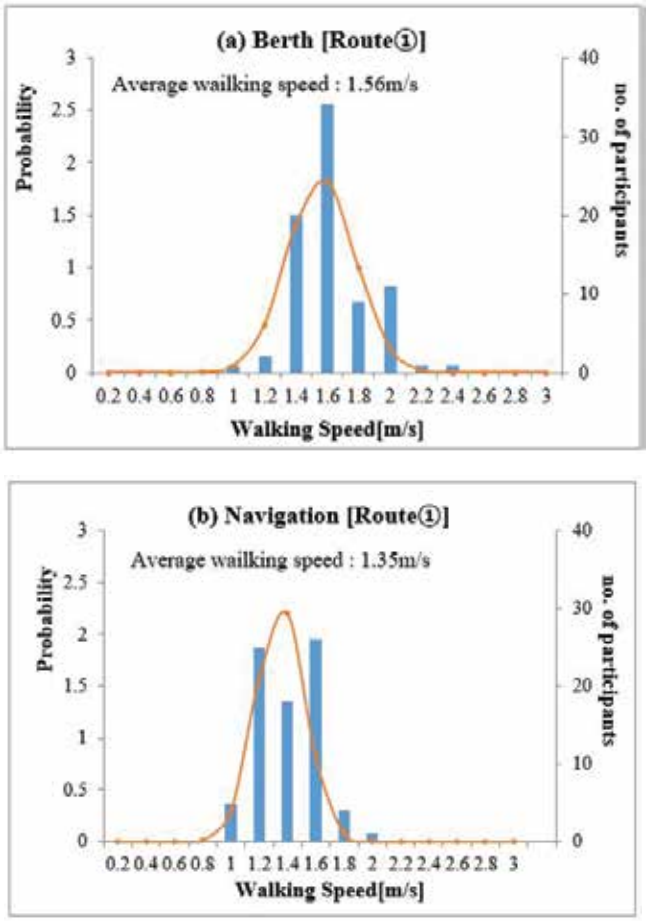
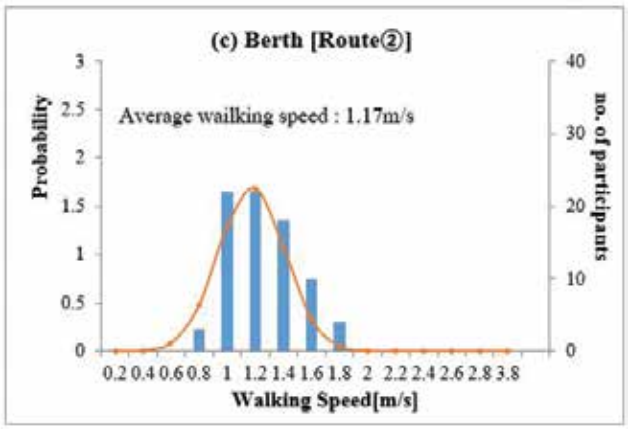


Figure 2: Horizontal Walking speeds on Route①

At Route ①, the average walking speed was 1.56m/s when the ship was at berth, and 1.35m/s at sea, or a 13.5% drop due to movements of the ship.

Figure 3 show walking speed for Route ② that is partly narrowed with obstacles. The average walking speed was 1.17m/s when the ship was at berth, and 1.07m/s at sea, a smaller drop of 9.5% in speed.



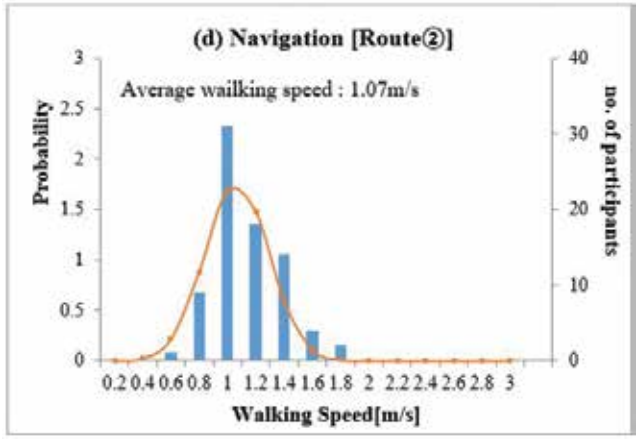


Figure 3: Horizontal Walking speeds on Route ②

Compared to Route ①, walking speeds both at berth and at sea slowed down on Route ②, each by 25% and 20.7%, indicating that the obstacles had even greater impact on walking speed than the ship's movement. Dispersion was greater for Route ② than for Route ①, indicating that passengers could not walk as they usually did due to obstacles. Then the participants' walking speed was compared by age and gender (Table 1).

For horizontal walking, walking speed was slower for all age groups when the ship was sailing than at berth. At berth, walking speed was the lowest for participants ages 60 and over at 1.47m/s, and the highest for participants ages 20 to 39 at 1.68m/s.

When the ship was sailing, the difference of walking speed across age groups was relatively smaller, indicating that physical ability had greater influence on walking speed when the ship was at berth.

Table 1: Walking speed was compared by Age and Gender (m/s)

Age	Gender	Route①				
		Berthⓐ		Seaⓑ		ⓐ-ⓑ
Over 60	Female	1.38	1.47	1.36	1.97	0.03
	Male	1.56		1.38		0.18
50~59	Female	1.49	1.55	1.33	1.33	0.17
	Male	1.61		1.33		0.29
40~49	Female	1.56	1.57	1.41	1.35	0.16
	Male	1.58		1.30		0.29
20~39	Female	1.56	1.68	1.29	1.38	0.28
	Male	1.81		1.43		0.39
Teenager	Female	1.54	1.70	1.31	1.36	0.25
	Male	1.83		1.45		0.50

Conted…

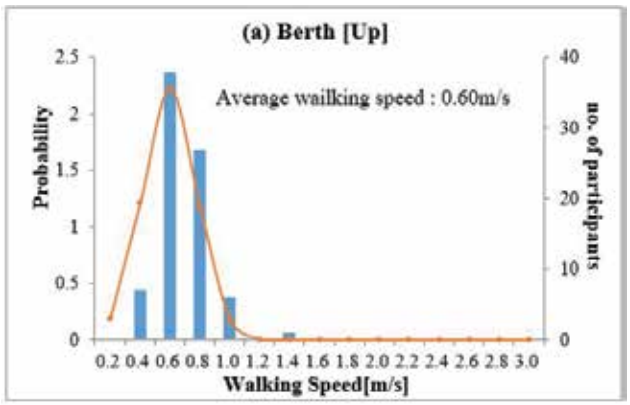
Age	Gender	Route ②(Obstruction)				
		Berthⓒ		Seaⓓ		ⓒ-ⓓ
Over 60	Female	1.06	1.12	1.10	1.04	-0.04
	Male	1.18		0.97		0.21
50~59	Female	1.11	1.12	1.03	1.01	0.08
	Male	1.14		0.98		0.16
40~49	Female	1.20	1.19	1.07	1.09	0.13
	Male	1.18		1.11		0.07
20~39	Female	1.24	1.31	1.09	1.11	0.15
	Male	1.39		1.13		0.26
Teenager	Female	1.06	1.34	0.87	1.19	0.19
	Male	1.63		1.50		0.13

In other words, when the ship was sailing, its movement did not affect people's walking speed by their age as much. By age, male participants' walking speed on Route ① was 1.7m/s, compared to female participants' 1.51m/s when the ship was at birth. When the ship was sailing, they each was 1.34m/s and 1.38m/s. Men walked faster than women, and the gender difference was not significant when the ship was sailing. On Route ②, walking speed was 1.3m/s for men, 1.14m/s for women when the ship was at berth; when the ship was sailing, it was 1.14m/s and 1.03m/s, respectively.

The speed difference depending on the ship's state was relatively smaller for women, indicating that men's walking speed was more affected by the ship's movement.

Vertical walking: Vertical walking experiment was done on Route ③ for when the ship was at berth and at navigation. Figure 4 show the participants' average

walking speed, frequency of walking speed and normal distribution when climbing up the stairs. When the ship was at berth, participants' average walking speed was 0.6m/s when climbing up. When the ship was sailing, it was 0.57m/s, respectively. In the case of the upward movement, the was similar results as the average walking speed of moving in a general building.



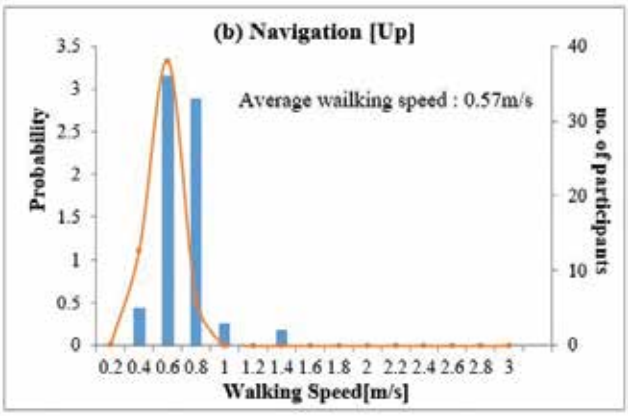
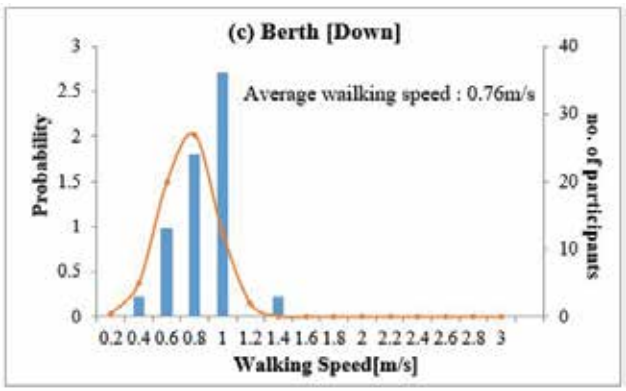


Figure 4: Upward walking speeds on Berth and Navigation

Figure 5 shows participants' average walking speed when climbing down the stairs. When the ship was at berth, participants' average downward walking speed was 0.76m/s and when the ship was sailing, it was 0.71m/s.



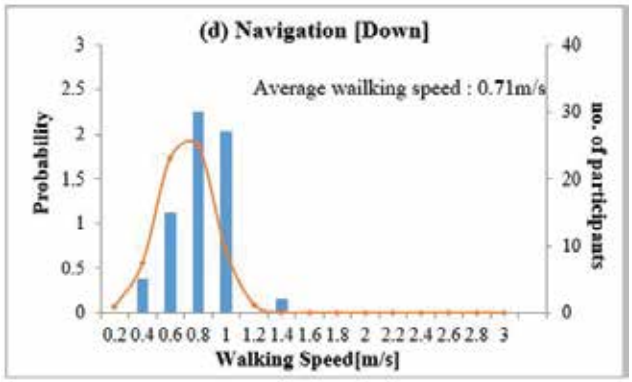


Figure 5: Downward walking speeds on Berth and Navigation

For vertical walking, the speed was about 20% faster for downward movement both when the ship was at sea and at berth. Walking speed was slower when the ship was sailing, but the difference was smaller compared to horizontal walking. This suggests that a ship's movement has less impact on vertical walking on the stairs compared to horizontal walking. Another observation is that dispersion was greater for downward walking speed than for upward walking speed, indicating that the participant's walking ability varied more widely for downward walking. And the older participants were more likely to use the handrails on the stairs.

Vertical walking speed by age and gender compared the participants' walking speed for vertical walking by age and gender. The speed was the lowest for the participants ages 60 and over and the highest for teenagers. For participants ages 60 and over, upward and downward walking speeds were similar, but as the age got lower, downward walking speed increased faster than upward walking speed.

Conclusion

For this study, passengers unaccustomed to on-board life, who cannot easily grasp a marine emergency and not familiar with internal space of the ship, participated in an experiment to measure their walking speed when the ship was at berth and at sea.

It is a preliminary study to minimize casualty in case of a marine accident, and produced the following findings.

- For horizontal walking, participants' walking speed dropped by 13.5% when the sea was sailing than when at berth, but the drop was smaller for vertical walking.

- For horizontal walking, participants' walking speed dropped sharply both when the ship was at berth(25%) and at sea(20.7%) in a section that is partly narrowed with obstacles, and the stride width significantly affected walking speed.
- For vertical walking, downward walking was 20% faster than upward walking for both when the ship was at sea and at berth, and the ship's movement did not significantly affect vertical walking on the stairs.
- For vertical walking, participants' physical ability had more impact on downward walking than upward walking.
- By age, participants ages 60 and over moved at the slowest speed for both horizontal and vertical walking.
- For horizontal walking, the ship's movement had relatively less impact on participants' walking speed by age when the ship was at sea compared to when at berth.
- As the participants' age got lower, downward walking speed increased faster than upward walking speed, but both speeds were similar for participants ages 60 and over.
- By gender, men walked faster than women in both horizontal and vertical walking.
- For horizontal walking, speed difference between gender was smaller when the ship was at sea, and men's walking speed was more influenced by the ship's movement.

In this study, an experiment was conducted on cruise ship passengers' walking speed. Further research needs to be done on passengers' evacuation speed in a simulation of a marine accident such as fire, with additional study on pre-evacuation time in consideration of sleeping facilities within a ship.

Ethical Clearance: Not required

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Conflict of Interest: Nil

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