Research on the Relationship between Awareness and Heart Rate Changes in the Experience of Safety Education Materials Using VR Technology

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Abstract –

The response of subjects having experienced VR content for safety education was confirmed by their heart rate. Ten male subjects with work experience in construction and ten without such experience used VR content for safety education. The subjects were allowed to walk through scaffolding which was defective in five facilities in that content. Their heart rates were measured, both at rest and during the experience, whereupon they were interviewed about their awareness during said experience. Following this experiment, it was suggested that there were some VR content for safety education to which subjects with work experience reacted only.

Keywords –

VR; Safety Education; Heart rate; Human factor

1 Introduction

Compared to other industries, the construction industry has more occupational accidents and safety education has been implemented in various forms for some time. Materials used vary from those commonly distributed in print, such as books and pamphlets, to videos and presentation materials created independently by each company or workplace. Conversely, declining numbers of skilled and inexperienced workers and foreign workers in recent years have raised expectations of new safety materials that are independent of experience or language. In this study, we focused on experiential teaching materials using VR technology and used physiological sensing technology to quantitatively confirm the response of the experimental subjects and examine the relationship between HR changes and awareness or feeling of fear.

2 Previous Studies and This Purpose

2.1 Previous Studies

Takagi's previous research examined safety materials used in construction companies and their effects, pointing out the mainstream of the so-called 'learning type' such as paper materials, DVD videos and discussions and doubts over their scope to effectively prevent crash disasters [1]. In previous research on the use of VR content, the "experiential" educational material focused on in this study, Ito et al. reported significant individual differences in the standard deviation of heart rate (R-R) intervals during the experience, as well as differing trends between males and females [2][3].

2.2 Purpose of this Study

VR contents have been published or sold by the Ministry of Health, Labour and Welfare [4] and private companies [5] in Japan. It is described that VR contents are characterized by their ability to provide an immersive, near-real experience in those HP. As in previous research [2][3], individual differences emerge in user responses, even for game content, which may mean differences emerging obtained in VR contents. We hypothesized that VR experience for safety education would have different tendencies depending on the presence or absence of work experience, and that difference would appear in the heart rate. In this research, we aim to verify this hypothesis by conducting an experiment in which multiple subjects use VR contents, and discussing differences in trends by interviewing them and measuring their heart rates.

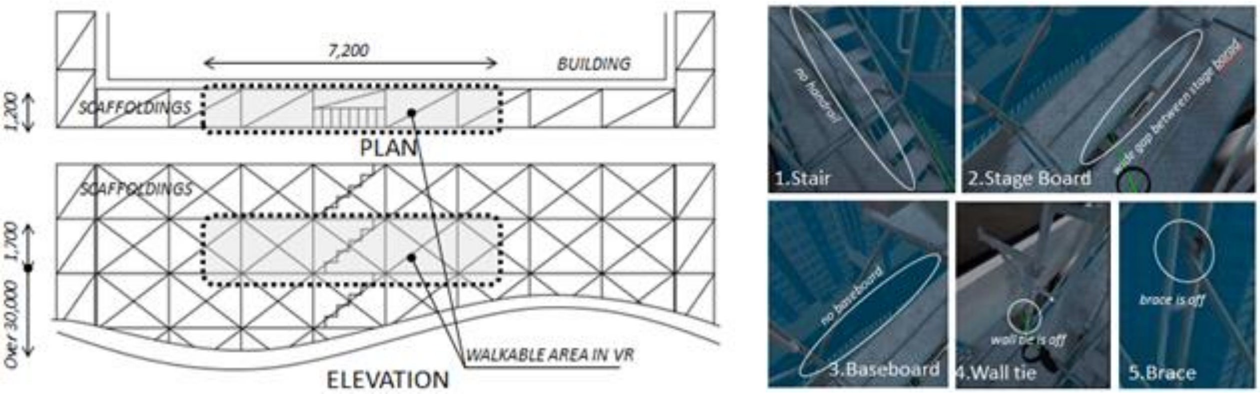


Figure 1. Image example of safety teaching materials using VR

3 Method of hypothesis verification

3.1 VR content used as the subject

In this study, the subject was a walking experience in a VR space of a temporary scaffold installed outdoors and at elevation in order to use the presence or absence of construction management experience as an evaluation index. During the experiment, it is assumed that work to inspect safety equipment is being carried out and the different between subject groups in terms of the sense of danger and reaction to the defective part is examined. Commercially available products are used for the content, which highlights deficiencies in five safety facilities (1. stairs, 2. scaffolding boards, 3. baseboards, 4. wall ties, 5. braces) (Fig. 1).

The movable range within the content is shown in Fig. 1, left. It is one layer of the upper part of the temporary scaffolding, which includes steps in the scaffolding and crossings to the main building. In the experiment, the walkable area was about two rows of scaffolding boards x four spans (W 1, 200 x L 7, 200). Defects in equipment were not mentioned at the start of the experiment and each person was capable of walking freely and performing visual checks.

3.2 Indicators to quantify subject response

In this study, the heart rate is measured to quantitatively capture the unconscious biological response that occurs during a VR experience. Since the heart rate changes immediately compared to the body temperature and other physiological responses, we deemed it suitable to evaluate an experience experiment like this one. In previous research [3] as mentioned above, the purpose was to use the heartbeat to quantify the comfort level or discomfort, etc. Accordingly, if a professional analysis using electrocardiographic data were required, measurements with electrodes placed on the chest would be performed. Conversely however, since this research aimed to detect the presence or absence of biological reactions, with the need for safe measurements that would leave the movement of subjects in the experiment unhindered, heart rate as a

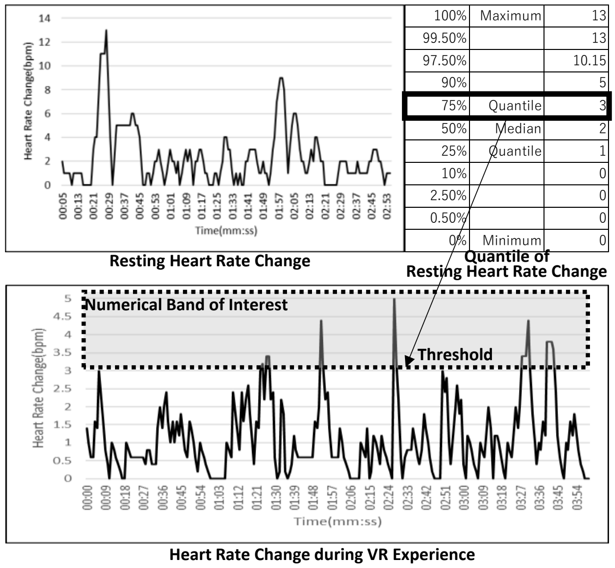


Figure 2. Heart rate analysis method

Table 1. Equipment list

HMD	OculusQuest2(FacebookTechnologies,LLC）
VR contents	Safety VR Experience Training (Tsumiki Seisaku Co., Ltd.)
HR sensor	A370（Polar Electro）

parameter estimated from the pulse taken at the wrist, etc., was adopted and wristwatch-type devices were selected.

The methods used to determine whether or not a reaction occurred during the experience were as follows: During the experience, heart rate changes over time were recorded, whereupon the absolute value of the change was used as an indicator to determine whether or not a reaction occurred at the threshold. The amount of change in heart rate was taken as the absolute value of a 5-second moving average, referencing the report of Hirota et al. [4]. To detect false responses, Hirota et al. measured heart rate variability during a question and answer session and found some changes having emerged between 5 and 20 seconds had elapsed since the response. In this study, the minimum value of

5 seconds was assumed to be the time required for heart rate variability to occur from the perception of danger. The threshold was based on the resting heart rate of each experimental subject, taking individual differences in heart rate variability into account. In the absolute value of heart rate variability at rest, the third quartile was used as the threshold and any scenario involving an amount of change that exceeded that threshold confirmed during the experience was deemed "significant change."

3.3 Selection of subjects for the experiment

To confirm differences in experiential effects, similar experiments were conducted on two groups: A: subjects with practical construction work experience and B: subjects without any practical experience. There were ten participants in each group, for a total of 20 and considerations were made to ensure the overall analytical results were not impacted by the unique data of some of the experimental subjects. The group A comprised construction managers at a construction company and B comprised students. Only men were surveyed in this study because previous studies exposed differing trends between men and women in terms of heart rate responses when experiencing VR content[3].

Photo 1. Subject wearing devices

Table 2. Background of subjects

experienced subjects	experience of VR game	years of work	inexperienced subjects	experience of VR game	experience of walking on scaffoldings
subject1	×	2	subject11	×	○
subject2	○	15	subject12	○	○
subject3	×	15	subject13	×	×
subject4	×	6	subject14	×	×
subject5	×	6	subject15	×	×
subject6	×	7	subject16	×	×
subject7	○	22	subject17	○	×
subject8	×	16	subject18	○	×
subject9	×	2	subject19	×	○
subject10	×	4	subject20	×	○

3.4 How the results were analyzed

①The relationship between heart rate variability and VR content

The VR content or specific behavior at the time of significant variation in heart rate was identified and any differences emerging between the groups considered.

②Relationship between Heart Rate Variability and Subjective Feedback

Immediately after the VR experience, the subjects were interviewed to determine their subjective awareness and changes in their feelings during the experience. The interview method was based on a study by Sukegawa et al. [6] that revealed the tacit knowledge of experienced carpenters based on protocol analysis and the subjects were shown videos of their own VR experiences, asked to verbalize wthat they felt thoughts in each scene and their keywords were recorded. The relationship between this subjectivity and heart rate variability was then discussed.

4 Overview of the validation experiment

4.1 Equipment used

Details of the head-mounted displays (Below: HMD),

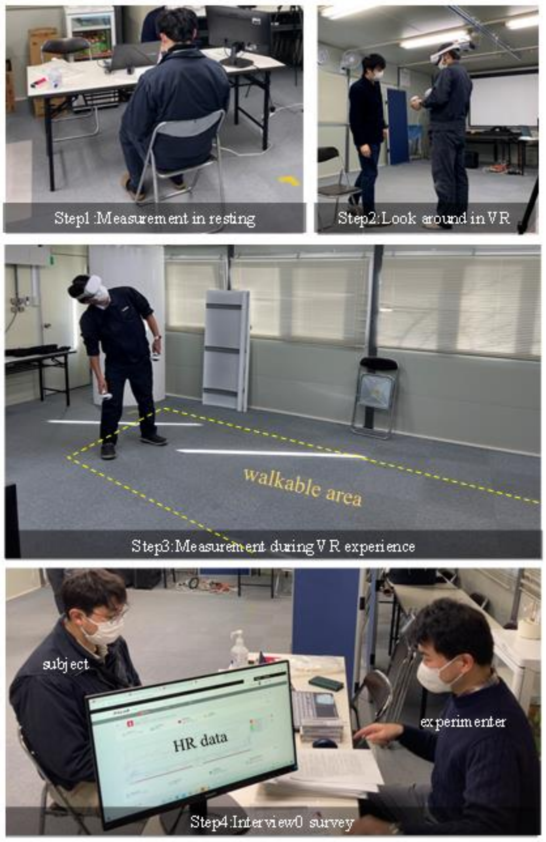


Photo 2. State of VR experiment

VR content and heart rate monitors used are listed in Table 1. The data recording interval was set at 1 Hz, the minimum value specified in the product specifications.

4.2 Experimental summary

The subjects, date, place and procedure of the experiment conducted are described below.

① Subjects, date and place of the experiment

[Group A: No work experience]

- (Subjects)10 male supervisors working for a general contractor
- (Dates)December 17 and 24, 2021
- (Venue)Shibaura Institute of Technology, Toyosu New Campus, Construction Office

[Group B: Work experience]

- (Subjects)10 male students majoring in architecture in a master's degree program
- (Dates)September 22, 2021
- (Venue)Shibaura Institute of Technology, Toyosu

② Experimental procedure

The experiment was performed for each experimental subject according to the following procedure. STEP 2 was set as a break-in time to calm tension, surprise, etc. To show subjects a video of their own experience in STEP 4, VR images reflected in the HMD were captured in STEP 3. In STEP 4, the subjects were asked to verbalize what they had been feeling about in each scene while displaying a video of their VR experience and a heart rate graph on the monitor screen and recorded it in writing. To understand the subjects' knowledge and the context behind their actions, they were asked about their experience walking on temporary scaffolding for those with no experience in practical work, their years of experience for those with practical work experience and their experiences using VR , etc.

- STEP 1: A heart rate monitor was worn and the resting heart rate while seated was measured (5 minutes)
- STEP 2: An HMD was worn and VR content was surveyed while standing (1 minute)
- STEP 3: The subjects were free to walk around and visually inspect the experience area (3 minutes)
- STEP 4: Face-to-face subjective feedback

5 Experimental results

5.1 Experience situation

During the VR content experience, the experimental subjects walked evenly through the walkable area of the content and scanned the VR space. Some of the experimental subjects also checked areas at elevation or squatted down to look at their feet.

5.2 Heart rate measurement results

The median resting heart rate was 62 ~ 104 and resting heart rate variability was 0 ~ 13, confirming individual differences. The third quartile of heart rate variability for each subject in the experiment was either 2 or 3, with these figures used as thresholds to distinguish between large and small heart rate variability during the experience. Figure 3 shows a graph of the 5-second moving averages in heart rate variability during the experience measured for each subject in the experiment, showing where the thresholds were exceeded. All heart rate variability exceeding the thresholds constituted changes on the rising side.

When the groups with and without work experience were compared, heart rate varied significantly at a median of 3.5 sites in the experienced group and 0.5 sites in the inexperienced group, with a tendency for the experienced group to have greater heart rate variability.

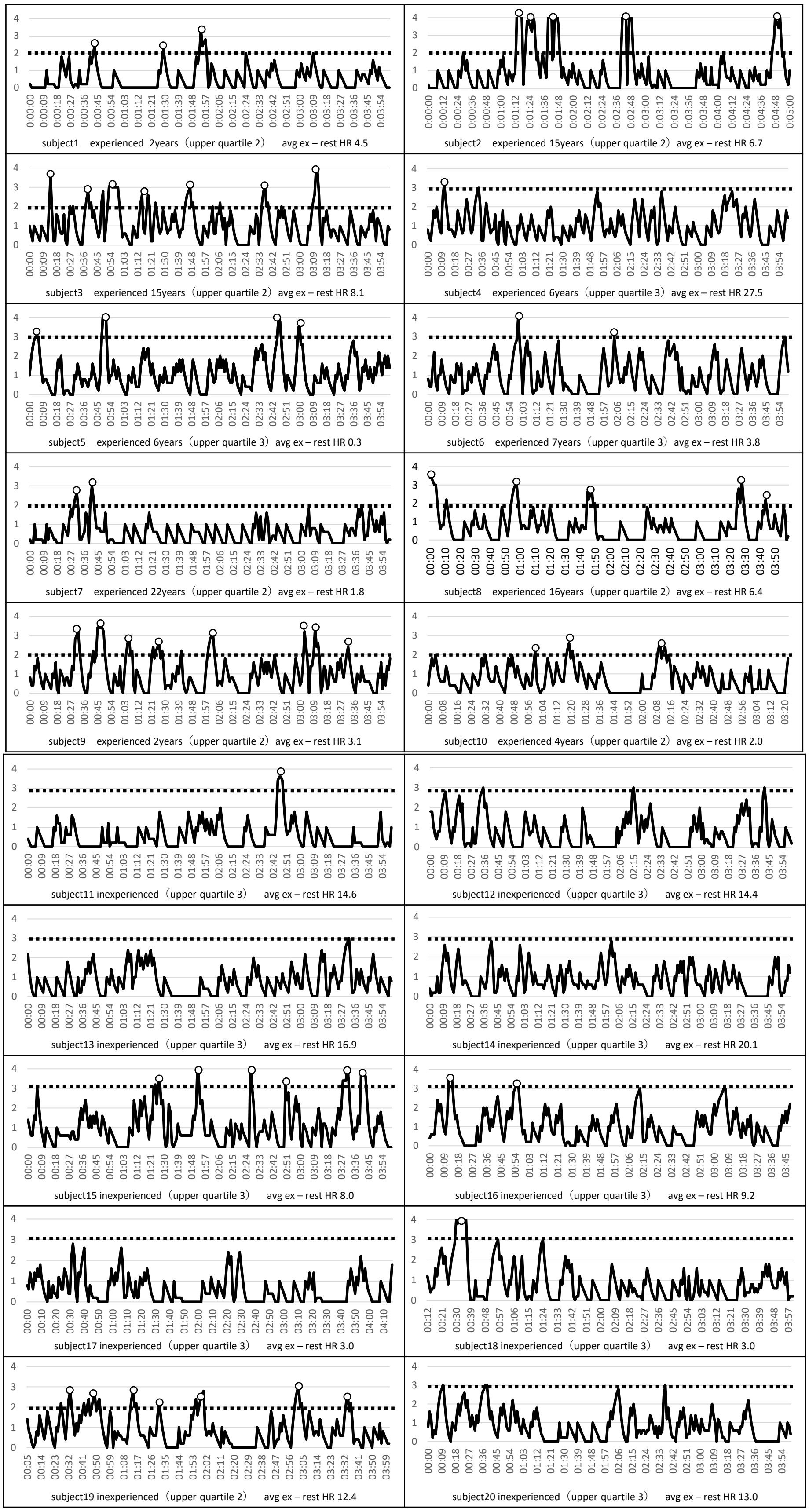
5.3 Feedback Results

First, the results of background interviews related to subjects' knowledge and behavior are shown in Table 2. Among the inexperienced workers, there were both subjects with and without experience walking on scaffolding. The years of work of the experienced subjects ranged from 2 to 22 years. Some subjects had experience using VR games, etc., while others did not.

Feedback on what was noticed and felt during the experience could be broadly divided into ①locations where fear was perceived during this experience and ② deficiencies in safety equipment noted in VR content

①The location where they felt fear the most was around the stairs, in which 7 out of 10 subjects with practical experience and all 10 subjects without pratical experience felt fear. Subjects without pratical experience were not frightened elsewhere. 5 subjects with practical experience felt fear around the defective scaffolding board, and 3 subjects felt fear while checking the inter-layer net.(Table 2)

②The number of places in which inadequacies in the safety equipment in VR content were noted varied considerably between those with and without practical experience respectively. Several experimental subjects proposed improvements to the installation status of interlayer and shatterproof nets as well as the five facilities that were intentionally flawed in the contents. For the total of seven points pointed out, those with practical experience noticed a median of 5.5 points, while inexperienced people noticed a median of 2.0 points.(Table 3)



(Legend) Vertical axis: HR change (HR at relevant time－average HR for the last 5s [bps]), horizontal axis: elapsed time (mm:ss)
……: Threshold for judging the magnitude of change in HR (resting HR 75% quartile), ○: Point exceeding the threshold

Figure 3. Changes in HR

Table 3. Location where subjects felt fear or noticed defective equipment

			Defective equipments					Other equipments	
	subjects	fear/noticed HR Change	Stairs	Stage board	Baseboard	Wall tie	Brace	Interlayer net	Anti-scattering net
experienced	subject 1	fear	○	○	×	×	×	○	×
		noticed	○	○	○	○	×	○	○
	subject 2	fear	○	○	×	×	×	×	×
		noticed	○	○	○	○	○	×	○
	subject 3	fear	×	×	×	×	×	×	×
		noticed	○	○	○	○	×	○	×
	subject 4	fear	×	×	×	×	×	×	×
		noticed	○	×	○	○	×	○	×
	subject 5	fear	○	×	×	×	×	×	×
		noticed	○	○	○	○	×	○	○
	subject 6	fear	○	×	×	×	×	×	×
		noticed	○	○	×	○	×	×	○
	subject 7	fear	○	○	×	×	×	×	×
		noticed	○	○	×	○	○	×	○
	subject 8	fear	○	○	×	×	×	○	×
		noticed	○	○	○	○	×	○	○
	subject 9	fear	○	○	×	×	×	○	×
		noticed	○	○	○	○	○	○	○
	subject 10	fear	×	×	×	×	×	×	×
		noticed	○	○	○	○	○	×	×
inexperienced	subject 11	fear	○	×	×	×	×	×	×
		noticed	○	○	○	×	×	×	×
	subject 12	fear	○	×	×	×	×	×	×
		noticed	○	○	×	×	×	×	×
	subject 13	fear	○	×	×	×	×	×	×
		noticed	○	○	×	×	×	×	×
	subject 14	fear	○	×	×	×	×	×	×
		noticed	○	○	○	○	○	×	○
	subject 15	fear	○	×	×	×	×	×	×
		noticed	○	×	×	×	○	×	×
	subject 16	fear	○	×	×	×	×	×	×
		noticed	○	×	×	×	×	×	×
	subject 17	fear	○	×	×	×	×	×	×
		noticed	○	×	×	×	×	×	×
	subject 18	fear	○	×	×	×	×	×	×
		noticed	○	○	×	×	×	×	×
	subject 19	fear	○	×	×	×	×	×	×
		noticed	○	○	×	×	○	×	×
	subject 20	fear	○	×	×	×	×	×	×
		noticed	○	×	×	×	×	×	○

5.4 Comparison of Heart Rate Variability with VR Content and Subjectivity

Next, we checked the location of the VR content that the experimental subjects were viewing during the time period when heart rate variability could be confirmed. We also compared the results of feedback to confirm any VR content associated with a change in awareness or sentiment, even when the heart rate remained unchanged. A table showing heart rate variability and the presence or absence of awareness by type of safety equipment in the VR content is shown for each experimental subject (Table 4).

When the relationship between heart rate variability and the location of the VR content was examined, heart rate variability around stairs was the most common in the faulty safety equipment, occurring in nine out of ten of the experienced group and five out of ten inexperienced participants. There were five experienced and two inexperienced participants in the scaffolding boards, two experienced participants in the wall connections and no other changes. In other areas, in the safety equipment noted by the experienced participants, there were five experienced participants in the interlayer net, one experienced participant in the vertical net and HR changes. None of the inexperienced group showed any changes here. Accordingly, in terms of HR alone, those with more experience showed changes for all items.

6 Discussion

First, consider the relationship between fear and

Table 4. Location and number of changes in HR data

	subjects	Defective equipments					Other equipments		Changes in subject's posture
		Stairs	Stage board	Baseboard	Wall tie	Brace	Interlayer net	Anti-scattering net	
experienced	subject1	0	0	0	0	0	2	0	1
	subject2	1	1	0	0	0	2	0	0
	subject3	3	0	0	1	0	1	0	2
	subject4	0	0	0	0	0	0	0	1
	subject5	2	0	0	0	0	0	0	2
	subject6	2	0	0	0	0	0	0	0
	subject7	1	1	0	0	0	0	0	0
	subject8	1	1	0	0	0	1	0	1
	subject9	1	1	0	1	0	1	0	2
	subject10	1	1	0	0	0	0	1	0
inexperienced	subject11	1	0	0	0	0	0	0	0
	subject12	0	0	0	0	0	0	0	0
	subject13	0	0	0	0	0	0	0	0
	subject14	0	0	0	0	0	0	0	0
	subject15	3	1	0	0	0	0	0	2
	subject16	1	1	0	0	0	0	0	0
	subject17	0	0	0	0	0	0	0	0
	subject18	1	0	0	0	0	0	0	0
	subject19	5	0	0	0	0	0	0	1
	subject20	0	0	0	0	0	0	0	0

awareness. Distinguishing between (A) locations where at least 1 subject felt fear and (B) places where at least 1 subject pointed out deficiencies but without fear, (A) stairs, scaffolding boards, inter-layer nets (B) Baseboards, wall ties, braces, and anti-scattering nets. Judging from the interviews, this is thought to be because (A) is a location where the person concerned would be endangered and (B) is a location where others would be endangered. In the VR content, it is speculated that the impressions of the experiment subjects differed between the above two. Examining the differences between the experimental groups, a difference in trends was comfirmed, particularly in (B). In the group with practical experience, the average number of (B) was 3.9, while in the group without practical experience, the average number was 1.2. (B) is deemed content that is difficult to notice without one. (Table 5)

Next, the relationship between fear/awareness and heart rate changes was considered. We counted the number of locations where heart rate changes occurred in all experimental subjects, and sorted them into three categories: locations where fear was felt, where was only noticed without fear, and those where there was no awareness (Table 6). There were a total of 52 heart rate changes, half of which, 26, were at locations where subjects felt fear. There was no bias among the experimental groups, and all of the locations were (A) in danger for themselves. This implies that the location which generally makes everyone feel afraid of, such as simulation of heights, could feel the same in VR without depending on practical experience.

Conversely, 8 changes in heart rate were confirmed in locations where only awareness and without fear, all of which were experienced workers. Specifically, these were 4 times on the stairs , once at the scaffold board, once at the inter-layer net in (A), and twice at the wall ties in (B). For these, no difference was confirmed according to the number of years of work experience. These can be considered cases in which subjects with practical experience react strongly and unconsciously in contrast to their own senses. Therefore, this case is defined as type (C) in this paper (Table 5).

Based on the above, it can be interpreted that there is a difference in the cases where the heart rate changes depending on the presence or absence of practical experience when VR content is used. In other words, it is speculated that practical experience is subconscious, VR evokes memories, and then causes the body to respond unconsciously.

Conversely, when it comes to VR content in which a person clearly perceives a personal danger, such as when gaps emerge under his/her feet at elevation, the results of the experiments suggest that everyone could obtain similar sense regardless of whether or not they have practical experience.

7 Conclusion

In this research, a quantitative verification method using interviews and heart rate as indicators was proposed and verification experiments on experienced and inexperienced users were conducted, aiming to identify differences in experiences obtained by users of VR contents on whether or not they had practical experience. As a result, similar awareness and biological responses, regardless of whether or not they had practical experience with content that made them feel fearful, were confirmed. Conversely, experiences that only those with practical experience could obtain with content that did not make them feel fearful were confirmed. There were cases in which the subject recognized it and cases in which individuals reacted unconsciously. In future, we will use this knowledge to explore how to use VR contents more effectively and propose ways to select materials that are more effective

Table 6. Relationship between HR changed and subject consciousness (number of times)

HR changed or not	group	subjects' consciousness: noticed and felt fear	noticed only	not noticed
HR changed	ex	15	9	12
	in-ex	11	0	5
HR not changed	ex	2	31	-
	in-ex	5	14	-

Table 5. Number of subjects noticed defective equipment or felt fear

subjects' consciousness	group	(A)location in danger for themselves: Stairs	Stage board	Interlayer net	(B)location in danger for others: Baseboard	Wall tie	Brace	Anti-scattering net
noticed and felt fear	ex	7	5	3	0	0	0	0
	in-ex	10	0	0	0	0	0	0
noticed only	ex	3	4	3	8	10	4	7
	in-ex	0	6	0	2	1	3	3
not noticed	ex	0	1	4	2	0	6	3
	in-ex	0	1	10	8	9	7	7

(C) Unconscious change in HR [8 number of times / 3 subjects] in practice, in conjunction with educational methods other than VR.

This research was conducted with the approval of the Bio-engineering Research Ethics Review Committee of the Shibaura Institute of Technology (No. 21069, August 19, 2021). This experimental subjects were informed of the contents of this experiment in advance and their approval was obtained before this experiment.

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