ORIGINAL ARTICLE

Human factors evaluation in VR-based shunting training

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Abstract

Shunting of trains is a task that requires meticulous adherence to all steps to guarantee safety for everyone involved during and after the procedure. These steps are currently taught using classical teaching materials, such as printouts, videos and training by experienced supervisors. However, due to limited availability of locomotives, hours for training and manpower, training of shunting operation becomes challenging in real life. In this paper, we implemented a lifelike, collaborative virtual environment for shunting training including a novel human factors evaluation system for fatigue and stress monitoring. An experiment with 12 subjects and 3 trainers has been designed and carried out to validate the usage of VR-based shunting training. Positive feedback toward the VR-based training was obtained from the subjects and trainers.

Keywords Virtual Reality · Human factors · Non-technical skills · Shunting · Training

1 Introduction

Shunting of engineering trains is a safety–critical activity as it involves collaborative maneuver of large trains in confined spaces, and the speed of trains has to be well controlled [1]. Various skills such as communication, decision-making, collaboration, coping with fatigue and technical knowledge are required in the shunting of engineering trains, without which, the possibility of human errors increases and is a major cause of 'crush' fatalities occurring each year in the transport industry [2]. Hence, it is essential to ensure that the operator has mastered these skills and knowledge, and that he/she became competent to conduct the shunting of engineering trains. Generally, effective training contributes significantly to the operators' competency and safety in rail industries [3].

There are numerous ways to provide training with both theory and practical elements to improve the competency of both novice and experienced operators. They can be broadly divided into two types, namely on-the-job and off-the-job training [4]. On-the-job training refers to the formal training where the operators acquire specific skills during working. Off-the-job training is normally conducted in specific environments using the same or similar tools to simulate how the regular job is done. The off-the-job training can be conducted via conferences, lectures, workshop, seminars, etc. [5].

However, due to the nature of railway, training of shunting operation via either on-the-job or off-the-job way is challenging in real life. On one hand, the safety–critical concern of shunting the engineering train requires the operators to be well trained before working on-the-job. On the other hand, limited availability of locomotives, training hours and manpower decreases the efficiency of off-the-job training in real life. To address these problems and provide an alternative way for shunting training, we implemented a lifelike, collaborative virtual environment for shunting training including a novel human factors evaluation system. Virtual Reality (VR) technology has been infused into education/training recently, as it provides a safe yet realistic environment which allows operators to undergo the training in an immersive manner. Nevertheless, VR technology has several restrictions in providing feedback to user actions, leading to impaired user experience. To provide feedback to user actions, a method was adopted to visualize user actions via

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analyzing functionality and behavior of interactive parts. Together with the VR training, the proposed human factors evaluation system can monitor the fatigue and stress level in real-time and provide an overall monitoring report about the fatigue/stress level experienced by the user, which could be used to correlate with the performance of the user during the shunting training. An experiment with 12 subjects was designed and carried out. A set of questionnaires was distributed to the subjects to get feedback about the VR-based training, and the corresponding results have been analyzed, which showed positive support for the use of VR in training shunting operations.

The rest of the paper is organized as follows: Sect. 2 presents literature review on VR-based railway operation training and human factors study in railway. In Sect. 3, the overall system design and implementation are introduced. An experiment to validate the training system and the collected user feedback are presented in Sect. 4 and Sect. 5, respectively. Section 6 concludes the study with discussions about the limitations and future works.

2 Related works

2.1 VR-based railway operation training

VR is a useful tool that enables railway operators to receive training in a safe yet realistic environment, learning the skills necessary to conduct operations in the real world. Much effort goes into creating credible mechanics that simulate the real world closely. Guan et al. [6] described how traction and braking operations can be mathematically simulated in VR, providing a realistic scenario for train operations.

A study in [7] utilized augmented reality (AR) to simulate locomotive dashboard and controls for driver training in scenarios ranging from normal operation to emergency stop procedures. However, there could be certain limitations by using AR. For example, fixed physical markers placed on a surface are required to generate the virtual train cockpit which would require either a) a dedicated physical space for the cockpit or b) time to set-up the space for each training session. A full VR solution would have the entire train cockpit reproduced within the virtual environment, circumventing these issues. A user experience study on VR training simulators conducted in 2016 and 2018 [8] reported generally positive responses to the use of VR simulator and supplementing training in virtual environment. Nevertheless, users reported relatively poor quality of the simulation, due to the resolution and control method of VR simulator.

Given the rapid advancement in technology in recent years and state-of-the-art devices such as the HTC VIVE Pro Eye which has eye-tracking integrated into the VR headset, the realism and immersion of the simulation can be improved, making such implementations increasingly feasible.

2.2 Human factors study in railway

Human factors study in the railway industry consists of evaluation on technical skills and non-technical skills. The technical skills, lacking which can potentially cause maintenance errors and failures [9], can be evaluated by performance metrics, such as behavior, error rates, response speed, reaction time and completion time when the subject is performing tasks.

Non-Technical Skills (NTS) refer to the cognitive, social and personal resource skills that complement technical skills. Learning technical skills is the first main step, and improving NTS is the key to guaranteeing efficient and safe performance. Generally, the core NTS include teamwork, leadership, situation awareness, decision making, communication, coping with fatigue, stress management, etc. To identify rail industry's requirements for the incorporation of NTS into current Competency Management Systems, Madigan [10] conducted an interview, and the results indicated the importance of training people in the support roles, in order to maximize their ability to provide individualized support and to understand the link between technical and non-technical competency.

Andrew et al. [11] developed a three-phase approach to let the operational trainers understand how to integrate NTS into training, and the three phases are namely awareness phase, practice and feedback phase and reinforcement phase. In the awareness phase, the trainers are provided with a classroom-based introduction to the concept of NTS. The practice and feedback phase focuses on the development of realistic simulator scenarios that incorporate NTS into skills development, while the reinforcement phase focuses on collating trainers' feedback from their experiences of using and assessing NTS within training and simulation exercises. Results show that this method allows creation of a group of trainers who are able to develop and deliver NTS training materials.

Takashi [12] conducted interviews to collect the non-technical error-prevention skills needed for railway drivers and designed specific situations to train these skills. For example, they found that drivers tend to apply old driving patterns to a new type of train, which could lead to potential mistakes. In order to prevent such mistakes, drivers were encouraged to increase the situation awareness by performing more checks and focus on the differences of the train types and environments.

Du et al. [13] evaluated four important NTS, which are situation awareness, decision-making, communication and self-management, in order to develop a NTS evaluation

system for railway drivers. Principle component analysis (PCA) method and structural equation model (SEM) were then used in the model to assess the reliability and validity of the NTS scale. Nayak et al. [14] investigated the development of NTS for front line managers, considering the challenges for them to manage routine tasks and handle emergencies and abnormalities. The proposed generic NTS could complement their technical skill and enhance their overall managerial skills. In order to identify the most important NTS desired to improve safety of Indian Railway, Nayak et al. [15] identified 17 factors, including scientific working, recovery from error, emergency response, decision making, teamwork and so forth, through brainstorming and proposed a map of the complex relationships of these factors.

Dana et al. [16] reviewed over 150 papers about education in railway sector for both technical and non-technical skills and summarized 12 promising existing, new and emerging tools/methodologies, including e-learning, virtual/augmented reality, gaming environment and so forth.

In this paper, we describe a novel VR-based system that allows training and evaluation of stress and fatigue of railway operators that are the indicators of the most challenging tasks in training.

3 System design and implementation

3.1 VR implementation

The virtual scene for the training scenario consists of the surrounding environment, two engineering trains and a wagon. No digital data of any part are available, and all parts needed to be created from scratch.

The environment can be split into two parts, the workshop (Fig. 1a) and an area outside the workshop in the depot (Fig. 1b and c), which are created to mimic the existing ones used by the SMRT Corporation (a multi modal transport operator in Singapore). All interactive parts are replicated with high precision based on pictures and manual measurements to guarantee that all parts match reality. The interactive parts in the environment are a manually operated point machine (Fig. 1c) that switches the direction of the rails and an aspect light that signals the permission to proceed on the rail, operated by the trainers.

The wagon consists of a lifting wagon with all its connectors required for coupling it to both engineering trains. No other functionality of the wagon is required, and all parts except the ones relevant for coupling are only a visual but not functional representation. The coupling portion is the same for both trains and wagon, which moves, collides, compresses and interlocks with each other, matching the

(a)

(b)

(c)

Fig. 1 An virtual environment for shunting training. **a** The workshop area. **b** A railway outside the workshop. **c** A point machine located beside the railway for switching the direction of the rail

real system. These details are needed in certain parts of the shunting workflow and will be observed by the trainees to conclude if a certain step of the coupling process was successful.

The engineering train was recreated with the focus on replicating all details and functionality as shown in Fig. 2. Every part required in the shunting operation was first measured and documented with pictures to allow a truthful
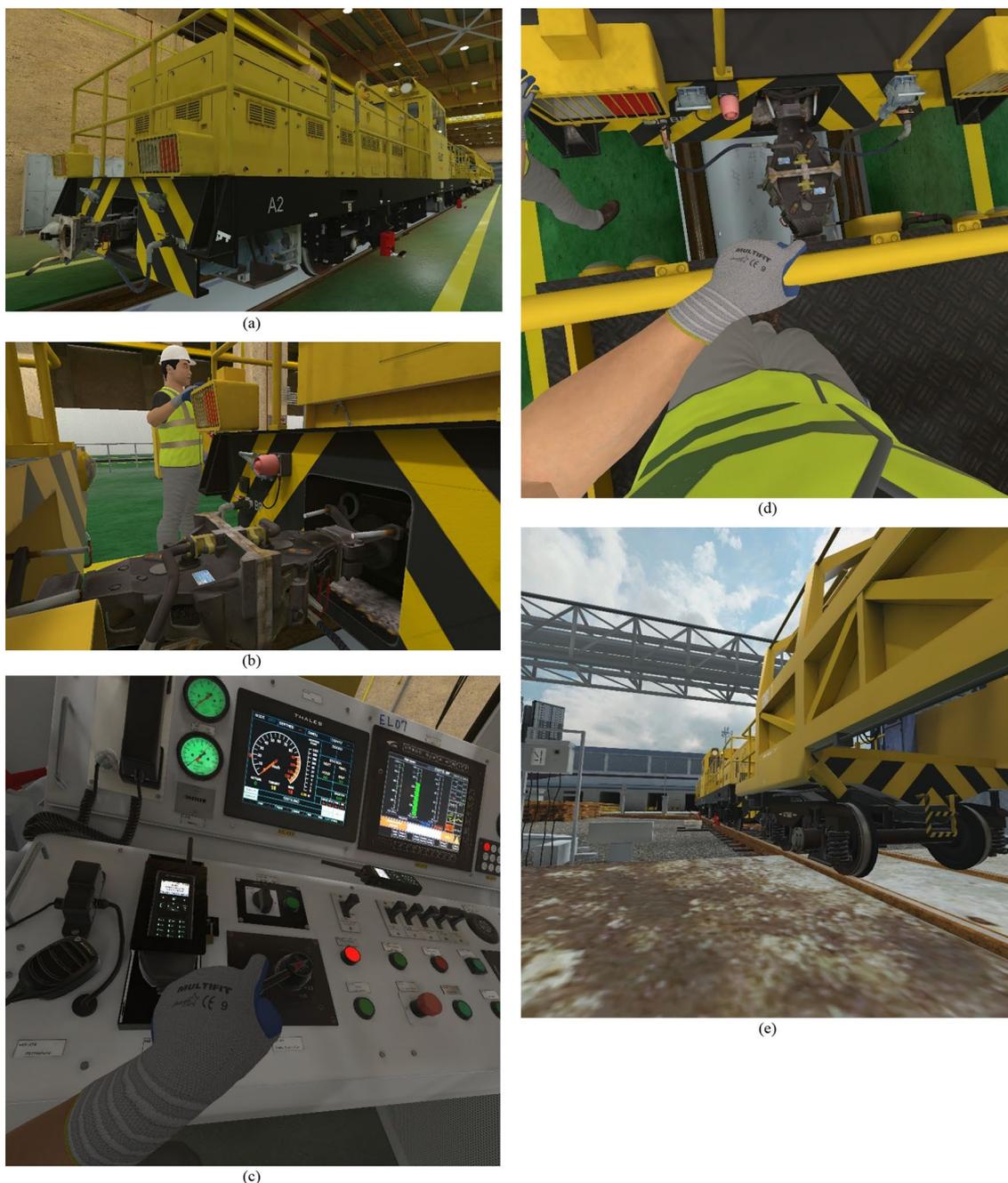
Fig. 2 An virtual engineering train. **a** The train inside the workshop. **b** An operator inspecting the train. **c** An operator grabbing the brake handle on the dashboard of the train. **d** The coupling/decoupling mechanism of the train **e** The train exiting the workshop

recreation of its virtual counterpart. The underlying system of invisible parts, such as the pressures in the pipes, has been analyzed, and a simulation system has been created that reacts to all input in the same way as would the real train for the required tasks. This includes the digital and analog systems in any part of the whole shunting procedure.

All interactive parts have been analyzed in their functionality and behavior, and for each part, the best implementation was chosen to mimic its behavior within the restrictions of virtuality, such as weightlessness or being unable to exert haptic force on the user. An example of a compromise required in VR is the insertion of a key into the keyhole. In the real world, this action is trivial, but in VR, moving a key into the keyhole without an opposing force as feedback upon collision turned out to be frustrating for the trainees. As a result, a method was

implemented that will automatically rotate and align the key while it is moved into the hole. The same method was used for putting the brake handle or the handle of the point machine into their respective holes.

Dial switches use a system that takes into account not only the angular movement of the hand grabbing it but also the turn of the wrist. Early tests showed that there are two types of users, those who move the dial switch like they were using a wrench and those who turn it like they were using a screwdriver. The implemented system considers both.

Other haptic impressions were more easily mimicked in VR, such as the airflow of the aircon, by modulating the vibration motor in the controller. Flipping switches gives a short burst of vibration in the controller as feedback that the action has been performed. Haptic feedback also allows the trainee to control the train through feeling if the position of the master control handle is above or below neutral or if the brake controller is moved into a different mode, without the need to look at the controllers.

Good immersion also requires the surrounding sounds to match the visuals. Recordings have been made that capture specific sounds such as the starting of the aircon, a hammer hitting the wheels or ambient noise of the depot. For some tasks such as turning the aircon on or checking applied brakes, the sounds need to precisely mimic reality because they are the only way to confirm if the state of the train is correct. For testing the brakes, the trainee would hit the wheel with a hammer and listen for a ringing or dull sound, which would tell if the brakes are applied (dull sound) or not (ringing sound).

Other effects that improve the immersion but have no direct impact on the scenario have been added. This includes the simulation of echo and reverb in the workshop. The electric and air horn of the train will sound louder and with more echo in the workshop, compared to the open space. All sound effects have correct locations, and the trainee can properly hear the train approaching and the direction which the air horn signal comes.

Pre-recorded audio messages are used for radio messages to the trainees in the simulation. This happens if the trainee shunts past a red aspect, in which case the trainee will be asked over the radio to stop the train immediately since there was no permission given to shunt beyond the aspect light.

The system allows multiple trainees to collaboratively work in the same scenario. The collaborative aspect of the training system is powered by a server-client-based network architecture. Client PCs can join the server which does not need to be dedicated and normally runs in the background of an own client. The state of the whole virtual world is synchronized between all clients, including the full representation of all users and their avatars with eye-tracking data if an eye-tracking capable head mounted display (HMD) is used.

To achieve smooth positioning, the location and rotation are transferred relative to a dynamic origin. The origin can be the depot, wagon or trains. This is necessary so that clients will have precise control of the master control handle. All simulations happen on the server side, but the clients do smaller temporary simulations during interactions so that the user receives instantaneous feedback of their actions. Even in a local network, the delay of a pure server-side simulation was noticeable and made precise movements of the train hard, which lead to the implementation of the aforementioned approach.

The avatars use inverse kinematics to determine the virtual body of the trainee based on the data from the controllers and HMD. A virtual avatar is necessary for collaborative tasks in which hand gestures are used to communicate, such as signaling the remaining distance to the coupling or indicating to the operator to slow down or speed up. It is recommended to adjust the height of the avatar in the user interface to match the height of the trainee. If the avatar appears crouching or tiptoeing, it is an implication of height mismatch. The avatar will appear crouching if the trainee is shorter than the height set, or tiptoeing if the trainee is taller than the height set. It is also impossible for the avatar to reach further than its arm length so a taller person cannot fully use their reach of their arms if the avatar height is not properly set.

To achieve good graphical quality, lighting has been realistically replicated with a mixture of baked global illumination, light probes and real-time lighting. Most of the materials have albedo, normal, specular and occlusion maps based on pictures from the real train. This creates a natural impression since wear and tear from the real train is reproduced on the virtual train. Reflections use a mixture of reflection probes and real-time reflections, which are applied to the floor. These are achieved by rendering a view from a camera mirroring the position of the eyes at the ground level, which is used as reflection input. Annotated marks drawn on the train by operators are also included on the virtual train. Only defects or undesired states such as broken lights that would affect the training scenario had been artificially fixed for the virtual train.

To ensure that the training system is accurate, iterative feedback and testing had been done with the actual operators of SMRT until the point was reached where the operators did not find any unwanted difference in behavior between the real and virtual train. This feedback and testing loop also ensured that the end users have the chance to shape the interactive parts and behaviors of the application to their satisfaction and expectations.

The required hardware for the application is a steamVR compatible VR system and a powerful PC. Since the application uses skeletal-based hand tracking, the recommended controller would be the Valve Index Controller, but it also

has been used and tested with conventional controllers, for which a default grip position of the hand is assumed. The minimum recommended hardware requirements for the PC are a GTX 1080 graphic card, 16 GB of RAM and an i7-6800 k CPU.

3.2 System interface for stress and fatigue monitoring

The system provides an interface for the trainers to supervise the trainees in the virtual environment, which displays the current states of the train such as power status, wheel chock status, brake pressure, etc. The interface overlays the VR scene at the upper left corner and is visible only to the trainers. This enables the trainers to quickly help a trainee if they are stuck in a procedure. It can further show the live stress and fatigue values of the trainee (Fig. 3), and they can be gathered on a by-task basis to visualize trends and enable day-to-day performance comparison. The fatigue and stress recognition algorithms are implemented based on the state-of-art methods published in [17–20], respectively.

In the real-time stress and fatigue monitoring as shown in Fig. 3, the green and red ribbon represent the levels of fatigue and stress, where green color indicates a low level of fatigue/stress, red indicates a high level of fatigue/stress, and a yellow color indicates a medium level of fatigue/stress. The system supports two assessment modes. In the first mode, the trainers have to click the tags in the task panel to indicate which task is being executed at the current moment

(as illustrated in Fig. 3, Task 5.4 is selected by the trainer as it is being executed and monitored). As a result, the average stress and fatigue during each task performance is displayed upon the completion of that task as shown in Fig. 3.

A comprehensive report is generated after the completion of tasks, which includes mean fatigue/stress states of every 5-min interval and the mean fatigue/stress states over every selected task. A result analytic is also included in the report, which lists a summary of the intervals of low/medium/high stress/fatigue, tasks of low/medium/high stress/fatigue, average fatigue/stress over the entire session, percentage of low/medium/high stress/fatigue intervals over the entire durations and percentage of low/medium/high stress/fatigue tasks over all tasks.

In the second mode, if the trainers are busy monitoring multiple trainees and do not have time to click the task tags (Fig. 4), the system provides assessment report of mean fatigue/stress states of every 5-min interval. In the report, mean fatigue/stress states of every 5-min interval, a summary of the intervals of low/medium/high stress/fatigue, average fatigue/stress over the entire session and percentage of low/medium/high stress/fatigue intervals over the entire durations are presented.

Further convenience options are available to adjust the interface or skip certain procedures and events that happen in a training session are logged and available as a text file. Every training session requires both a session name and trainee name.

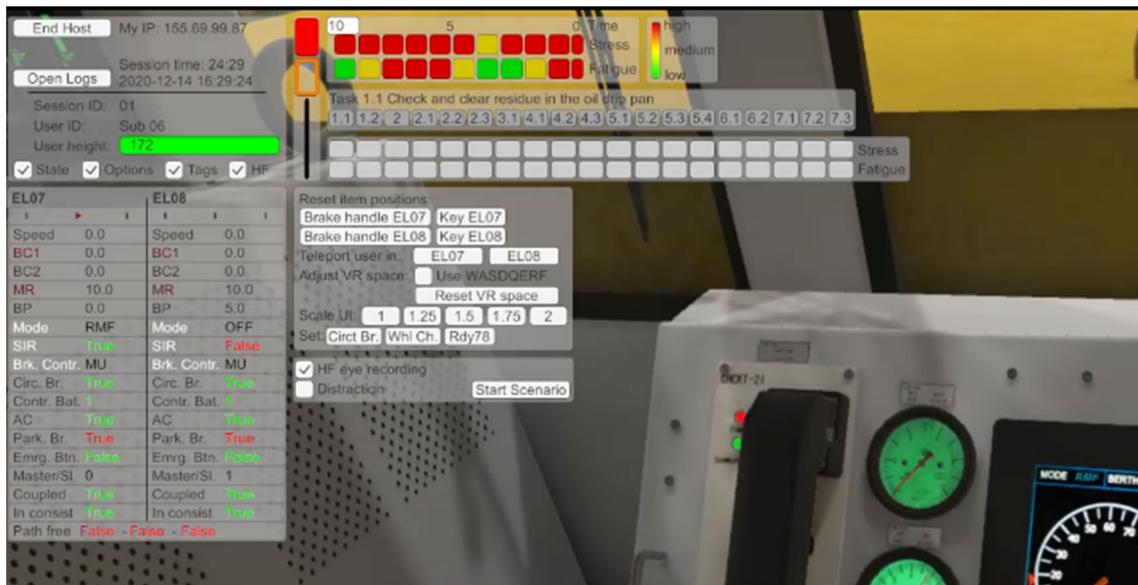
Fig. 3 Interfaces when trainers click task tags

Fig. 4 Interfaces when trainers do not click task tags

An optional feature for the trainee is a virtual touch tablet that contains information defined by the supervisor. This would normally be the description of all tasks and, if made available to the trainee, can help trainees to solve problems by themselves instead of relying on the supervisor. The tablet is created dynamically and appears if a certain text file is in the folder of the application. The text in the file will then be visible on the tablet, supporting common text formatting methods. The trainee can interact with it, like with any real world tablet. It is not synchronized over the network so that trainees can have different content on their tablets.

4 Experiment

4.1 Subjects

Twelve technically skilled trainee subjects and 3 trainer subjects participated in the experiment. Among the subjects, 8 are male, and the age of subjects ranges from 23–59-years-old. All subjects were recruited from SMRT Train Ltd. Specifically, the trainee subjects are competent train operators that have undergone rigorous on-site training before they assumed duty at SMRT.

4.2 Scenario description

The subjects were asked to conduct shunting operation scenario in VR. In the designed scenario, the signal aspect is red by default and can be switched to yellow by the trainers. The master Executive Train Operator (ETO) is expected to respond and stop shortly before the red aspect and wait for

it to be changed to yellow. If the master ETO passes the red aspect, Operations Control Center (OCC) would inform ETO to stop immediately. After the trainer changes the aspect to yellow, ETO should respond and proceed. ETO also needs to sound the horn to alert others of the approaching train. The speed should be controlled at all times (should not exceed 5 km/h in the workshop and 18 km/h in the depot and pit). If the speed exceeds 18 km/h, the consist will stall, and the ETO has to restart the consist. The corresponding timeline is illustrated in Fig. 5.

4.3 Experiment procedure

Multi-source data, including eye-tracking, behavioral and logs from VR were collected during the experiment. Two sets of questionnaires were designed and distributed to the trainers and trainees subjects. For trainers, the questionnaires are used for trainee performance evaluation and feedback toward the VR simulation. For trainees, the questionnaires are mainly for feedback toward the VR training. During the experiment, the trainers were in the same room with the trainees, who were going through the VR scenarios. Three researchers attended the experiment to help with the VR set-up and acted as the slave ETO/ground shunter. The experimental procedure is shown in Table 1.

4.4 Device

In the experiment, the HTC VIVE Pro Eye VR headset with integrated eye-tracking technology is used in the implemented VR training system.
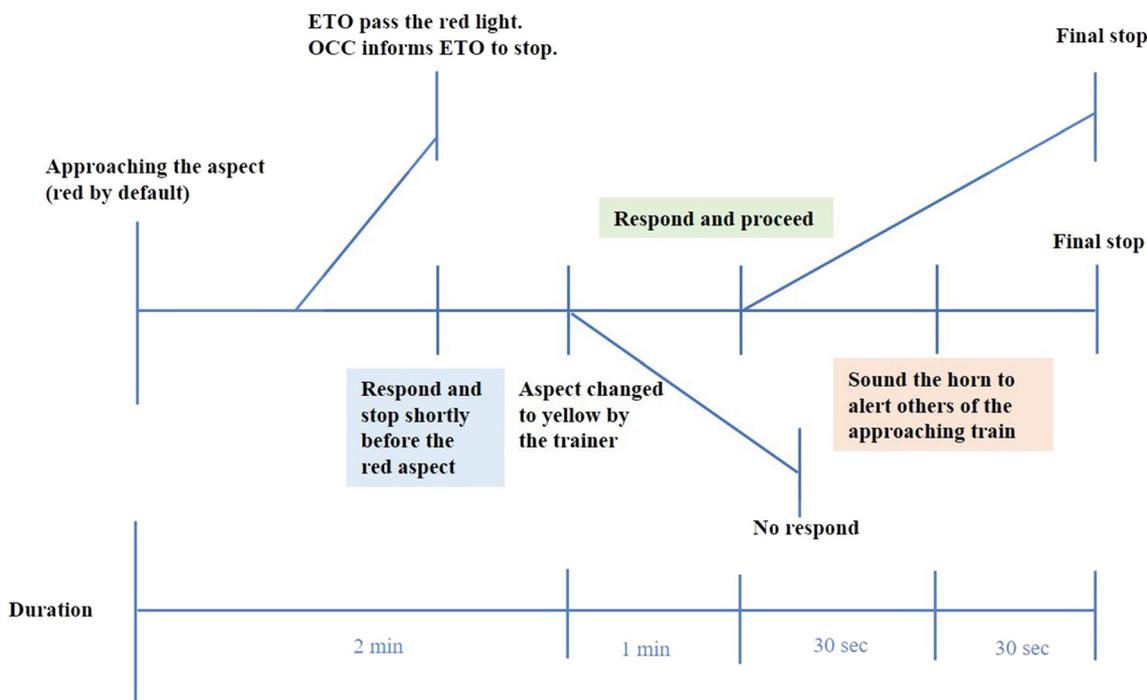
Fig. 5 Timeline of scenario (duration not drawn to scale)

4.5 Questionnaires

Trainees completed intake and post-experiment questionnaires before and after the experiment, respectively. The intake questionnaire for trainees include personal information such as gender, age, experience, working position and perceived mental states such as their fatigue/stress level on that day. Figure 6 shows the specific items that were used to understand fatigue and stress states in the questionnaires.

The post-experiment questionnaire includes three parts—questions on the fatigue/stress states, feedback about VR experience and evaluation of the VR-based training simulator. The VR experience questions were modified based on the study in [21]. Eleven questions are chosen to assess the feeling of presence, reality, stressfulness, tiredness, effectiveness, attention to scenes and sound within VR. To compare the VR-based training simulator with other traditional training methods, such as video training, lecture training and on-site training, 8 questions are proposed. In addition, trainees are required to tick their perceived advantages and disadvantages of VR-based training, as shown in Fig. 7.

The trainers received three questionnaires including intake, trainee performance assessment questionnaire and post-experiment questionnaires. The intake questionnaire records the information of experiment time, trainer ID and experience. The trainee performance assessment questionnaires are used by the trainers to report the performance of the trainee after observing his/her behaviors and activities in VR. The post-experiment questionnaire of trainers includes feedback about the effectiveness of training in VR and on-site, the difficulty of tasks in VR and real life and the possibility of using VR for SMRT shunting training. Questions comparing the VR training simulator with other traditional training methods, such as video training, lecture training and on-site training were also asked. In addition, trainers were required to tick their perceived advantages and disadvantages of VR-based training.

Hypothesis The data collected from the experiment are used to validate three hypotheses as listed below.

- Hypothesis 1: the VR-based training will not induce extra fatigue/stress and physical uncomfortableness to the trainees.
- Hypothesis 2: The VR-based simulation provides a suitable environment for shunting operation training.
- Hypothesis 3: Trainers and trainees prefer to utilize VR-based simulation for shunting operation training than other traditional training methods, such as video training, lecture training and on-site training.

Table 1 Experiment procedure

Time Elapsed	Duration (mins)	Activity	Action	Equipment
0 h 00 m	10	VR preparation	Calibrate VR space boundary, set-up VR environment and device, start and check human factor recording and eye-tracking recording, start video recording (screen recorder)	VR device
0 h 10 m	5	Arrival of two trainees and two trainers	Experiment briefing to trainees Trainees fill the consent forms and intake questionnaires Trainers fill the consent forms	Questionnaires
0 h 15 m	5	VR goggles set-up	VR goggles to be mounted on both trainees	VR device
0 h 20 m	5	VR environment familiarization	Calibration of VR eye-tracking Manipulate VR device to learn basic VR operations such as grabbing items, teleportation	VR device
0 h 25 m	5	Shunting Scenario—normal switching lights	Trainees conduct the experiment Trainers monitor the performance of the trainees	VR device
0 h 30 m	5	Questionnaire completion	Trainers complete "Questionnaire of Trainee's Performance – Task 6.1 Normal Switching Lights" Trainees complete "Experiment Questionnaire for Trainee – Task 6.1 Normal Switching Lights"	Questionnaires
0 h 35 m	5	Questionnaire completion	Trainees complete "Post-experiment Questionnaire" and provide feedback	Questionnaires
0 h 40 m	5	Data archiving and device clean-up	Save screen recording video, eye-tracking data, human factor data and questionnaire data Wipe and clean the VR device for the next subject	
The above procedures will be repeated for each of the subjects.				
End of the experiment	5	Questionnaire completion	Trainers complete "Post-experiment Questionnaire" and provide feedback	Questionnaires

How do you feel?

| Feeling active | 1 | 2 | 3 | 4 | 5 | | Completely exhausted |

| Not at all stressful | 1 | 2 | 3 | 4 | 5 | | Extremely stressful |

Additional Questions:

1) How tired are your eyes?

| 1 | | 2 | | 3 | | 4 | | 5 |

2) How clear is your vision?

| 1 | | 2 | | 3 | | 4 | | 5 |

3) How do your eyes feel?

| 1 | | 2 | | 3 | | 4 | | 5 |

4) How tired is your back?

| 1 | | 2 | | 3 | | 4 | | 5 |

5) How tired is your neck?

| 1 | | 2 | | 3 | | 4 | | 5 |

6) How severe is your headache?

| 1 | | 2 | | 3 | | 4 | | 5 |

7) How sleepy do you feel?

| 1 | | 2 | | 3 | | 4 | | 5 |

Fig. 6 Questionnaire on the mental states of trainees

Any advantages of training in VR? Please select all that apply.
☐ Provide outstanding visualizations that aren't possible in the traditional trainings (e.g., video and lecture).
☐ Create Interest.
☐ Increase engagement.
☐ Increase training accessibility.
☐ Immersive Learning.
☐ Save physical effort
☐ Convenience
☐ Allow repetitive training
☐ Not restricted to environmental conditions
Others: _____

Any disadvantages of training in VR? Please select all that apply.
☐ Deteriorates human connections.
☐ Functionality issues.
☐ Cause physical side effects (headache, blurred vision)
☐ Artificiality
☐ Data security
☐ Motion sickness
☐ Dizziness
☐ Eyestrain
☐ Unrealistic interaction
☐ Misleading
Others: _____

Fig. 7 Questionnaire on advantages and disadvantages of training in VR

Table 2 Physical and mental states change before and after experiment

Items	Changes between post- and pre-experiment	P value of t-test
Overall fatigue	0	0.75
Overall stress	0.25	0.43
Eye tiredness	0.25	0.34
Vision (visual acuity)	0	0.37
Strain eye	-0.25	0.08
Back pain	-0.125	0.17
Neck pain	0.375	0.44
Headache	-0.125	0.59
Sleepiness	-0.375	0.08

Table 3 Trainees' post-experiment feedbacks

Subjective feelings	Average
1. presence of VR experience	3.33
2. realism of VR experience	3.50
3. stress of shunting in VR	2.75
4. sense of movement in VR	3.92
5. fatigue after VR experience	2.25
6. attention to aspect in VR	4.33
7. how real the sound is in VR	3.67
8. attention to ambient sound	2.92
9. effectiveness of the shunting training in VR	4.25
10. effectiveness of the on-site training	4.36
11. difficulty of task in VR comparing to real life	2.67
12. preference to use VR over video	4.00
13. preference to use VR over lecture	4.00
14. preference to use VR over on-site training	2.67
15. VR learn faster than videos	4.50
16. VR learn faster than lectures	4.50
17. level of trust in VR	3.50

5 Results and discussion

The data from the questionnaires given to trainees and trainers were analyzed, and the results are shown in the following sections.

5.1 Trainees' physical and mental states before and after experiments

Table 2 shows the changes of both physical and mental states of trainees before and after the experiment. It was found that after the experiments, the average changes across all 12 subjects in all these items are minor. T-test was conducted to compare the mean value between post- and pre-experiment. The overall fatigue levels and visual acuity remain unchanged. The overall stress, eye tiredness and neck pain increased a little. Other states, such as eye strain, back pain, headache and sleepiness decreased. In general, the results of t-test in all the states are above 0.05. Accordingly, hypothesis 1 is confirmed.

5.2 Trainees' feedback on the VR training simulator

By averaging the ratings from the post-experiment survey questionnaires across all trainees, the following results are shown in Table 3. The average rating of presence is 3.33/5, which indicates that during the VR training, the trainees had a strong sense of being present in the virtual world. The average rating of realism is 3.5/5, which indicates that

the trainees felt shunting operation in VR were real to them almost all the time. The trainees also reported that they can sense the movement during training (3.92/5), which proves again that the VR scenario created a realistic environment. In addition, the trainees rated that they paid a lot of attention to visuals—such as the aspect in VR (4.33/5), though less attention to audios—such as the ambient sound (2.92/5). However, they still rated that the sound in the VR scenarios was real to them with an average rating of 3.67/5.

The stress and fatigue level after the VR training were lower than 3, which indicates that the VR training did not bring any extra stress and fatigue to the trainees. The effectiveness of the training in VR was rated as 4.25/5, which is slightly lower than the effectiveness of the on-site training (4.36/5), and the preference is still with on-site training. However, the trainees rated that they preferred to use VR over other traditional training methods such as video- and lecture-based ones. Our finding of preference for VR training over its traditional counterparts is in agreement with that reported in [7], which also shows positive feedback for new VR training from the majority of users. The trust toward VR training is also high (3.50/5), which could be a sign that VR is suitable for shunting training. Thus, hypothesis 2 is confirmed, and hypothesis 3 is partially confirmed by the trainees.

5.3 Trainers' feedback on the VR training simulator

Questionnaires have been given to the trainers to get feedback from them about training in VR as well. As shown in Table 4, the trainers agreed that training in VR is effective, and they preferred to use it over videos and lectures, though on-site training is still considered as the best training method. They also mentioned that the possibility of using VR for shutting training is very high, as the VR system can help individuals learn the shunting operation faster than training based on videos and lectures. Thus, hypothesis 2

is confirmed, and hypothesis 3 is partially confirmed by the trainers.

5.4 Feedback on the advantages and disadvantages of training in VR

Several possible advantages and disadvantages were listed in the questionnaire based on literature review about the VR-based training. Both trainers and trainees were asked to indicate based on their perception toward VR-based training. The percentage of trainers/trainees who agreed on each advantage/disadvantage point is shown in Tables 5 and 6, respectively. Compared with trainers, trainees tended to tick more advantage points of the VR training. Four listed advantages, namely "increase engagement", "increase training accessibility", "immersive learning", "allow repetitive training" were selected by all trainees. Whereas only two advantages of the VR training, namely "save physical effort" and "allow repetitive training" were selected by all trainers. For disadvantage of the VR-based training, the focuses are

Table 5 Feedback on advantages of training in VR

Advantages of training in VR	Trainees' feedback	Trainers' feedback
Provide outstanding visualizations that aren't possible in the traditional trainings	83%	50%
Create interest	83%	33%
Increase engagement	100%	50%
Increase training accessibility	100%	67%
Immersive learning	100%	67%
Save physical effort	75%	100%
Convenience	83%	17%
Allow repetitive training	100%	100%
Not restricted to environmental conditions	83%	33%

Table 4 Trainers' post-experiment feedbacks

Post-experiment feedbacks	Average
1. effectiveness of the shunting training in VR	4
2. effectiveness of the on-site training	4.7
3. difficulty of task in VR comparing to real life	3
4. the possibility of using VR for SMRT shunting training	4
5. preference to use VR over video	4
6. preference to use VR over lecture	4
7. VR training systems can help individuals learn the shunting operation faster than training by videos methods	4
8. VR training systems can help individuals learn the shunting operation faster than training by lectures	4.2

Table 6 Feedback on disadvantages of training in VR

Disadvantages of training in VR	Trainees' feedback	Trainers' feedback
Deteriorates human connections	17%	17%
Functionality issues	25%	5%
Cause physical side effects (headache, blurred vision)	42%	67%
Artificiality	25%	33%
Data security	8%	0
Motion sickness	58%	100%
Dizziness	25%	67%
Eye strain	42%	67%
Unrealistic interaction	33%	5%
Misleading	0	0

mainly on physical side effects (headache, blurred vision), motion sickness and eye strain. However, very few trainees reported discomforts during or after the experiment despite indicating it in the questionnaires. Besides the advantages and disadvantages listed in the questionnaires, the trainers and trainees were also asked to write down any comment regarding the training in VR. We received feedback from some trainees that VR did help in better memorization of the procedure, but cannot fully mimic the feel of the physical objects. In addition, physical touch, the weight of items, physical movement up and down of the real locomotive are absent from VR, and no effort to move is needed due to teleportation which further detracts from reality.

6 Conclusion

In this paper, we present a VR-based training for shunting operations in railway. An experiment was carried out to validate the implemented VR-based training. Twelve trainees and three trainers were recruited in the experiment. Questionnaires were distributed to both trainees and trainers to get their feedback toward the VR-based training. The obtained results confirmed the hypothesis that the VR-based training will not induce extra fatigue/stress and physical uncomfortableness to the trainees; the VR-based simulator provides a suitable virtual alternative for shunting operation training and both trainees and trainers reported a positive VR experience. Furthermore, trainers and trainees prefer to use a VR-based simulator for shunting operation training than other traditional training methods, such as video training and lecture training.

The VR-based training comes with the unique human factors evaluation which could monitor the fatigue/stress level of the user in real-time and generate a comprehensive report after the training regarding mean fatigue/stress states of every 5-min interval and the mean fatigue/stress states over every selected task, etc. The report also include analytics results such as a summary of the intervals of low/medium/high stress/fatigue, tasks of low/medium/high stress/fatigue, average fatigue/stress over the entire session, percentage of low/medium/high stress/fatigue intervals over the entire durations and percentage of low/medium/high stress/fatigue tasks over all tasks.

In the next step, we are going to analyse the biosignal and behavioral data collected from the experiment and assess the competence of the trainees.

Declarations

Conflict of interest The authors declare that there is no conflict of interest.

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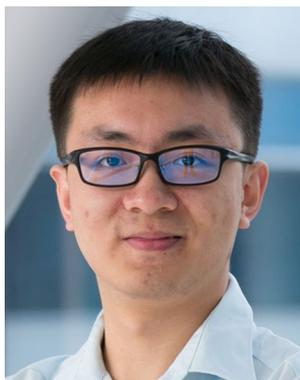

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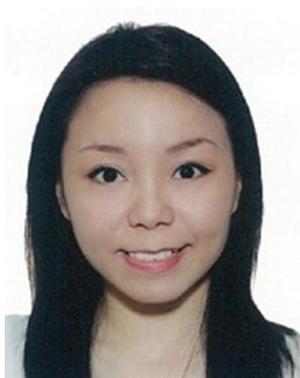
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