International Journal of Innovation, Creativity and Change. www.ijicc.net
Volume 15, Issue 3, 2021

Pilot Study of Heartbeat Sensors for Data Streaming in Virtual Reality (VR) Training

Yui-yip Lau[a], Yuk Ming Tang[b*], Ka Yin Chau[c], Ho Yan Hui[b], [a] Division of Business and Hospitality Management, College of Professional and Continuing Education, The Hong Kong Polytechnic University, [b] Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University, Hong Kong, [c] Faculty of International Tourism and Management, City University of Macau, Macau

Virtual reality (VR) training is important for medical staff nowadays especially for those who handle sharp objects. The training can be used to prevent accidents or potential injuries to them as they can happen at any moment during surgical procedures, disassembling, or disposal of sharp objects. For education and training purposes, VR simulated precautions training in hospitals, caring centres, etc. is proposed. In this article, we describe a pilot study of VR simulated training. The pilot study involves an initial experiment and data collection of a simulated VR education and training program by using the biosensors of the developed wearable device. Through the development of an immersive and 3D VR environment in the working place, the simulation is intended to provide VR training for health care employees and medical practitioners. In this pilot study, we attempt to design and develop a wearable device for heartbeat rate data capture and collection when the trainee is undergoing VR training. Thus, the medical workers can be trained under supervision and monitoring. The developed heartbeat device can successfully collect the bio-data of the trainees during simulated training, and the accuracy of the sensors was also validated.

Keywords: *virtual reality (VR); simulated training; healthcare; education; heartbeat sensor; wearable device*

Introduction

1.1 Project Background

The Centres for Disease Control and Prevention of the United States estimated that there are about 385,000 sharp and other related injuries among health care workers in hospitals. The average of injuries is 1,000 cases per day (Musa and Peek, 2014). According to the report from the World Health Organisation, there are 35 million health care workers around the world, and more than 2 million health care workers experience percutaneous exposures to infectious diseases every year. Further 39% of Hepatitis C, and 4.4% of HIV/AIDS infected cases among those health care workers in the world are attributed to the injuries, while the majority of cases of injuries occur within their working environment such as the operation theatre (Lam et al., 2014). There is no doubt that a well-designed and implemented injuries' precaution training is beneficial for doctors and nurses in learning the correct handling of medical tools and equipment. However, the traditional training is deficient as it is hard to fully simulate the real healthy working environment due to physical or access restrictions.

The VR industry has been growing fast in recent years, and this technology can be applied in many applications including healthcare and training. In VR, various hardware can be used to collect data from the trainees. A wired glove helps capture the finger movement such as bending the finger, and a motion sensor is installed for tracking the movement position. All of the data can be transmitted to the computer. Other techniques such as eye gaze, mixed reality (MR) can also be used for obtaining feedback from users (Tang, et al. 2018 and 2020), however, the use of biosensors to collect user feedback has still seldom been used in VR training. This project attempts to design and develop a heartbeat sensor to collect and stream the user's feedback and data to the computer during training. These data are useful for further analysis in the future to understand the performance of the trainee during training.

1.2 Literature review

1.2.1. Injures and training

Medical injuries are usually associated with penetrating wounds with an instrument that is potentially contaminated with the body fluids of another person. These injuries are the most common occupational injuries for healthcare workers and threaten all people employed in the medical industry (Heidari, M. and Shahbazi, 2011). Ali et al. (2013) and Benner (1984) indicated that sharps injuries are among the most common occupational injuries to healthcare workers (HCWs). Tarantola et al. (2003) also estimated that there are about 3 million who suffer from injuries every year. It was shown that nurses have the highest incidence of related injuries (Ng and Chan, 2002; Muralidhar et al., 2010). Therefore, it has attracted attention to promoting job safety for the healthcare workers (Heidari, M. and Shahbazi, 2011).

To achieve a competent level, a nurse should be “on the job in the same or similar situations for two or three years”. Novices to advanced beginners devote most of their efforts to remembering the rules that they have been taught (Benner, 1984). Petrucci et al. (2009) argued that nursing student's clinical skill proficiency and knowledge of biological risk increase during their course of study. To strengthen the occupational health and safety concepts for students, it is of paramount importance to integrate both prevention training programs into the nursing curriculum.

1.2.2 Virtual Reality

Craig et al. (2009) stated that VR refers to computer simulation that creates an image of the world and appears to our senses in the much same way we perceive the real world. To convince the brain that a synthetic world is authentic, the computer simulation monitors the movement of the participant and adjusts the sensory display that produces a feeling of being immersed in the simulation (Li et al., 2019). It is the interaction between the system and the person, called telepresence, that is different from 3D cinema. In VR, the concept of feedback is also considered in the system so that the person can be immersed in the digital environment. Sometimes, the haptic system will also be used to provide feedback to the user in VR. For example, when the object is touched or picked, a vibrating controller will be triggered and operated to send reactions to the user.

1.2.3 VR training and education

VR can be applied in many different applications, especially in education and training. VR technology can rebuild the clinical scenarios such as hospitals, healthcare centres, etc. that grants experience for the participants not only visualizing, but also hearing and touch. Also, not only nursing students, educators would be able to guide students from a distance, in real-time, to pick up surgical instruments, and learn how to handle these following the instruction. As such, Tang et al. (2020) proposed to adopt VR to supplement the traditional approach to facilitate procedural training for medical practitioners.

VR in healthcare education such as learning human anatomy provides an immersive virtual environment that permits learners to interact three-dimensionally with a digital human body (Maresky et al., 2019). The use of VR applications in anatomy education contributed to the formation of an effective and productive learning environment. This case was successful for later replications and applications.

Nowadays, augmented reality (AR) technology is also developed for providing training in the healthcare and manufacturing industry. Hanna et al. (2019) reviewed the use of the AR program for healthcare training. The technology provides an opportunity for nurses to assist health behaviour adjustment interventions and optimism care.

1.3 Project objectives

This project aims to design and develop a wearable device, which is developed to collect the heartbeats of the trainees during training. The collected data should be able to stream to the computer in real-time. The wearable device is developed to collect heart rate data wirelessly. We will make use of simulated training through a simulated working environment to provide an injuries' precaution training program for health care employees and medical practitioners as the pilot trial. The experiments in the pilot study were used to validate the accuracy of the developed sensors.

2. Methodology

Nowadays, there are many different types of VR simulated training. Nevertheless, investigation of the effectiveness of the VR training is difficult not only in the measurement of trainees' learning effects quantitatively but is also difficult to collect trainees' feedback objectively. Heartbeat rate monitoring is a useful experiment method for training assessment. In this project, we designed a wireless wearable device for heartbeat rate monitoring and data collection. By analysing the change of heartbeat rate, the changes in a trainee's emotion can be identified during the training. On the other hand, the data collected from the devices can be extracted into a secured monitoring computer through Bluetooth or other wireless communication. This allows trainers to evaluate the performance of trainees in the VR procedural training. Figure 1 illustrates the workflow diagram of the proposal wearable device. The wearable device consists of two major parts: the heartbeat rate sensor and the wireless Bluetooth receiver. In order to receive the data from the wearable device, the Bluetooth receiver is connected to the hosting computer and paired up with the wearable device. In the hosting computer, the VR simulated training program is installed to provide a VR experience to the trainees. The program can be developed by using Unreal, or other game Engines. Once the data is collected in the wearable devices, the data can be uploaded to the hosting computer in the CSV format file type. The bill of materials (BOMs) of the wearable device is listed in Table 1.

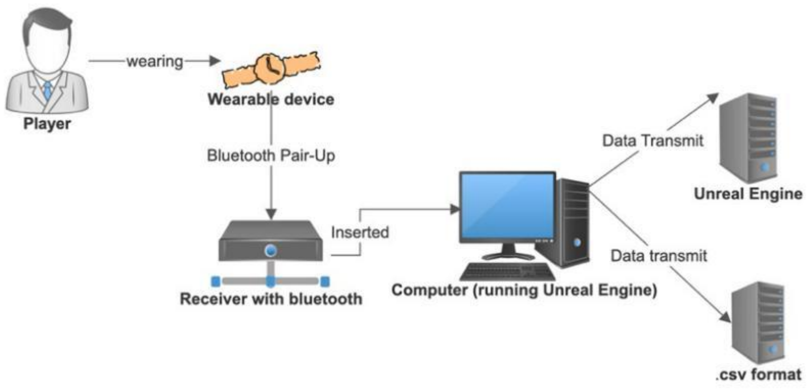

Figure 1. The workflow of the heart-rate monitor system

Table 1. The bill of material of the wearable Heartbeat rate monitor system

Item	Quantity
Heartbeat rate Sensor	1
OLED display	1
Arduino with Bluetooth	2
Rechargeable Battery 3.7V	1
Wrist Band	2
Device Housing	1
Receiver Housing	1
Lithium battery charging circuit board 5V to 4.2V	1

2.1 Hardware and software development

3D computer-aided design (CAD) software available in the market is used to design the device and receiver housing. To minimise the size of the device, the hardware is packed effectively into the case. After designing the Housing, the file was generated into STL format for the 3D printing process, using a 3D Printer. To shorten the time of 3D printing, the position of the object was rearranged, and the PLA (Polylactic Acid) materials were used. In order to develop the program for streaming the data from the hardware in the VR training program, Unreal engine network programming was employed to read the data from the receiver (Arduino) and stored in CSV format.

2.2 Arduino programming

The wearable device and the receiver were programmed by Arduino language for operation. A wearable device needs to display the heartbeat rate in real-time, so the groups of OLED's Arduino program texts are downloaded to motivate the display through the Arduino Library. The language groups of the text display are programmed, and the refresh rate is similar to the heart beat recorded rate; the language groups of the heartbeat rate collection are programmed to collect the data and transmit the data to Arduino Nano. The language group of Bluetooth Pair-up aims to connect another Arduino and transmit data. The receiver only programs the language group of Bluetooth pair-up that connects with the wearable device, and the USB port is able to connect with the computer and stream the data to the Unreal engine.

2.3 Data validation

After the hardware installation and programming, the device streamed the real-time data to the Unreal Engine via Bluetooth, and the data is shown on the OLED display and saved in the CSV format.

In order to validate the heartbeat rate accuracy of a wearable device, an experiment was designed to validate the data. The experiment aimed to compare the performance of a wearable device and an apple watch. Participants in the pilot test were randomly invited, and we recorded their heartbeat rate 30 times per 3 seconds with a wearable device and an apple watch. It was assumed that their heartbeat rate was stable as they were sitting comfortably. Along with this preposition, the data are normally distributed to the participants. Z-test was used for data validation in this experiment. Z-test is a statistical method to compare the similarities of two functions when the variance has been calculated (Stein, 1972). The assumption of the Z-test is normally distributed, and the variance is known for z-test analysis. To obtain more reliable results, the sample sizes of the investigation should be greater than 30 since the sample is determined approximate normal distribution based on the central limit theorem.

2.4 Validation of sensor device

In order to validate the heartbeat rate accuracy of a wearable device, an experiment was designed to validate the data. Testing was performed to determine the type of hypothesis applied in the z-test. Table 2 summarizes different scenarios in the test:

Table 2. Different scenarios of z-test

	Alternative Hypothesis	Rejection Region for Level α test
Upper-tailed	$H_a: \mu_1 - \mu_2 > \Delta_0$	$z \geq z_a$
Lower tailed	$H_a: \mu_1 - \mu_2 < \Delta_0$	$z \leq z_a$
Two-tailed	$H_a: \mu_1 - \mu_2 \neq \Delta_0$	$z \geq z_{\alpha/2}$ or $z \leq -z_{\alpha/2}$

The p-value in the z-test indicates evidence of the hypothesis in the z-test. There are three scenarios in the p-value; When the p-value is less than 1%, there is solid evidence to deduce that the hypothesis is true, so the test is highly significant. When the p-value is between 1% and 5%, there is supportive evidence to deduce the hypothesis is true, so the test is important; When the p-value is between 5% and 10%, there is insufficient evidence to deduce the hypothesis is true, so the test is less important; When the p-value is larger than 10%, none of the evidence to deduce the hypothesis is true.

3 Results

In the pilot study, 5 participants participated in the test. In order to validate the developed wearable device, the results were compared with the results from an apple watch. Table 3 shows the raw data received from the developed wearable device and the apple watch. The mean and the variance of the wearable device and Apple watch were calculated for further processing in order to calculate the p-value with 2-tails.

The heartbeat rate data were collected and recorded 30 times per 3 seconds by a wearable device and an apple watch. From the result of P1, the p-value of the two tails is 3.34% (between 1% and 5%), so there is strong evidence that indicates the alternative hypothesis is true. The mean difference between the wearable device and the Apple watch was 1.07 (64-62.93 = 1.07). As the result from P2, the p-value of two-tails was 0.06 %, (less than 1%), which means there is solid evidence to deduce that the hypothesis is true. The mean difference between the wearable device and the Apple watch was 2.6 (74.03-76.63 = -2.6). As the result from P3, the p-value of two-tail was 0.01 %, (less than 1%), which means there was solid evidence to deduce that the hypothesis is true, and the result is significant. The mean difference between the wearable device and the Apple watch was 3.17 (61.67-58.5 = 3.17). From the result from P4, as the p-value of two tails was 30.1%, (greater than 10%), so none of the evidence for deducing the hypothesis is true. As a result of P5, as the p-value of two tails was 3.34%, (between 1% and 5%), there is supportive evidence indicating that the alternative hypothesis is true. The result is significant. The mean difference between the wearable device and the Apple watch is 1.67 (70.67-68.4 = 2.27). The result of data validation indicates that consistency of P1, 2, 3, 5 was reached based on the hypothesis, while the result of P4 was inconsistent with hypothesis. Regarding this exception, more tests are needed, but in terms of average calculation, it can be ignored. Thus, it means that participants 1, 2, 3, and 5's heartbeat rate data comparison between the wearable device and Apple watch is reliable. The accuracy of the wearable device is acceptable compared with the Apple watch (Table 5).

Table 3 The data obtained from the wearable device and apple watch of the five people tested

Participant 1			**Participant 2**			**Participant 3**			**Participant 4**			**Participant 5**		
TE	**WD**	**AW**	**TE**	**WD**	**AW**	**TE**	**WD**	**AW**	**TE**	**WD**	**AW**	**TE**	**WD**	**AW**
1	60	61	**1**	68	73	**1**	55	60	**1**	54	56	**1**	70	74
2	62	63	**2**	72	75	**2**	58	62	**2**	55	55	**2**	72	74
3	64	65	**3**	74	78	**3**	58	62	**3**	56	56	**3**	74	72
4	64	65	**4**	72	74	**4**	60	64	**4**	55	60	**4**	74	72
5	64	66	**5**	74	78	**5**	58	60	**5**	53	55	**5**	70	72
6	62	63	**6**	76	80	**6**	55	64	**6**	54	56	**6**	70	72
7	64	65	**7**	75	78	**7**	58	62	**7**	59	59	**7**	68	68
8	65	65	**8**	74	75	**8**	62	64	**8**	62	60	**8**	66	68
9	67	66	**9**	74	75	**9**	58	60	**9**	62	62	**9**	66	68
10	62	63	**10**	75	78	**10**	55	60	**10**	61	61	**10**	68	72
11	64	65	**11**	74	72	**11**	55	58	**11**	65	60	**11**	66	68
12	60	61	**12**	76	76	**12**	55	58	**12**	71	60	**12**	68	68
13	64	65	**13**	78	84	**13**	58	62	**13**	65	58	**13**	70	72
14	60	61	**14**	74	82	**14**	60	64	**14**	60	60	**14**	68	72
15	58	60	**15**	70	80	**15**	62	66	**15**	57	55	**15**	70	76
16	60	61	**16**	74	75	**16**	62	66	**16**	56	54	**16**	72	78
17	62	63	**17**	74	72	**17**	60	64	**17**	55	52	**17**	70	74
18	64	65	**18**	75	72	**18**	58	60	**18**	54	50	**18**	70	72
19	66	64	**19**	72	75	**19**	52	62	**19**	57	55	**19**	68	72
20	64	65	**20**	74	78	**20**	54	60	**20**	58	58	**20**	65	68
21	64	66	**21**	78	82	**21**	53	55	**21**	59	60	**21**	65	66
22	62	66	**22**	75	85	**22**	58	60	**22**	55	55	**22**	68	68
23	64	65	**23**	75	78	**23**	60	62	**23**	56	56	**23**	70	66
24	66	65	**24**	76	80	**24**	60	72	**24**	57	55	**24**	70	68
25	64	65	**25**	75	78	**25**	62	64	**25**	62	62	**25**	68	66
26	62	64	**26**	72	75	**26**	62	64	**26**	61	60	**26**	66	66
27	62	64	**27**	73	75	**27**	63	62	**27**	62	62	**27**	64	68
28	60	62	**28**	73	72	**28**	62	60	**28**	59	59	**28**	64	66
29	64	65	**29**	74	73	**29**	60	58	**29**	60	60	**29**	66	68
30	64	66	**30**	75	71	**30**	62	58	**30**	61	61	**30**	66	68

P1: Average (mean) 62.93, 64; Var () 4.41, 3.17

P2: Average (mean) 74.03, 76.63; Var () 4.17, 13.76
P3: Average (mean) 58.5, 61.77; Var () 9.5, 10.46
P4: Average (mean) 58.7, 57.73; Var () 16.49, 9.79
P5: Average (mean) 68.4, 70.07; Var () 7.21,10.62

Note: TE: Times of experiments; WD: Wearable Device; AW: Apple Watch; P 1,2,3,4,5 stands for five participants

Table 4 Summary of the results in the z-test

Two-Sample for Mean	P1-Z-test		P2-Z-test		P3-Z-test		P4-Z-test		P5-Z-test	
	HBP	AW	HBP	AW	HBP	AW	HBP	AW	HBP	AW
Mean	62.93	64.00	74.03	76.63	58.50	61.77	58.70	57.73	68.40	70.07
Variance	4.41	3.17	4.62	12.65	11.27	11.47	16.49	9.79	7.21	10.60
Observation	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Hypothesised Mean	0.00		0.00		0.00		0.00		0.00	
z	-2.12		3.43		3.75		1.03		2.16	
P(Z<=z) one-tail	0.02		0.00		0.00		0.15		0.02	
z Critical one-tail	1.64		1.64		1.64		1.64		1.64	
P(Z<=z) two-tail	0.03		0.00		0.00		0.30		0.03	
z Critical two-tail	1.96		1.96		1.96		1.96		1.96	

Note: HBP: HBP device; AW: Apple watch

Table 5. Comparison of heartbeat rate between the developed wearable device and apple watch

	Developed device	**Apple watch**	**Difference**
P1	62.93	64	1.07
P2	74.03	76.63	2.6
P3	58.5	61.77	3.27
P4	58.7	57.73	-0.97
P5	68.4	70.07	1.67
Average			**2.15**

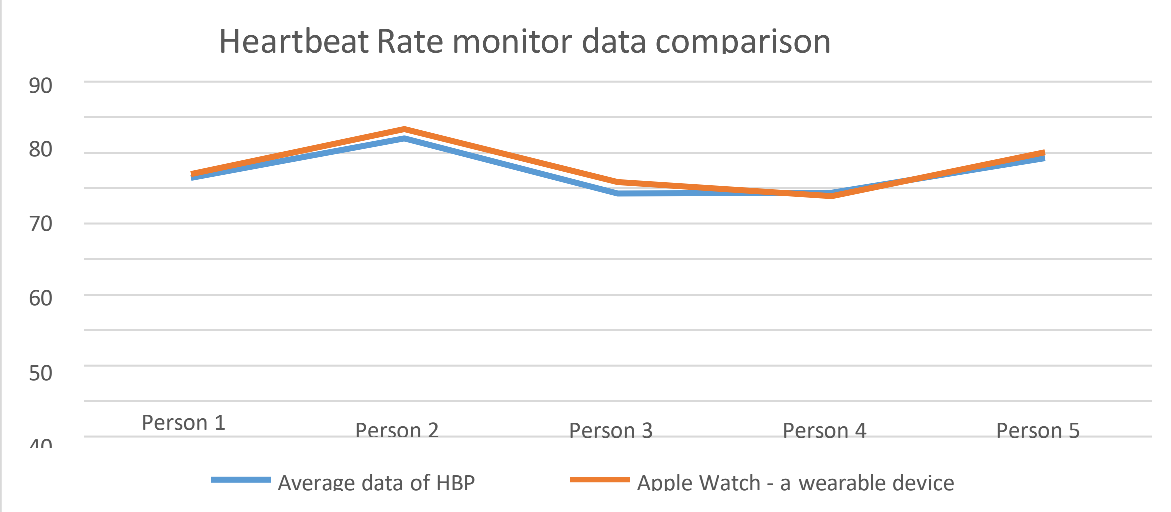

Figure 2. Data comparison the heartbeat rate result of the 5 participants

4. Conclusions

Health care workers in hospitals suffer from injuries, and suitable training is hard to simulate. Training in the real environment is not safe as there are a variety of object tools for surgery purposes. It is expected that the investigation and development of virtual reality can help for further development of training. VR game development for training purposes provides a secure training environment for health care workers. However, the existing approaches are difficult to investigate the effectiveness of the training program. Therefore, we propose to receive biosensor data from participants during training. In this project, the heartbeat rate monitor system for capturing and collecting the data in the virtual reality application was developed to record the change of heartbeat rates. To validate the accuracy of the developed device, a pilot study was conducted. Regarding the accuracy, data validation was proven by comparing the measured data with an Apple watch record. The developed wearable device can replace with other sensors as it can provide a high-frequency refreshing rate, as well as the ability to stream the real-time data to the VR training program. Nevertheless, further study should be conducted to investigate the relationship between the changes of emotion and heartbeat rate, so as to make improvements in the VR training program in the future.

REFERENCES

Ali, G., Abasalt, B. & Pegah, L. (2013). Risk Factors of Needlestick and Sharps Injuries among Healthcare Workers. International Journal of Hospital Research, (2(1)), 31-38.

Benner, P. (1984). From novice to expert: excellence and power in clinical nursing practice. American Journal of Nursing, 84 1480.

Craig, Alan B., William R. Sherman, and Jeffrey D. Will. Developing virtual reality applications: Foundations of effective design. Morgan Kaufmann, 2009.

Hanna, W., Jonathan, B. & Marcus, G. A scoping review of augmented reality in nursing. BMC nursing 18.1 (2019): 19.

Heidari, M. and Shahbazi, S. (2011) Prevalence of needle sticks exposure in operation room's staff of Borujen & Lordegan hospitals - 2010-2011. Journal of School Nursing Midwifery and Allied Health, 5 (2).

Lam, T. H., Cheung, K. B. & Chiu, S. S. (2014). Recommendations on the Management and Postexposure Prophylaxis of Needlestick Injury or Mucosal Contact to HBV, HCV and HIV. Centre for Health Protection. 2007.

Li, Y., Huang, J., Tian, F., Wabg, H. A. & Dai, G. Z. (2019). Gesture interaction in virtual reality. Chinese: KeAi.

Maresky, H.S., Oikonomou, A., Ali, I., Ditkofsky, N., Pakkal, M. and Ballyk, B. (2019), Virtual reality and cardiac anatomy: Exploring immersive three-dimensional cardiac imaging, a pilot study in undergraduate medical anatomy education. Clin Anat, 32: 238-243. doi:10.1002/ca.23292

Muralidhar, S., Singh, P. & Malhotra, M. Needle stick injuries among health care workers in a tertiary care hospital of India. Indian Journal of Medical Research 131.3 (2010): 405.

Musa, J. J. & Peek-asa, C. (2014). Needle Stick Injuries, Sharp Injuries and other Occupational Exposures to Blood and Body Fluids among Health Care Workers in a general hospital in Sarajevo, Bosnia and Herzegovina. Int J Occup Saf Health, 4 (1), 31-37.

Ng, Lim, H. L. & Chan, Y. L. Analysis of sharps injury occurrences at a hospital in Singapore. International journal of nursing practice 8.5 (2002): 274-281.

Petrucci, C., Alvaro, R. & Cerone, M. P. Percutaneous and mucocutaneous exposures in nursing students: an Italian observational study. Journal of Nursing Scholarship 41.4 (2009): 337-343.

Stein, C. (1972). The Annals of Mathematical Statistics. United States: Institute of Mathematical Statistics.

Tang, Y.M., Au, K.M., & Leung, Y. (2018). Comprehending products with mixed reality: Geometric relationships and creativity. International Journal of Engineering Business Management. https://doi.org/10.1177/1847979018809599

Tang, Y.M., Au, K.M., Lau, H.C.W. et al. Evaluating the effectiveness of learning design with mixed reality (MR) in higher education. Virtual Reality 24, 797–807 (2020). https://doi.org/10.1007/s10055-020-00427-9

Tang, YM, Ng, GWY, Chia, NH, So, EHK, Wu, CH, Ip, WH. Application of virtual reality (VR) technology for medical practitioners in type and screen (T&S) training. J Comput Assist Learn. 2020; 1– 11. https://doi.org/10.1111/jcal.12494

Tarantola, A., Golliot, F. & Fleury, L. Occupational blood and body fluids exposures in health care workers: four-year surveillance from the Northern France network. American journal of infection control 31.6 (2003): 357-363.