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Cognitive Load/flow and Performance in Virtual Reality Simulation Training of Laparoscopic Surgery

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Figure 1: The participants operated on a training box(Left). The heart rate and EEG were recorded and quantitatively analyzed. They were trained on VRLS (Middle: screenshot of picking small balls. Right: operation illustration).

Abstract

VR based laparoscopic surgical simulators (VRLS) are increasingly popular in training surgeons. However, they are validated by subjective methods in most research. In this paper, we resort to physiological approaches to objectively research quantitative influence and performance analysis of VRLS training system. The results show that the VRLS could highly improve medical students' performance ($p < 0.01$) and enable the participants to obtain flow experience with a lower cognitive load. The performance of participants is negatively correlated with cognitive load through quantitatively physiological analysis.

Index Terms: Human-centered computing—Human computer interaction—User Evaluation—

1 Introduction

Traditional laparoscopic surgical training usually utilizes the training box within vitro animals or corpses organs, which could give rise to negative effects, such as high cost, low reusability, and related ethical issues. The VR surgical simulator has changed the surgeons learning mode by simulating the surgery from the visual, auditory, and tactile aspects. Many scholars validated the effectiveness of VR based laparoscopic surgery simulators (VRLS) using subjective methods [4]. In this paper, we resort to physiological approaches to objectively and quantitatively measure the influence of VRLS on medical students from the aspect of cognitive load and flow.

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At present, the main cognitive load measurement methods are subjective measures such as NASA-TLS scale. The most commonly used methods to measure flow experience are retrospective questionnaires and interviews [6]. The main advantages of the psychophysiological measurement of cognitive load are its objective, the sensitivity to different cognitive processes, the non-interference of the program, and their implicitness and continuity. EEG is considered a physiological indicator, which can be used as an online and continuous cognitive load measurement method to detect subtle fluctuations in instantaneous load. Measuring the changes in alpha and theta brainwave rhythms reflects what happens in the participant's information processing situation, even if the participant does not know these changes or cannot express them in words [2].

2 Materials and Methods

2.1 Participants and Procedures

In this study, we recruited 41 medical students between 17 and 27 years old (21.10 ± 2.79, 15 male and 26 female). The whole experiment consists of three main steps. Firstly, the participants were required to conduct a pre-test on a training box. The pre-test contains three fundamental surgery skills tasks and one colon resection task (Pre-CRT). During the operation, we recorded the heart rate and EEG data, using Polar H10 heart rate monitor chest strap and Muse 2 brain wave monitor respectively. Besides, the whole procedure was recorded as videos. Secondly, the participants were asked to conduct the same kind of tasks on VRLS. Everyone had to complete 4 trials within a week, and each trial lasts about 30 minutes. Finally, we required our participants to conduct the post-test. The post-test (Post-FT and Post-CRT) is the same as the pre-test. After finishing all experiments, participants were asked to complete four questionnaires regarding the cognitive load and flow experience. We utilize the NASA-TLX scale to measure the cognitive load. To measure the

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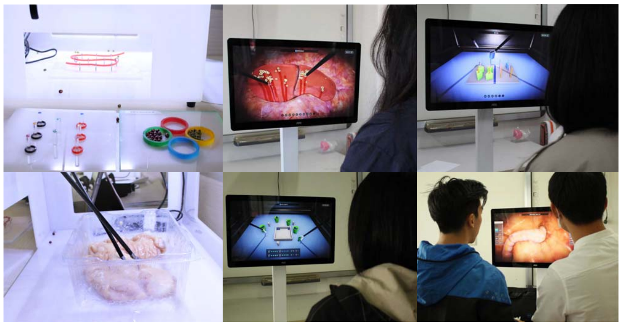

Figure 2: Three fundamental surgery tasks including peg transfer, picking beans an threading skill practice (Left upper) and the colon resection task (Left below). Medical students were training on VRLS(Right two columns).

flow experience during the experiments, we combine two scales from EGame scale [3] and Cheng's scale [5] and redesigned the questions according to our experiments.

The VR laparoscopic simulator (Fig. 2 right two columns) was developed by State Key Lab of VR Tech & Syst of Beihang University. The simulator consists of two major components. The first component a high-performance PC connected with a touch-screen monitor. The second component is the simulation module, which contains two surgical handlers connected with haptic devices and a navigation camera in a box. Two-foot pedals were utilized to activate the electrosurgical coagulation during surgery training.

2.2 Data Processing

In this study, we obtain three types of data. The first is the performance scores computed from recorded videos according to the GOALS standards for colon resection task and our designed measure rules (e.g. completion time, number of mistakes, etc.) for fundamental surgery skill tasks. The second is the physiological data extracted from heart rate and EEG. The performance scores and physiological data need to be processed before getting meaningful information. The third is the self-reported scores including cognitive load scores and flow experience scores computed from questionnaires.

For performance scores, the fundamental surgery skill tasks and colon resection tasks are measured from different dimensions. The scores of each dimension are normalized and scaled to $[0,10]$, then we obtain the final performance score by the sum of all items.

For physiological data, we filtered the EEG data according to four data quality indicators and the EOG signal. Then, we could process physiological data from the time domain, frequency domain and nonlinear domain. For heart rate data, we compute each participants' average, minimum, maximum heart rate. To study the cognitive load change between pre-test and post-test using EEG data, we compute the participants' cognitive load score according to [1].

3 Results

We could measure one's surgical skill proficiency using task completion time. The efficiency of participants improved 1.6 and 5.4 times for the fundamental surgery task and colon resection task respectively. The Pre-FT and Pre-CRT scores are significantly lower than Post-FT and Post-CRT scores ($p < 0.01$) respectively. We also inspect the performance change of colon resection task in each dimension of GOALS standard. We found that the participants' performance are enhanced in all four dimensions: depth perception ($p < 0.001$), bimanual dexterity ($p < 0.001$), efficiency ($p < 0.001$), tissue handling and autonomy ($p < 0.001$). In summary, the results of performance scores indicated that VRLS could significantly improve the acquisition of surgical skills.

When calculating cognitive load, we only considered α and θ frequency spectrums. The post cognitive load is significantly lower than cognitive load of Pre-FT ($p = 0.04 < 0.05$). The results demonstrate that the participants' surgery performance has a relation with their physical-psychological state. Developed skills might indicate lower cognitive load, moderate heart rate and flow experience. According to NASA-TLX scale, the overall cognitive load of 41 participants is lower than the midpoint of the full range ($[0,10]$). The mental demand (M = 5.00 SD = 1.67), physical demand (M=5.34, SD = 2.44) and effort (M = 6.00, SD = 1.48) dimensions were the mainly components that affect participants' cognitive load. The flow experience of the participants is investigated through self-reported psychological flow questionnaires and heart rates. We observe that the average heart rate decrease significantly ($p < 0.05$). Especially, the maximum heart rate decrease at the post-test procedure ($p < 0.05$). From the aspect of flow dimension, the score is $3.95/5.0 \pm 0.96$ which is a relatively high score. We might conclude that the participants obtain a good experience during the whole experiment.

In four tasks, we found that the cognitive load has negative influence on the participants' performance. For the Pre-FT, the cognitive load score is negatively related with the performance score ($R^2 = 0.79, p = 0.1$). For the Post-FT task, it also shows negative relation but not significant ($R^2 = 0.74, p = 0.3$). For Pre-CRT, the cognitive load score is significantly negatively related with the performance score ($R^2 = 0.74, p < 0.001$). The negative relation is also shown in Post-CRT ($R^2 = 0.61, p = 0.05$).

4 Conclusion

In this paper, we quantitatively investigate the influence of VRLS on medical students from three aspects: performance evaluation, physiology (heart rate and EEG) and self-reported cognitive load and flow experience. The experimental results demonstrate that the VRLS could highly improve medical students' performance and enable the participants to obtain flow experience with a lower cognitive load.

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