Research on the Relationship between Virtual Reality Content and Physiological Response

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Abstract. The development of VR (virtual reality) technology has greatly promoted immersion, but it may cause people to worry about the safety of humans. This study aims to determine the effect of virtual reality based on 9D-VR seat (9 Dimension VR Seat) on the physiological response of users. Recruit 20 volunteers to experience the VR roller coaster and VR big pendulum. Through analysis of heart rate data with visualization and statistical, it is found that there is a significant effect on heart rate when users experience virtual reality, and the excitement points of the VR content were related to the changes in heart rate. Further, we found that the difference between the first experience and the second experience for the same VR content, and the changes in heart rate have eased. These findings provide references for the analysis of users for VR and the design of content of the VR.

Keywords. Virtual reality; immersion; heart rate.

1. Introduction
Virtual reality technology has always aimed to build a realistic virtual world and constantly pursues high immersion. Immersion refers to the psychological feeling that users feel as if they have entered the real world in a virtual environment constructed by virtual reality technology. Realistic virtual environments, natural interactions, and perception systems are the determinants of immersion [1-3]. With the popularization of head-mounted displays such as Oculus Rift [4] and Htc Vive [5] and the innovation of multi-dimensional interactive technology [6], the development of virtual reality technology has been promoted, which greatly improves the immersion of virtual reality and continues to deepen application to various fields.

The higher the degree of immersion created by the virtual environment, the higher the degree of existence felt by the individual [7]. If the user faces the stimulus of fear through virtual reality, he will feel that the situation is real because he has received sensory information. At this stage, the sympathetic nervous system will be active and work to detect signs of danger [8]. One of the possible effects is a change in heart rate. Therefore, the impact of virtual reality technology on the user’s physiological response and emotional state needs to be explored [9].

The testers took advantage of the objective advantage of the college cohort: college students were selected for the experiment because they were included in the emerging adult category, which tends to be more immersed in virtual reality than mid-to-late adults. The higher immersion tendency makes it
easier to show the effects of virtual reality on physiological responses and emotional conditions. The immersion and adaptability of college students to virtual reality content indicate that the experimental data of college students are more representative [10-12].

9D-VR seat follows the content of the virtual scene and provides corresponding changes, such as virtual roller coasters [13-14] etc., which not only form a realistic virtual world, but also simulate the climbing and falling movements of the virtual scene, enhancing the user’s overweight and weightlessness. Such experience further enhances the immersion of virtual reality. In reality, patients with some diseases such as heart disease or fear of heights, etc. are not allowed to participate in this kind of exercise. Therefore, it is an urgent problem to be explored whether virtual reality technology has an impact on the stimulation of users.

In summary, this study aims to explore the impact of virtual reality scenes based on 9D-VR seat on the user’s physiological response and emotional state. First, we designed the virtual reality roller coaster and virtual reality pendulum project based on 9D-VR seat and designed the user’s physiological parameter acquisition system. Then recruit 20 volunteers to participate in the virtual reality project experience to obtain heart rate data in resting, the first experience and the second experience for the same VR content state. Finally, the correlation between the virtual reality content and the user’s physiological response is analysed through data visualization and statistical analysis methods.

2. Materials and Methods
We present the research questions, research participant information, experimental VR projects, experimental equipment, and experimental design.

2.1. Research Questions
The research questions were:
· Does virtual reality technology affect the heart rate of users?
· Is the virtual reality content related to the user’s heart rate?
· Is there a difference between the first experience and the second experience of virtual reality for the user’s experience?

2.2. Participants
The research project in this study recruited 20 volunteers, including 13 males and 7 females (average age of 20 and 17 years). Volunteers are generally proficient in the use of the Internet and computers. The volunteers did not have cardio-cerebrovascular diseases, motion sickness, etc., and passed the basic VR experience test without abnormalities. The volunteers fully understood the nature of the research and signed a consent form before participating.

2.3. The Design of VR Experience and Data Collection System

2.3.1. System Hardware Design. This research needs to obtain the user’s physiological data in the VR environment. Therefore, it requires a better VR experience environment and accurate and convenient data collection. The system hardware consists of a computer, a heart rate monitor, a virtual reality head-mounted display (VR headsets) and a 9D-VR seat. The structure of the system hardware is shown in figure 1.

The heart rate monitor comprises a host, a pulse wave probe, cables, straps, etc., and is wirelessly connected to a display terminal such as a smart phone via Bluetooth. One end of the pulse wave probe interface is connected to a cuffless sphygmomanometer, and the other end is a pulse wave probe clip. Between the index finger. During the measurement, the measured value will be displayed in real time. After the measurement is completed, the measured heart rate data will be exported on the mobile phone APP.
The follow-up of the 9D-VR seat greatly restores the scene seen in the VR headset. The 9D-VR seat is based on a highly interactive social link design and has a strong dynamic simulation system that supports up and down, left, and right, forward, and backward movements, and enhances the VR experience the authenticity of the content. And the game screen is played in real time, which makes the game atmosphere more intense, and because of its continuous output of virtual reality content, the experiencer’s sense of immersion is stronger.

2.3.2. System Software Design. To achieve a better VR immersion experience, we designed the VR roller coaster and VR big pendulum project. VR roller coaster and VR big pendulum are typical VR experience projects. VR roller coaster can experience the feeling of overweight and weightlessness by simulating a roller coaster to climb, slide, and reverse on the track. The VR big pendulum can experience overweight and weightlessness by simulating the user riding on a rotating pendulum to swing back and forth. With a VR headset, users can view the entire virtual environment in real time, and combine the ups and downs of the 9D operation to simulate the climbing and falling effects of a roller coaster, which has a strong simulation effect and a strong stimulus. There are three different sound effects in the entire roller coaster project, namely wind, Screaming, and Cheers. Among them, wind and Screaming are played in a loop, while Cheers are cheers after the roller coaster runs, which enhances the immersion of the VR experience. The heart rate data is obtained directly through the mobile phone APP, and the measurement data is exported for data analysis. Calibration is required during the experiment to ensure the synchronization and accuracy of the data acquisition and the VR content.

2.3.3. Design of the Experiment. This experiment is to explore the changes in the heart rate of users in the VR environment, and to analyse the relationship between the irritation of VR content and the changes in heart rate. Further, we analyse the relationship between the heart rate changes between the first VR experience and the same content experience again.

Each participant conducts three heart rate data acquisitions, which are the heart rate data acquisition under three scenarios of resting no VR experience, first VR experience, and VR experience again, as follows:

(1) Measurement of heart rate at rest without VR experience. Under the condition of ensuring that the experiencer is in a resting environment, and the experiencer maintains a resting state throughout
the whole process, the normal heart rate of the experiencer is measured by the heart rate monitor as a control experiment, as shown in figure 2.

(2) Heart rate data collection for the first VR experience. In the same resting environment, the experiencer wears a VR headset and a heart rate monitoring device, and sits on a dynamic seat to experience the roller coaster and the pendulum project for the first time, as shown in figure 3.

Figure 2. Measurement of heart rate at rest without VR experience.

Figure 3. User experience 9D-VR Seat project.

(3) Experience heart rate data collection in VR. In this experiment, after experiencing the two items for the first time (the time interval is about 10-15 minutes), the experiencer sits on the dynamic seat again, experiences the same item as the second group, and measures real-time heart rate data.

2.3.4. Data Visualization and Statistical Methods. In order to compare the relationship between heart rate changes and the stimulation points of the VR project, MATLAB was used for image rendering and image visualization analysis. In order to further analyse the changes of the user in the resting state and the VR experience state, analysis of variance [15] and sample t-test [16] are used for analysis, and calculations are performed by SPSS software.

In this experiment, the analysis of variance was used to study the three-time heart rate comparison between the resting state and the first experience roller coaster and the pendulum project, to study whether the VR content will affect the human heart rate changes. The significance level>0.05 indicates that in the existing samples, the independent variable has no significant influence on the dependent variable.

In this experiment, the sample t-test was used to analyse the heart rate changes of the same
experiencer for the first experience and the second experience of the VR project content, and calculate whether there is a significant difference. Judging whether there is a difference through the significance data. If the significance is <0.01, the two variables are different at the 0.01 significance level; if 0.01<significance value <0.05, the two variables are different at the 0.05 significance level; if the significance is >0.05, the two variables are significant at 0.05 There is no difference at the sexual level.

3. Results and Discussion

3.1. Heart Rate Analysis at Rest and the First VR Experience State
In the resting state (as the first group), the first roller coaster experience and the first big pendulum experience (as the second group), the user’s heart rate (average value) curve is shown in figure 4.

![Figure 4. The user’s heart rate curve of the resting state and the first experience state.](image)

It can be observed from figure 5 that the heart rate of roller coaster project changes significantly in VR state, while the heart rate of pendulum project does not change significantly in VR state.

Further analysis of variance is carried out. If the significance level is lower than 0.05, indicating that the heart rate in the resting state is indeed different from that in the first VR experience, as shown in tables 1 and 2.

| N  | Mean  | Std. Deviation | Std. Error | 95% Confidence Interval for Mean | Minimum | Maximum |
|----|-------|----------------|------------|---------------------------------|---------|---------|
| 1  | 60    | 67.85          | 3.107      | 67.05                           | 62      | 76      |
| 2  | 60    | 79.90          | 8.014      | 77.83                           | 67      | 105     |
| 3  | 60    | 71.58          | 5.353      | 70.20                           | 65      | 85      |
| Total | 180  | 73.11          | 7.701      | 71.98                           | 62      | 105     |

| Table 2. Test of Homogeneity of Variances. |
|-------------------------------------------|
| Levene Statistic | df1 | df2 | Sig. |
|------------------|-----|-----|------|
| 12.143           | 2   | 177 | 0.000 |
The result of homogeneity test of variance is to obtain significance level, namely Sig value. T usually says sig is lower than 0.05, reject the assumption of homogeneity of variance, and support it on the contrary. In this experiment, the homogeneity of variance test “significance” is 0, because the significance of 0 is lower than 0.05, therefore, homogeneity of variance is not equal. The premise of ANOVA is that ANOVA has a requirement on the homogeneity of variances of each group (that is, whether the variances of each group are consistent). If the variances are not homogeneous, ANOVA cannot be used.

In this experiment, non-parametric test (Kruskal-Wallis test was selected) was used because the variance test did not meet the conditions. Kruskal-Wallis test: a nonparametric method for one-way analysis of variance. The test result is shown in figure 5.

![Hypothesis Test Summary](image)

As can be seen from figure 6, the significance was 0, less than 0.05, indicating that the significance is obvious, the null hypothesis is not valid, that is, the difference in the mean of the two groups of experiments indicates that the heart rate data of the two groups are indeed significantly different.

Further, we analysed the correlation between heart rate and VR content. We annotated the time points of important excitement events in the VR content and observed the response of heart rate to these stimulation points. Figure 7 shows the corresponding comparison between the excitement points recorded in the roller coaster project and the heart rate curve. Figure 8 shows the corresponding comparison between the excitement points recorded in the big pendulum project and the heart rate curve.

From figures 6 and 7, we found that the fluctuation of user’s heart rate basically conforms to the design of excitement points in VR content, and the heart rate changes accordingly with different degree of excitement events. This result can confirm that VR content is related to the physiological changes of human.

![Figure 6](image)

**Figure 6.** The comparison between the excitement points recorded in the roller coaster project and the heart rate curve.
3.2. Heart Rate Analysis at the First and the Second VR Experience State

In the first and the second VR experience of the roller coaster and the big pendulum experience, the user’s heart rate (average value) curve is shown in figure 8.

Figure 8 shows a significant difference in heart rate between the first experience and the second experience in the roller coaster project, and the fluctuation of heart rate in the second experience is significantly alleviated. There is an overall instability between the first and second experiences in the Great Pendulum project. The heart rate curve from the first experience also found that the change of heart rate caused by the pendulum was not obvious. The comprehensive analysis shows that the big pendulum project is after the roller coaster project and has certain psychological adaptability. Meanwhile, the big pendulum is a periodic movement, so the users have enough psychological preparation. Further analysis is made through sample t-test, as shown in table 3.
Table 3. T-test results of paired samples.

|                        | Mean  | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | t     | df  | Sig. (2-tailed) |
|------------------------|-------|----------------|-----------------|------------------------------------------|-------|-----|-----------------|
| The Second & The Third | 10.650| 8.635          | 1.115           | 8.419 - 12.881                          | 9.553 | 59  | 0.000           |
| of Roller Coaster Heart Rates |       |                |                 |                                          |       |     |                 |
| The Second & The Third | -6.650| 7.942          | 1.025           | -8.702 - -4.598                         | 6.486 | 59  | 0.000           |
| of Big Pendulum Heart Rate |       |                |                 |                                          |       |     |                 |

According to the paired-sample t-test results, Sig (double-tailed) is lower than 0.05, proving that the original hypothesis is not valid, there is a significant difference. In other words, there are differences in the effect of VR experiment contents on heart rate.

4. Conclusion and Future Work

User security concerns are an important challenge affecting virtual reality technology. The results of our study show that the content type is one of the influencing factors. By comparing the user’s heart rate data in the resting state and VR state, it can be confirmed that the heart rate changes significantly in the VR state, indicating that VR experience can well improve the user’s psychological tension. At the same time, we also confirmed that heart rate changes were closely related to VR content. This has a high reference for us to design the content of virtual reality. Finally, we found significant differences between the first experience and the second experience of VR content. The change of heart rate during the second experience was significantly lower than that of the first experience, indicating that the second experience could effectively relieve the psychological tension due to the predictability of the content but could improve the pleasure of the user experience.

In future studies, we would like to include additional VR devices and types of physiological parameters. It can explore the relationship between more user physiological parameters and virtual reality content and establish user-centered virtual reality technology design and content specifications.

Acknowledgments

This research was funded by the Key Project on Anhui Provincial Natural Science Study by Colleges and Universities under Grant (No.KJ2019A0555), Anhui philosophy and Social Sciences Planning Project (No.AHSKQ2018D74), Key Projects for Supporting Outstanding Young Talents in Colleges and Universities (No.GXYQ2017213), Natural Science Project of Anhui Province (No.KJ2019A1194).

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