Measuring Experience of Immersion with Heart Rate: The impact of a Haptic Backpack

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Abstract—
In the world of virtual reality gaming, haptic devices such as haptic backpacks are used to achieve a higher level of immersion. Measuring the experience of immersion evaluates the user experience and has previously also been physiologically measured by measuring heart rate. This paper researches how a haptic backpack influences the correlation between the heart rate and the experience of immersion in virtual reality games, since heavy vibrations in the chest potentially impact heart rate. The hypothesis is that with a haptic backpack, the positive correlation between the heart rate and the experience of immersion still exists. To correlate heart rate and experience of immersion, we vary the immersion and evaluate if the heart rate follows. To do so, twenty participants played two games each: a high immersion game and a low immersion game. The heart rate was measured and the participant filled in a questionnaire on experience of immersion. One group played both games while wearing a haptic backpack and the other group without. The correlation between the heart rate and the experience of immersion score was significant for the group with haptic backpack, but not for the group without haptic backpack. The slopes were not significantly different. We conclude that the heart rate can still be used as a measure for the experience of immersion with a haptic backpack. Limitations are that physical activity must be approximately the same in both games, and that stress should increase when experience of immersion increases.

Virtual reality, haptic backpack, heart rate, experience of immersion.

1 Introduction

Over the past few years, virtual reality (VR) games have become increasingly popular. A factor that determines the VR experience satisfaction of the user is the experience of immersion [1], which is defined as *"the phenomenon in which the subject feels part of the experience as a whole, encompassing all spheres of attention"* [2]. The most important outcomes of playing an immersive game are the lack of awareness of time, a loss of awareness of the real world and involvement or a sense of being in the task environment [3].

Previously a positive correlation between presence and heart rate has been shown in stressful environments, and additionally that heart rate is a reliable, sensitive, valid and objective measure for presence [4]. Here, presence is *"the feeling of actually being in the virtual environment"*. For measuring how immersed people feel in games, not only presence, but also basic attention, temporal dissociation, balance of ability level and challenge, emotional involvement and enjoyment are important factors [3].

With the advancements in the VR industry, accessories such as haptic vests are becoming more prominent. In our experiment we will use the "bass speaker" haptic backpack. The feedback given by this backpack can be felt through the entire torso, all the way to the front. Since this haptic feedback is intense and applied to the chest, the haptic feedback may impact the heart rate, making it unsuitable as an objective measure for the experience of immersion. This is what we will evaluate in this paper.

This paper aims to answer the following research question: *"How does the haptic backpack influence the relation between the heart rate and the experience of immersion in a virtual reality game?"*. This will be done by accepting or rejecting the following hypothesis.

- H_1: With a haptic backpack, the positive correlation between the heart rate and the experience of immersion still exists.
- H_0: With a haptic backpack, the positive correlation between heart rate and the experience of immersion does not hold anymore.

First we evaluate whether experience of immersion for our chosen games shows a positive correlation with heart rate. After, we can evaluate whether we still obtain a similar correlation with the haptic backpack.

This paper is structured as follows. Section 2 explains how the experiment was setup and what measurements were taken to find the result. Section 3 presents the results of the experiment and section 4 interprets their meaning and validity. Finally, section 5 concludes the paper.

2 Method

This section describes the experiment setup, how the metrics were obtained and the experimental procedure.

2.1 Experiment setup

The experiment was conducted on 20 participants that were split up into two groups of 10 people. One group played while wearing the haptic backpack. The other group played without the haptic backpack

To evaluate the correlation between heart rate and experience of immersion, the data must contain a difference creating a correlation first. This was achieved by varying the immersion and measuring the resulting heart rate and experience of immersion. Using a HTC Vive Pro [5] headset

and controllers, all participants played both a low immersion and a high immersion game. Each group of ten was further split into two groups of five to play the games in different orders, eliminating any order effects. People with prior VR and game experience were divided as equally over the groups as possible, see section 2.2.3.

(a) High immersion game (b) Low immersion game

Fig. 1: The two games used to create a difference in immersion. A video from the high immersion game is visible here [6]. A video for the low immersion game (b) is visible here [7].

2.1.1 High immersion game

Asgard's Wrath, a game by *Sanzaru Games*, is available in the Oculus Store [8]. The kraken emerges and the player has to fight it, see Figure 1a and the video [6]. The kraken attacks by throwing ships, sending fish and picking the player up with his tongue. The player has to defend himself and attack by swinging his sword.

2.1.2 Low immersion game

Unity blocks is a self-made game in Unity, where the participant slices blocks with a white cylinder representing a sword, while the blocks are moving towards the player, see Figure 1b and the video [7]. If the sword is not swung hard enough, the block will not break, but bounce off the sword. When the block breaks, the sound of a breaking ship from the high immersion game is played. The Unity source code is available on Github [9].

The hits in the low immersion game were timed such that these occur at the same moment as each sword slashes in the video of the high immersion game [10]. This is to prevent that the heart rate varies due to a difference in physical activity.

2.1.3 Haptic Backpack

The haptic backpack used is the *Aura Interactor*. The backpack contains a bass speaker, which is attached to an amplifier, connected to the computer game sound. The amplifier filters out higher frequencies and converts the sound to a lower frequency. The amplifier settings were tuned to a power level of 6. Do note that the volume output of the PC affects the backpack vibration as well, it was set to 32 for the PC. With this power level it was possible to feel subtle differences in intensity, while you could feel it all the way to the front of the chest. The filter level was tuned until all ships, fish (softly) and some kraken sounds could be felt, but not other ambient sounds. The filter level also depends on the power output, which was set to 8.7 in our case.

2.2 Measurements

During the experiment the following variables were measured.

2.2.1 ΔHeart rate

The heart rate was measured objectively by the *Polar H10* [11] heart rate chest band. The heart rate measurement was split up into three parts, namely the heart rate during the first game, during the second game and in rest, measured during the questionnaire after each VR session. Since it took time for the heart rate to decrease after the experiment, only the measurements after 100 seconds were used for determining the heart rate in rest as we noticed the heart rate became stable after this time period for all participants. The participants filled in two questionnaires, where both the rest measurements were averaged to obtain *mean heart rate in rest*. The measure used is given in Equation 1.

$$\Delta \textit{Heart rate} = \textit{mean heart rate in game} - \textit{mean heart rate in rest} \quad (1)$$

For both games the measurement was started at the first hit of the game and stopped after the fight.

2.2.2 Experience of immersion

The experience of immersion was measured subjectively with the experience of immersion questionnaire [3], which is commonly used to measure the experience of immersion in games. Two questions regarding moving around in VR were removed, since the participant were not required to move around in the virtual world. The full questionnaire to determine the experience of immersion consists of questions 1 to 31 as shown in appendix A. The participants indicate per question if they strongly disagree or agree with scores from 0 to 4 respectively. Each question was asked twice, but then formulated with a negative statement to compensate for any answering bias. For these questions the scale was flipped to calculate the score. The scores per question were summed up to obtain the final experience of immersion score ranging from 0 till 130, including Q31 with a maximum of 10 points. Each participant filled in the questionnaire twice in total, once after every game.

2.2.3 Participants

The participants were mostly university students. Out of 20 participants, 15 were male and 5 were female. The age ranged from 18 to 27 years old. Prior to the experiment participants were asked about their experience in VR games. Participants were said to be experienced when they had at least played three hours with motion controllers. They were also asked for experience in regular 3D third of first person games. They were considered experienced when they played these games weekly. Three participants had VR experience and 13 had experience in playing traditional video games. These people were evenly distributed between the four possible combinations: with and without backpack combined with the playing order of the two games.

2.3 Procedure

First the participants filled in the consent form containing a brief explanation of the experiment, the two games, and the risks of nausea and getting scared. They put on the heart rate belt and received an explanation on the controls and creating a sharp view in the headset. When they started the VR game, their heart rate was measured, see section 2.2.1.

Afterward, they filled in the immersion score questionnaire, during which the rest heart rate is measured. Then they played the other game and filled in the same questionnaire again.

3 Results

After summing up the experience of immersion scores and processing the heart rate measurements as described in section 2, the Δ*Heart rate* was plotted against the *the experience of immersion score*. This was done separately for both with and without backpack. The result is shown in Figure 2. Each point here is the result of one participant playing one game, resulting in one low immersion and one high immersion point per participant.

To find if the slopes in Figure 2a and Figure 2b are significantly different, a non-significant p-value of 0.1547 was found with the *regression, comparing slopes and intercepts* tool in the Prism software [12].

The mean values for the heart rate and the experience of immersion scores were computed and can be found in table 1.

Mean values	ΔHeart rate [bpm]	Exp. of Immersion scores
No backpack, low immersion	12.87	76.5
No backpack, high immersion	18.34	92.5
Backpack, low immersion	9.43	82.3
Backpack, high immersion	16.48	97.9

TABLE 1: The mean values for the heart rate and the experience of immersion scores are shown for each condition. Each cell contains a mean from ten participants.

For both groups, the Δheart rate and the experience of immersion scores are higher for the high immersion game than for the low immersion game, see Table 1. For both heart rate and experience of immersion between no backpack and with backpack, no significant difference was found. Because the experiment has a small sample size, the data was compared using the *Mann-Whitney U test* as shown in in Table 2. Only without backpack, the difference in heart rate between low and high immersion environment is non-significant ($p > 0.05$).

Mann-Whitney Test p-value	ΔHeart rate	Exp. of Immersion scores
No backpack	0.060612252	0.005054286
Backpack	0.022577285	0.031861125

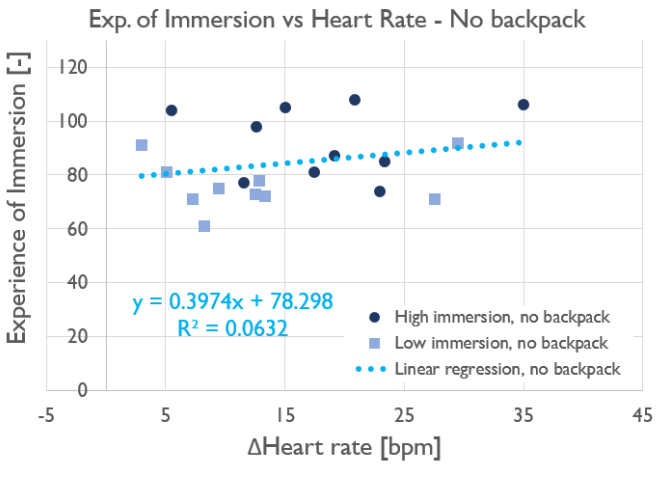
TABLE 2: The Mann-Whitney test p-value comparing between low and high immersion game.

4 Discussion

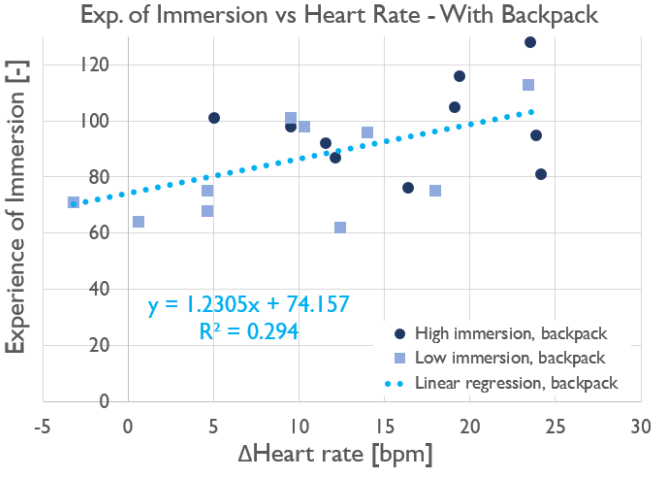
4.1 Results interpretation

The correlation between the heart rate and experience of immersion was not significant without the backpack, while it was significant with the backpack. The non significance can be due to the high variability between the participants in the group without the backpack. It could also be that the haptic backpack does increase the contrast between the low and high immersion environment, since some participants found the haptic backpack annoying in the low immersion game, while they thought it added something in the high immersion game.

The slopes in the high and low immersion games were compared and are not significantly different ($p = 0.1547$, $p > 0.05$). This means that if the slopes of the two groups with and without backpack are identical in reality, there is a chance of 15.47% of choosing 10 points randomly that would result in slopes with the same difference as the current difference. Therefore, it can be concluded that the differences between the slopes are not significant. However, this does not necessarily mean that the slopes are significantly the same.



(a) Without backpack



(b) With backpack

Fig. 2: The correlation between experience of immersion scores and ΔHeart rate without haptic backpack (a), is non significant ($p = 0.2851 > 0.05$), while with backpack (b) it is significant ($p = 0.0135 < 0.05$ and $F = 7.495 > 2.1906$). In both plots the linear regression through all points is plotted with the corresponding formula. The slopes of these lines are not significantly different ($p = 0.1547 > 0.05$).

The difference in heart rate and experience of immersion score between the two games were evaluated per participant. In this case, 18 of of 20 participants showed a higher heart rate for the high immersion game. 17 out of 20 participants reported a higher experience of immersion score for the high immersion game compared to the low immersion game, where the experience of immersion outliers were different individuals compared to the outliers in the heart rate. From the data it can be seen that for 15 out of 20 participants, both the heart rate and the experience of immersion score increased for the high immersion game.

There was no significant difference in heart rate or experience of immersion score between with and without backpack. This was probably due to it being tested between subjects: they could not compare with and without. However, asking if they found the haptic backpack to add immersion (Q35), people reported they found it to increase immersion during playing (3.4/4 average), especially for the high immersion environment. The backpack was hardly perceived as being annoying (Q36), with an average score of 1/4 and 0.3/4 for the low and high immersion game respectively.

4.2 External influences

To evaluate if the haptic backpack interfered with the heart rate sensor on the chest, a separate subject was seated, and the game audio played through the backpack. The data from the sensor did not give any indication that there was interference compared to sitting without the haptic backpack.

Questions 32 to 37 evaluate the effects of external factors. Participants on average said they noticed the chest band on 4/10 scale during playing (Q32). This may have distracted them, but it was scored approximately equal for all groups.

Nausea can influence the experience of immersion, but only 3 out of 20 participants rated nausea higher than 3/10 (Q33). Remarkable was that all three of these scores were given after playing the high immersion game without the haptic backpack. Only one of those participants rated the high immersion game with a lower immersion score than the block game.

The low immersion game was created to have the same movements as the high immersion game. The self reported physical activity score of the participants without backpack are close to each other 5.89/10 and 6/10 for low and high immersion respectively (Q34). However, with the backpack the low immersion game was averaged on 4.5/10 and high immersion on 5.9/10. This might be caused by the larger difference in immersion, because if a participant feels more immersed, they experience the activity as more intense. Another possibility is that it is just noise due to the variability between subjects. While watching the participants, there did not seem to be a large difference between the movements of the participants between the games.

In the low immersion game 5 out of 10 people filled in a score of 3/4 for whether they could hear the haptic backpack during playing (Q37), the rest filled in 0. For the high immersion game 3 out of 10 people filled in a score of 3 or higher.

Something else that could affect the experience of immersion was the background noise of the environment. The experiment was not conducted in a private closed room. There were other people in the room working and sometimes talking. This external factor was not consistent throughout the experiment and thus could have influenced the participants experienced immersion differently.

4.3 Study Limitations

This experiment was executed with 20 participants: 10 participants played with the backpack and 10 without. They played both the high and low immersion game, which gives 20 sample points per plot. The conclusions in this paper are drawn based on this small number of samples, which causes uncertainty if the result is applicable to a larger population.

The participants in this experiment were put in a stressful virtual environment. In a study where participants were seated in a virtual airplane, a negative correlation was found for presence and heart rate [13], while in a different study with a stressful environment a positive correlation was found [4]. While presence is not the same as experience of immersion, it may indicate that using heart rate is only suitable for certain games, with more immersion causing more stress.

Physical activity must also be taken into account as it could influence the heart rate apart from immersion. The physical activity must therefore, like in this experiment, be approximately the same between the compared conditions.

4.4 Future Research

For future research, the same experiment should be conducted on a larger test group. It is also recommended to examine the effect in different types of games, such as relaxing games. Thereby, comparing the effect of smaller differences in immersion than changing the entire environment, such as the impact of (haptic) hardware or specific changes in the gameplay or environment, may be interesting.

5 Conclusion

This paper aimed to investigate the impact of a haptic backpack on the correlation between the heart rate and the experience of immersion. This was done by making participants play a low and a high immersion VR game, one group played with a haptic back and one group without. Then correlation between the experience of immersion and the heart rate was determined. Both groups showed an increase in the experience of immersion and heart rate for the high immersion game, this correlation was significant for the group with a haptic backpack and not significant for the group without. This resulted in the following conclusions:

- The correlation between heart rate and experienced immersion is found to be significant in the 'haptic backpack' group($p = 0.0135 < 0.05$).
- The correlation between heart rate and experienced immersion is found to be not significant in the 'no haptic backpack' group ($p = 0.2851 > 0.05$).]
- Comparing the correlation slopes of the 'haptic backpack' and the 'no haptic backpack' group do not show a significant difference.
- Therefore, the heart rate can be used as an objective measure for experience of immersion while wearing a haptic backpack.

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APPENDIX A
IMMERSION QUESTIONNAIRE

Participant number

_____

Which game did you just play?

- The block game.
- I fought the sea monster Cthulu.

Please rate how far you would agree with the statements below just before you were interrupted.
0 = Strongly Disagree; 1 = Disagree; 2 = Neutral; 3 = Agree; 4 = Strongly Agree.

1) *I felt that I really empathised/felt for with the game.*
2) *I did not feel any emotional attachment to the game.*
3) *I was interested in seeing how the game's events would progress.*
4) *It did not interest me to know what would happen next in the game.*
5) *I was in suspense about whether I would win or lose the game.*
6) *I was not concerned about whether I would win or lose the game.*
7) *I sometimes found myself to become so involved with the game that I wanted to speak to the game directly.*
8) *I did not find myself to become so caught up with the game that I wanted to speak to directly to the game.*
9) *I enjoyed the graphics and imagery of the game.*
10) *I did not like the graphics and imagery of the game.*
11) *I enjoyed playing the game.*
12) *Playing the game was not fun.*
13) *The controls were not easy to pick up.*
14) *There were not any particularly frustrating aspects of the controls to get the hang of.*
15) *I became unaware that I was even using any controls.*
16) *The controls were not invisible to me.*
17) *It was as if I could interact with the world of the game as if I was in the real world.*
18) *Interacting with the world of the game did not feel as real to me as it would be in the real world.*
19) *I was unaware of what was happening around me.*
20) *I was aware of surroundings.*
21) *I felt detached from the outside world.*
22) *I still felt attached to the real world.*
23) *At the time the game was my only concern.*
24) *Everyday thoughts and concerns were still very much on my mind.*
25) *I did not feel the urge at any point to stop playing and see what was going on around me.*
26) *I was interested to know what might be happening around me.*
27) *I did not feel like I was in the real world but the game world.*
28) *I still felt as if I was in the real world whilst playing.*
29) *To me it felt like only a very short amount of time had passed.*
30) *When playing the game time appeared to go by very slowly.*

Please rate the following statements from 1 till 10.

31) *How immersed did you feel? (1 = not at all immersed, 10 = very immersed)*
32) *I noticed the chest band during playing? (1 = not at all, 10 = very much)*
33) *I felt nauseous after playing? (1 = not at all, 10 = Very nauseous (retching))*
34) *How physically active did you feel while you were playing? (1 = Not active, 10 = Very active (sport))*

Did you use the haptic backpack?

- Yes (Go to haptics questions)
- No (Skip haptics questions)

Please rate how far you would agree with the statements.
0 = Strongly Disagree; 1 = Disagree; 2 = Neutral; 3 = Agree; 4 = Strongly Agree.

35) *The haptic backpack gave a more immersive game experience.*
36) *The haptic backpack was distracting.*
37) *I could hear (so not just feel) the haptic backpack itself during playing (and not just the sound from the headset).*

Do you have any comments, tips or remarks?

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