

1           **The Influence of Color and Texture Design in Virtual Reality Environments on**  
2           **Time Perception**  
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12          Virtual Reality Environments (VRE) allow users to fully immerse themselves, even forgetting how time passes. The manipulation of  
13          time perception is a widely discussed and investigated issue in psychology, and lately in studies of Human-Computer Interaction (HCI).  
14          Previous studies showed that different sensory cues affect the way people perceive time [6, 15]. The use of music, for instance, helps to  
15          reduce the experienced duration during gaming sessions, making Virtual Reality (VR) more enjoyable. However, there are only a  
16          few studies that investigated the influence of colors and textures on a person's time perception, as well as their effect on a person's  
17          mood in VR. Moreover, we aim to investigate whether the perception of the room and its initial impression can influence a person's  
18          perception of time. Considering these aspects, we conducted a study using four rooms with different colors (red and blue), and textures  
19          (brick and wood), which we presented to the user for a specific time in VRE. After each room, the user was asked to estimate the time  
20          they spent in the room. The results showed that participants estimated their time spent in the blue rooms to be closer to their actual  
21          times, while participants estimated their times spent in the red rooms to be longer than their actual times. Regarding texture, subjects  
22          overestimated time in brick-textured rooms more than wooden-textured rooms, regardless of the color. Therefore, our study suggests  
23          different assessments of duration depending on the color and texture. The results also showed a significant connection between  
24          comfortableness in the rooms and its impact on time perception. However, the interaction of color and texture had no influence on the  
25          time perception. The results serve as a guide for future works and help HCI researchers to create appropriate rooms according to their  
26          desired effect on users and increase the popularity of using VR in psychology for mental health care and enhance people's emotional  
27          well-being during VR sessions.  
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29          CCS Concepts: • **Human-centered computing** → **Virtual reality; Laboratory experiments.**  
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31          Additional Key Words and Phrases: VR, colour theory, time perception  
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37          **1 INTRODUCTION**  
38

39          Virtual Reality (VR) provides many possibilities to explore the interaction and perception between humans and the  
40          virtual world. Oftentimes, users report a sense of immersion when they resort to Virtual Reality Environments (VRE)[15].  
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53 One key trait for this phenomenon is the obliviousness of time passing. Recently, researchers in Human-Computer  
54 Interaction (HCI) showed interest in this field and attempted to understand time perception of humans during their  
55 engagement with the virtual world. Studies on the effect of visual stimuli, especially colors, are prevalently conducted in  
56 psychology. It is known that different colors can have different effects on humans and their mood [4, 10]. Nevertheless,  
57 there is a lack of research on the effect of colors and the influence of different patterns and the way people perceive  
58 time, and their overall experience in VRE. Resolving these questions can result in creating a more comfortable and  
59 enjoyable stay during VR sessions.  
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61 Research in HCI and psychology have shown that the way people perceive and estimate time can be influenced through  
62 stimulation of the sensory system for example by using visual [2], audiovisual and auditory [2, 6, 15] as well as olfactory  
63 cues [19]. In their study, Igazábal et al., created a waiting room based on the model of Witowska et al. real waiting  
64 room study. While comparing the real world to the virtual one, the latter displayed a longer perceived time experience  
65 regarding the time perception [8].  
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67 The influence of colors on time perception was investigated scientifically with different conclusions. Examining the  
68 effect of the colors red and blue on time perception are most common in both fields. Shibasaki et al. concluded that  
69 users perceive the duration of a red screen to be longer than a blue screen. However, the results reflected sex differences  
70 with men overestimating the duration of the red screen more than women [17]. The overestimation of duration, when  
71 enclosed with the color red, has been supported by various other studies [16]. Yet, in other studies, people overestimated  
72 the duration of blue as opposed to the color red with the conclusion that the influence and perception of time differ  
73 depending on the context and conditions [7, 16].  
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75 An assertion for the different results could be explained from a psychological view. Especially soothing colors like pink  
76 or blue are perceived as relaxing [12]. While designing a calming airport waiting room, the color red causes stress or  
77 fatigue, while purple is associated with anxiety, and a rise of blood pressure and heart rate [9]. This raises the question  
78 whether the initial perception of colors and change in mood can influence the perception of time.  
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80 Another possible and less investigated time manipulating factor is the impact of different textures - natural textures in  
81 particular - in VR on human time perception. In our study, we will investigate this aspect more closely.  
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83 To gather more information on how different textures and colors affect users' perception of time in VR, we conducted a  
84 VR lab study. In this study design, participants are placed in four virtual environments using VR glasses for a specified  
85 time interval. From the field of psychology [1, 5, 8, 11], we intend to transfer the gained knowledge into the virtual world.  
86 Our aim is to investigate whether there are differences in the perceived sense of time between real and virtual reality.  
87 For this purpose, a VR study is going to be conducted to contribute to a better understanding of human interaction with  
88 virtual reality for further VR studies by showing the correlative influence of different colors and textures on human  
89 perception of time in VR.  
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## 91 **2 METHODOLOGY**

92 There are only a few studies that examined the influence of colors, particularly in combination with textures on time  
93 perception in VR. Shibasaki and Masataka [17] proved that people overestimate the time spent in a red room. In textured  
94 rooms, however, subjects have to process more information leading to a greater load of data on memory and information  
95 processing. As a result, subjects overestimated the duration as they are being distracted by the information overload  
96 [13, 14]. Based on these results, we hypothesize that the combination of colors and textures has a significant influence  
97 on time perception in VR. In order to test if the interaction of colors and textures in VR is in line with our hypothesis,  
98 we conducted a VR study.  
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## 105 2.1 Study Design

106 We used a within-subject design. The independent variables were COLORS, TEXTURES and TIME. The examined  
107 colors are *red* and *blue*, and the textures are a *brick texture* and a *wooden texture*. In reference to the study of Davydenko  
108 and Peetz, we chose natural textures. They concluded that participants tended to overestimate time in nature settings,  
109 resulting in a reduction of stress level, and an elevated mood [14]. The subjects' estimated durations in the particular  
110 rooms were compared to findings in other studies [17, 18].

111 In order to analyze the influence of colors and textures on time perception, the participants are placed in virtual  
112 environments using VR glasses. The study participants are given the task to estimate the time spent in each individual  
113 room. The times spent in each room ranged from 15 to 47 seconds and were assigned randomly before every round.  
114 To ensure that the estimated durations correlate with the specific rooms and are not coincidental, the procedure was  
115 repeated four times per room with the set time duration rotating (latin square design).

## 116 120 2.2 Stimuli and Equipment

121 This study design allows us to measure the effect of the colors red and blue, as well as natural textures, on the individually  
122 perceived time spent in a particular room. These two colors are used in many psychological studies on time perception  
123 and allow us to ensure the comparability between similar studies [17, 18]. Furthermore, we investigated the effect of  
124 different wall textures on the subjects' perceived times spent in a virtual room. In a psychological study, Peetz and  
125 Davydenko detected an overestimation of time in nature settings in VR [14]. By adapting the previous knowledge  
126 and measured variables in a different context for our study, we initially needed to set up our test setting. For the  
127 implementation of the virtual rooms we used Unity, a development environment for games<sup>1</sup>. To achieve an aesthetic,  
128 real-looking wall texture, we used a package of the Unity Assets store<sup>2</sup>. Moreover, it is easy to integrate in the  
129 development environment and free for use. As technical output device, we used the Oculus Quest 2 (cf. fig. 1), by which  
130 the rooms were mapped. We decided to leave the rooms empty, in order to exclude any factors that may influence the  
131 results. The more data that has to be processed, the more likely it is that the participants overestimate the time spent in  
132 a room [13]. The subjects were given a break in between each room, during which they completed a survey about the  
133 virtual room they had just stayed in.

## 134 138 2.3 Procedure

139 Each participant was introduced to our study, explained the procedure, and later given a questionnaire on their demo-  
140 graphics. Afterwards, the subject entered the virtual rooms using the VR glasses. After each session, the participants  
141 were asked to estimate the duration they had spent in each room. Each room was presented with four different time  
142 spans in the colors red and blue, as well as the textures wood and stone, resulting in a total of 16 runs. After the  
143 participants focused on assessing the time, they entered the rooms again, but now concentrating on the textures and  
144 colors. At the end of the study, the subjects were asked to fill in a questionnaire on the effect of the color and texture on  
145 their individual time perception and attitude towards the presented colors and textures.

150 <sup>1</sup><https://unity.com/de>

151 Source Code on Github: [https://github.com/leoniehandschmann/MMI\\_VR\\_Color\\_Texture\\_TimePerception](https://github.com/leoniehandschmann/MMI_VR_Color_Texture_TimePerception)

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153 <sup>2</sup>Stone Texture: <https://assetstore.unity.com/packages/2d/textures-materials/brick/18-high-resolution-wall-textures-12567>

154 Wood Texture: <https://assetstore.unity.com/packages/2d/textures-materials/wood-textures-4k-179233>

155 Walls: <https://assetstore.unity.com/packages/3d/environments/snaps-prototype-office-137490>

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Fig. 1. Oculus Quest 2

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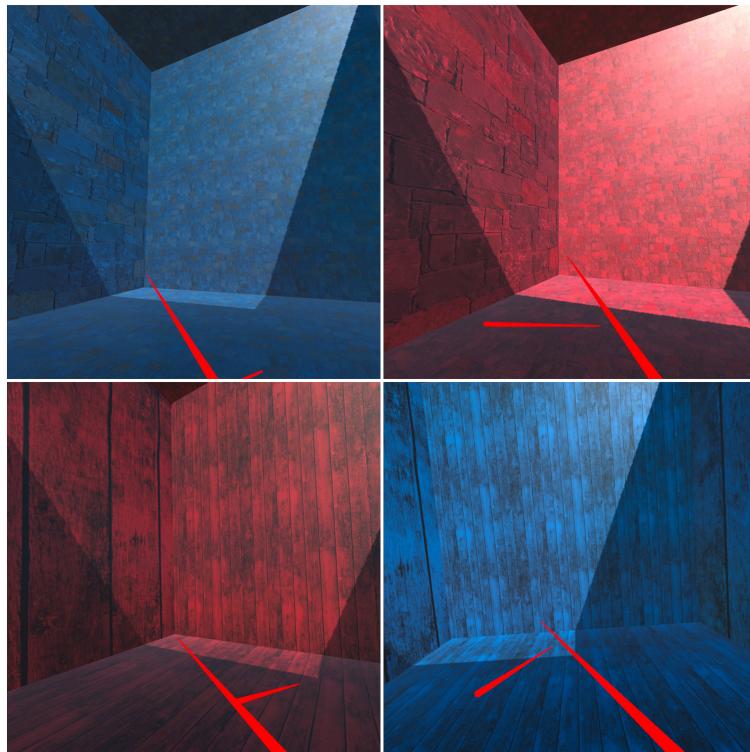


Fig. 2. Image of the VR-Rooms

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Fig. 3. Setup of the study

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## 2.4 Participants

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For the VR study we recruited 24 participants (12 male, 12 female) with their age ranging from  $M = 26.3$ ,  $SD = 10.22$ . The participants were mostly students of the Faculty of Language, Literature and Cultural Studies, especially from the Institute for Information & Media, Language & Culture. The students of the University Regensburg were compensated with credit points for their study course.

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## 3 RESULTS

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### 3.1 Quantitative Results regarding perceived times

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For our data analysis, we performed a two-way repeated measures ANOVA (rmANOVA). The analysis was performed on all measures with COLOR, TEXTURE and TIME as independent variables. For the classification of the results we chose a significance level of  $p=0.05$ . Additionally, we found a significant effect of color ( $F_{1,23} = 11.086$ ,  $p<0.003$ ) on the participant's individual time perception. Furthermore, with a value of  $p<0.008$  texture shows significant effects, too ( $F_{1,23} = 8.518$ ). These values are reflected in the qualitative results. Simultaneously, there were no statistically significant interactional effects of color and texture at the same time ( $(F_{1,23}) = 2.206$ ,  $p<0.151$ ). Reasons could be either the selection of the sample size, or not normalized data/ outliers in the data collection or unnoticed bias effects during the conduction of the experiment. Therefore, we executed a qualitative data collection at the same time to find out more about possible solutions for our quantitatively determined data.

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### 3.2 Qualitative Results regarding color and texture

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In order to understand the assessment of the perceived time, we asked the participants questions on how the colors and textures influenced their decision. The final survey on colors and textures yielded the following results: The room

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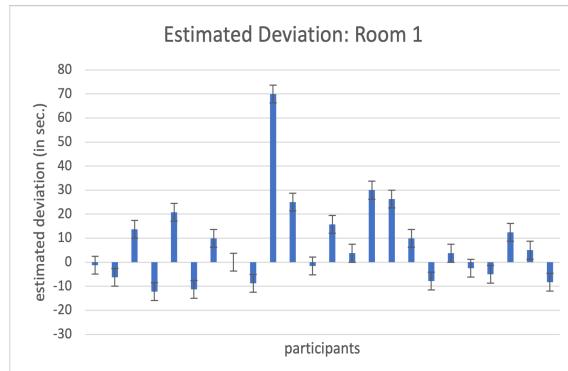


Fig. 4. red colored and stone textured room

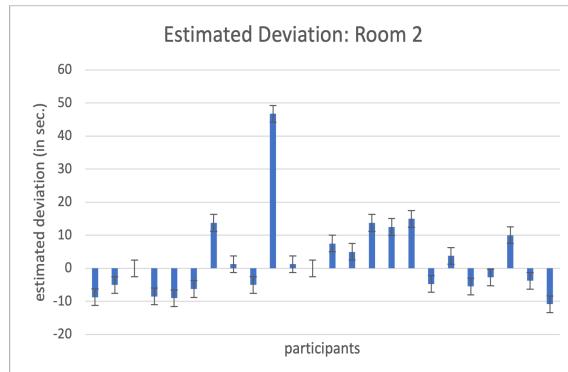


Fig. 5. blue colored and stone textured room

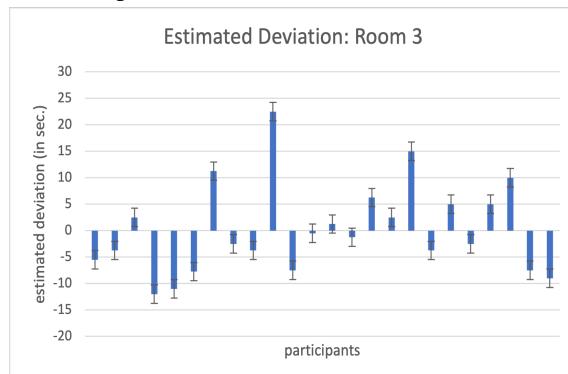


Fig. 6. red colored and wooden textured room

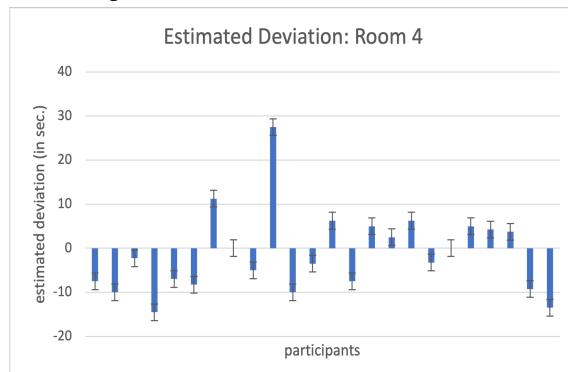


Fig. 7. blue colored and wooden textured room

313 with the blue color and stone texture was rated most positively overall. It is considered the tidiest with Ø4.25 out of 5,  
314 the most pleasant with Ø3.83 out of 5, and the clearest with Ø4.00 out of 5. Subjects felt most comfortable in the blue,  
315 stone-textured room (rated Ø4.17 out of 5). Overall, the blue room with wood texture scored the worst. It is considered  
316 the most boring room with Ø2.42 out of 5, and the most soporific room with Ø2.33 out of 5. Additionally, it is perceived  
317 as the most unpleasant with Ø2.79 out of 5.

318 Qualitative data can provide a more thorough explanation on why the participants perceived the rooms as they did.  
319 Furthermore, the free text responses of the survey support the findings that the blue stone-textured room is most  
320 relaxing. In addition to that, it is more pleasant for the eyes in the long run than, for example, a red room, since the color  
321 red was perceived as too glaring and dangerous to the participants. Some even reported getting headaches from the  
322 color red. The straight lines of the stone texture were observed as pleasant but rather cold, whereas the wood texture  
323 was deemed more realistic. The blue wood-textured room was regarded as constricting by the majority.  
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325 Additionally, subjects rated the color and texture per room, in terms of their effect, from 1(unpleasant) to 5 (pleasant).  
326 In order to prove that the color and texture of a room have an influence on the effect of the room, we performed  
327 a 2-way repeated measure anova. The Anova resulted in an F-Measure of 3.0914 and a p-Value of 0.0283 at a fixed  
328 significance level of 0.05. Thus,  $p < 0.05$ , which means there is a statistically significant difference between the room  
329 condition (regarding color and texture) and the effect of the room on a participant.  
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#### 331 4 DISCUSSION

332 Our study investigated the influence of colors and design patterns on the perceived time in VR. The results show that  
333 subjects overestimated time in brick-textured rooms, regardless of the color. However, participants overestimated time  
334 in red rooms compared to blue rooms. It is evident that we detected gender differences in their time assessment. Men  
335 tend to overestimate in all four rooms, but were closer to the actual time in rooms with wooden-texture, whereas  
336 women, even though the duration was also overestimated, guessed the duration better in all four rooms compared to  
337 men. However, women underestimated time in wooden-textured rooms.  
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339 Previous studies have shown different results regarding the effect of colors on the perception of time [17, 18]. Confirming  
340 the findings by Shibasaki et al. [16] that merely male participants surrounded by the color red tend to overestimate the  
341 duration, we concluded that men tend to overestimate the time in all four conditions, regardless of color and texture.  
342 However, male participants overestimated the duration more in red rooms, in line with the results of Shibasaki et al.  
343 [17].

344 Davydenko and Peetz [14] proved that natural settings in VR resulted in the participants overestimating the time  
345 during a walk, but caused a reduction in stress and improvement of the mood. Our study concluded similar results  
346 as Davydenko and Peetz [14]. Male subjects overestimated the time spent in all four rooms, whereas female subjects  
347 only overestimated the duration in brick-textured rooms. Female participants, however, underestimated the duration  
348 in wooden-textured rooms. To fully understand their decision and judgment of time, we collected qualitative data.  
349 The results showed that participants had mixed feelings towards the different textures, for instance, describing the  
350 stone-texture as cold but calming due to the many lines. The wooden-texture was described as more realistic and  
351 natural. Overall, participants preferred the stone-texture over the wood-texture. Even though the participants preferred  
352 the brick-textured rooms, the data showed that they overestimated the time more in the brick-textured rooms. This  
353 phenomenon can be explained with the storage-size memory model presented by Ornstein [13]. This model suggests  
354 that the amount of information that a human has to store during a particular time-slot is used to estimate time duration.  
355 If a subject has to process a great amount of information, he or she perceives the duration to last longer because  
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more information has to be recalled [13]. On the other side, the stone-texture rooms provided more information to be processed, being more fun to the eyes and offering more lines and texture. This resulted in an overestimation of time by the subjects since there was more visual information to process. Our results were in line with the theory of Ornstein. The issues presented supported the suggestion that the influence of color and texture is context-dependent. The different results of studies on the effect of the color red and blue on time perception were conducted in the real world with different tasks and conditions, resulting in different outcomes. Our study, however, was executed in VR and the participants were surrounded by the different color-texture combined rooms and could emerge themselves and perceive the color better than in real life. With the data showing a higher overestimation in red rooms and overall overestimation in all rooms, this suggests that the conditions (color as well as texture) have a greater influence on the time perception in VR compared to real life. Nevertheless, we concluded that the color and texture combination affected the mood of the subjects, which in result influenced the overall perception of time duration. According to psychological findings regarding the effect of color on humans [4, 10], colors influence the mood of human beings. Participants pointed out that the two colors had a different effect on them, with red being perceived as warm but dangerous, glaring and head-ache inducing when exposed for a long time. The color blue, however, appeared cold, fresh and calming. These assertions are well acquainted in psychological studies [3, 10]. According to the data, the color and texture affected the mood of the subjects, which is reflected in their judgment of time. While staying in a room that has been perceived as most comfortable and calming by subjects, the duration was overestimated compared to rooms that were perceived as uncomfortable and constricting. Another implication that rooms influenced the mood, and therefore the time duration estimation, is the combination of the color and texture. Combinations that are familiar and comfortable had a greater effect on time estimation because participants were more likely to overestimate the time. Unrealistic combinations were perceived as constricting and disturbing, resulting in better estimation of time.

It is noteworthy that there was a connection between the perception of colors and textures, and the perceived duration. In an uncomfortable environment, participants estimated the duration more accurately compared to rooms, which they perceived as stress reducing and comfortable. Therefore, the estimation of time was greatly influenced resulting in the participants' inaccurate assessment of time.

Even though we detected an effect on the perceived time, the data showed that there was no influence on time perception regarding the interaction of color and time. However, as we confirmed through the qualitative data, the rooms had an influence on the mood of participants and in turn on the time perception, in line with the study conducted by Davydenko and Peetz [14].

## 5 CONCLUSION & FUTURE WORK

In this paper, we investigated the influence of color in combination with natural textures on humans' time perception in VRE. We built four different VR rooms in Unity. The rooms were either red or blue, and either stone or wooden textured. Furthermore, the participants spent time spans ranging from 15 to 47 seconds in each virtual reality room and were asked to estimate the time they spent in it. Our results are based on the data of 24 participants, of which are 12 female and 12 male. The data collection includes the perceived time of each participant, and qualitative data from our survey, in which we gathered information about the well-being and perception of the room regarding the color and texture. After the collection of data, we used a two-way repeated measure Anova to see if the color and texture of a room have an impact on the perceived time and well-being of a subject. Additionally, we used the average rating of the questionnaire to better understand the results.

After having completed the first half of the study, we concluded that participants overestimated the time spent in red

417 rooms compared to the time spent in blue rooms, regardless of the textures. The second half of the study presented  
418 a connection between the participants' perception of the rooms and the estimated duration. The subjects tended to  
419 overestimate the time when they stayed in a room they felt comfortable in, but underestimated the duration by a lot  
420 when staying in a room they perceived as uncomfortable. The results of qualitative and quantitative data showed that  
421 participants liked the blue brick-textured room best but estimated the duration more accurately in wooden-textured  
422 rooms. Participants that stayed in the red room with wooden texture guessed the time spent most accurately compared  
423 to the actual time, with an average difference of 0.125 seconds. The blue wooden room followed with -1.240 seconds  
424 difference. The blue stone textured room, which was rated as most comfortable, was estimated with a difference of  
425 approximately 2.520 seconds. The estimated time spent in the red stone textured room was most off from the actual  
426 times with an average difference of 7.573 seconds.  
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428 Our study focused only on the effect of the colors red and blue in combination with brick and wood textures on time  
429 perception of humans. Consequently, future work could investigate other colors and textures, and the influence of  
430 different combinations with modern or abstract textures instead of natural textures. Another issue that has to be studied  
431 further could be the setting, such as whether participants are standing or sitting during the study. It would also be  
432 interesting to see if free movement and interaction with the VRE has a larger effect on time perception compared to  
433 sitting. Finally, future studies could compare the perception of time in real life and in VR in a joint study to examine  
434 whether the results differ greatly depending on the degree of realness and immersion of the rooms.  
435

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