A Journey Through Nature: Exploring Virtual Restorative Environments as a Means to Relax in Confined Spaces

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ABSTRACT

Virtual Reality (VR) technologies can counteract stress or fatigue and restore attention, e.g., by recreating the beauty of nature in a Virtual Restorative Environment (VRE). This has gained additional relevance in the current pandemic: When facing the stress of physical restrictions and a limited activity space, how can VR technologies provide the individual experience of being away? We created a VRE that can be used during trips in automated cars using a captured natural environment and simulated artifacts that communicate vehicle information during VR relaxation. In a user study (N = 21), we compared the proposed in-car VRE to simply closing the eyes. We found that the VRE strongly improved the subjective ratings of mood and slightly increased attentional capacity and the objectively measured performance in a working memory test. Our results provide a concrete starting point for exploring calming VR experiences for future passengers, but also users at home.

CCS CONCEPTS

• **Human-centered computing → User studies**; *Virtual reality*.

KEYWORDS

virtual restorative environments, virtual reality, ambient information visualization

ACM Reference Format:

Jingyi Li, Yong Ma, Puzhen Li, and Andreas Butz. 2021. A Journey Through Nature: Exploring Virtual Restorative Environments as a Means to Relax in Confined Spaces. In *Creativity and Cognition (C&C '21), June 22–23, 2021, Virtual Event, Italy*. ACM, New York, NY, USA, 9 pages. https://doi.org/10.1145/3450741.3465248

1 INTRODUCTION

Physical and mental recovery has become a relevant topic in HCI with the increasing level of stress for humans in modern urban environments. Consequently, the concept of mindfulness and fostering wellbeing has received increasing attention [37]. Some of this research builds on a theory of restorative environments [6], which aims to reconnect people with nature by exposing them to, e.g., photos or videos of natural scenes in order to help them recover from mental fatigue. Novel designs of restorative environments benefit from the immersiveness of virtual reality (VR) by increasing the experience of presence [10]. This exposure to virtual restorative environments (VREs) [36] simulated in VR has been found to provide similar restorative effects as the exposure to the real nature, leading to mood improvement [3], stress reduction [20] and physiological restoration [17]. From their original purpose of empowering patients with physical disabilities to explore spaces in virtual trips, VREs transition to a daily context in modern city life. The mobile but confined car context was our starting point: With rapidly developing vehicle automation, travelers voiced an increasing demand for non-driving-related activities (NDRAs) [27], in which calm VR applications were found well suited to this automotive context [26]. Gradually, the whole topic has gained a different relevance due to COVID-19. In the current situation of the global pandemic, people are suffering from lockdown fatigue being physically restricted in a living space with much less exposure to the outside world [24]. In contrast to an overall global recession, the lockdown boosts sales figures for game consoles which can provide a small escape from the limited, monotonous living space [28]. In our study context, we see VR head-mounted displays (HMDs) as an opportunity for mitigating daily stress by providing a break in virtual environments to future passengers [23] and users at home [34].

The research question behind this exploratory study was: *How can VR technologies create a restorative, unlimited virtual natural environment to ease daily stress or fatigue in a limited activity space?* To explore this question, we designed an in-car VRE application with simulated and controlled artefacts in a captured real natural environment. The captured environment provides the nature stimulus, while the simulated artefacts - acting as metaphors, communicate non-critical vehicle information in an unobtrusive way during the relaxation. In a within-subjects study (N = 21) we compared this VRE to a control condition in which participants simply close their eyes to relax. We found that the VRE has more distinct restoration effects on affect, attentional function, and working memory than relaxing by just closing the eyes. More specifically, after the exposure to the virtual natural environment, participants reported an increased positive affect and decreased negative affect, rated their attentional capacity slightly higher, and performed slightly better in a memory test compared to the control condition. The restorative effects of the in-car VRE on cognitive fatigue and the significant influence on affect confirmed previous work in VRE. We see a potential for the design of future restorative environments in various contexts with physical limitations such as car rear seats and small living spaces. Based on our observations, we will discuss insights for VREs in these spaces and implications of such restorative environments for research on mobile and domestic VR usage.

C&C '21, June 22–23, 2021, Virtual Event, Italy

ACM ISBN 978-1-4503-8376-9/21/06…$15.00
https://doi.org/10.1145/3450741.3465248

Our paper makes three main contributions: First, we discuss the design of a novel in-car VRE, in which controlled simulated artefacts in a captured real natural environment metaphorically convey basic vehicle information (which we refer to as automotive ambient information). Second, we present a study that confirms the restorative effects of our VRE using subjective and objective measurements. Third, we discuss implications for future VRE design and research in mobile and domestic VR.

2 BACKGROUND AND RELATED WORK

Among a growing body of literature regarding mindfulness, well-being, and meditation in HCI [37], some work is grounded on theories of restorative environments [11, 33, 39]. In this exploratory study of VREs, we align with the existing research paradigm of attention restoration [25, 35], the effects of which are mainly measured by attention and affect scales, and response tests. In particular, we review how passengers can use calming VR experiences, in order to apply the concept of VREs to future mobility. Moreover, we examine the literature on ambient information visualization as a design approach for displaying vehicle information unobtrusively embedded in the immersive relaxation experience.

2.1 Effectiveness and Design of Virtual Restorative Environments

The concept of restorative environments is based on two main theories from psychology: One is the Stress Recovery Theory (SRT) [38] which states that only minutes of exposure to nature, or even just watching a videotape of natural surroundings, can rapidly reduce physiological stress and aversive emotion. The other is the Attention Restoration Theory (ART) [13] which asserts that people can better resume attentional capacity after spending some time in nature or even after just looking at the pictures of natural scenes [5] and cognitive function [4] after intense mental activity or fatigue brought on by directed attention. This mechanism builds upon the "soft fascinations" in nature such as clouds moving across the sky, which people can reflect upon effortlessly, using indirect attention [13]. In addition, the concept of restorative environments relates to biophilic design [14] as a nature-inspired design methodology prevalent in architecture.

With the rise of immersive technologies, Stone et al. [36] advocate the use of Virtual Restorative Environments (VREs) by recreating locations and scenes of natural beauty and "soft fascinations" in VR to reduce stress and restore attentional capacities. Following this approach, previous work found distinct effects on mood improvement [3], stress reduction [20], physiological restoration [17], and therapeutics [44]. Different from conventional restorative environments, VREs offer the potential to be present in a virtual natural environment in a magical way, such as a bird's-eye view from the crowns of trees. To explore the relaxing effect of VREs, studies often compare an immersive condition, such as VREs in VR HMDs to a less immersive condition, such as image-/video-based natural scenes on desktop screens. The participant is asked to self-report on attention and emotion scales, and perform a memory test in different conditions [25, 35]. It was found that the higher level of immersion and the combination of acoustic and visual stimuli in the VR condition promotes a more effective restoration [17]. In this calming VR approach, visual or auditory natural elements have often been used with only passive user involvement, aiming to put users in a passive state of relaxation, or to lower physiological arousal, thus inducing a positive state of well-being [29]. To explore an ideal design of restorative environments in VR, we therefore cautiously combined visual and auditory stimuli from nature with passive, low-arousal interaction in our lab study setup.

2.2 In-Car Virtual Restorative Environments as a Calming Passenger Experience

Portable technology lets users engage in desired activities anywhere they want, independent of the limitations of a physical space. Examples range from mobile work to relaxing/entertainment (listening to music or watching videos) and can be used in all means of transport from airplanes to passenger cars. In particular, automated driving promises the freedom to engage in a wide variety of non-driving-related activities (NDRAs) [15]. Special interest groups across the automotive and VR communities investigate this design space of great potential with a focus on productivity [18, 19], gamification [16], and well-being [26] in cars. One promising approach adopted by McGill et al. [23] is to enhance the experience for passengers with varying requirements by utilizing the flexibility of a VR setup. Specifically, relaxation is among the most requested activities during an automated ride, probably in analogy to common passenger activities in public transportation, such as looking out of the window, daydreaming, and sleeping [27]. To explore and foster a calming passenger experience in upcoming automated vehicles, Paredes et al. [26] suggest that calm VR experiences, such as travel through an underwater scenery, are well suited to an automotive context. Compared to traditional PC-based VR headsets, standalone models are attracting more attention from VR users and developers [32]. We see the potential of such accessible and portable VR devices to extend the scope of VRE applications from a clinical setup (for patients with physical disabilities) to mobile or domestic usage (for mitigating daily stress).

2.3 Ambient Information Visualization in Dynamic Real Environments

As the scope of VRE usage expands, we face new challenges specifically from the absence of direct attention in the increasingly dynamic real environment while immersed in a passive relaxation state during a calming journey in VREs. The mechanism of soft fascinations was found to counteract stress or fatigue and restore attention. However, it is unclear if such artifacts could be designed to convey additional information when used in a novel, mobile context without disrupting their restorative effects. Specifically in the in-car VRE context, how can we actively guide the attention between NDRAs (relaxation in a virtual environment) and interruptions from ever-changing real environments (vehicle states)? To address this problem in general, existing work adopted the methodology of ambient information visualization to support passengers with system transparency. Ambient information systems are created to convey information to users that typically is important to a user's sense of well-being and general awareness, but not critical to their work or personal life [30]. Voit et al. [41] proposed that ambient display designs should provide unobtrusive visual cues that "weave themselves into the environment". In the automotive research, design variations of ambient information visualization have been researched intensively in the periphery of the driver's attention, such as the peripheral light display along the A-pillar [40], and peripheral visual motion cues in VR [22]. In contrast, research with the distinct goal of making passengers relax in a calming commute suggested to minimize peripheral stimulation. Users reported discomfort after additional head movements they had to make to inquisitively attend to simulated elements [26].

Based on these insights, we decided to use metaphors in which a gentle motion at the edge and beyond the peripheral area communicates the non-critical information of vehicle velocity, and another element within the central vision encodes the (only slowly changing) remaining journey duration. In our exploratory study, we aim to i) investigate the restorative effects of the VRE adapted to the confined space of a car and ii) explore metaphor design for conveying information of dynamic real environments to the passive relaxation state in virtual natural environments.

3 IN-CAR VRE SYSTEM DESIGN

In order to understand in what kinds of environments people would prefer to relax in future automated vehicles, we applied a user-centered design (UCD) [1] approach and recruited ten interviewees from the university mailing list. All interviewees regularly travel as the driver (n = 4) or the passenger (n = 6) in the urban traffic. None of them participated in the following system evaluation study to avoid bias. In one-on-one semi-structured interviews we found that watching videos (n = 7) was the most desired activity when people do not need to drive. In their daily life, people tend to relax in a quiet room with gentle light and music (n = 7) or by taking a walk in nature (n = 6). Some also mentioned that staying in an imaginary environment (n = 4), such as an underwater world or a starry universe would be fascinating. Regarding the requirements for a virtual natural environment design in automated vehicles, users mentioned system transparency (n = 5), such as the perception of the vehicle speed and surroundings, a progress bar of the journey, a large-scale display, and multiple interaction modalities. We further discussed our in-car VRE design considering both i) its virtual nature setting and ii) its ambient information visualization.

Our user research confirmed previous work by White et al. [43] that the more water was evident in observed photographs, the more attractive these were to the observers. We therefore decided to implement the frequently mentioned seaside scenery involving water, beach, seagulls and trees (as a subset of soft fascinations) as the in-car restorative environment. In addition to visual impressions of natural environments, previous studies found similarly restorative auditory stimuli [2, 31] in pleasant nature sounds such as a mixture of sounds from a fountain and tweeting birds. We therefore chose to implement background sounds based on birds warbling and waves to foster a realistic relaxation experience in nature. The speed and navigation information requires an unobtrusive visualization in the VRE to keep users informed of the current real environment (vehicle states) while not disturbing their relaxation. We decided to select and animate elements that are naturally embedded in the immersive scenario. For example, the changing position of a moving ship coming ashore is used as a metaphor for the entire progress of the journey. Besides, the flying rhythm of a flock of circling seagulls communicates the velocity of the vehicle (see Figure 1). These design decisions were also inspired by existing work in ambient information visualization [30].

Figure 1: Relaxing Mode: The moving path of seagulls (marked in blue) indicates vehicle velocity and the approaching ship (marked in yellow) shows the progress of the entire journey. Image ©pandorama360.

4 SYSTEM EVALUATION STUDY DESIGN

To evaluate our in-car VRE concept, we designed a within-subject user study, in which we compared it to a control condition for relaxing in cars. In the control group, we asked the participant to close the eyes, similar to sleeping on the way as commonly found in everyday transit. Sleeping was also a desired NDRA by travelers in future automated driving [27]. In the experiment, each participant experienced both types of relaxation in a counterbalanced order. We collected and compared subjective and objective measures both before and after the restorative experience. We hypothesized that the in-car restorative environment in VR would have significant restorative effects on attention, emotion and working memory. In addition, we also collected speech signals for a follow-up study that will explore a novel evaluation approach for restorative effects based on speech signals. The study setup and procedure were approved by the ethics review board of LMU Munich (ID: EK-MIS-2020-011).

4.1 Participants

In total, 21 participants (5 male) aged from 19 to 33 years (M = 26.7, SD = 4.0) took part in the lab study. Driving experience was dispersed with 57% of occasional drivers (<10,000 km/year), 10% of moderately frequent drivers (10,000–20,000 km/year) and 5% of frequent drivers (>20,000 km/year). More than half (n = 14) had prior experience in VR on a weekly to yearly basis. In addition, they showed a common preference for relaxation in daily life by watching videos (n = 13), staying in a quiet room with gentle music (n = 13), or in natural environments like parks or seasides (n = 14).

4.2 Measures

To measure attention restoration, we used both objective measures of working memory and subjective scales of attentional capacity and mood.

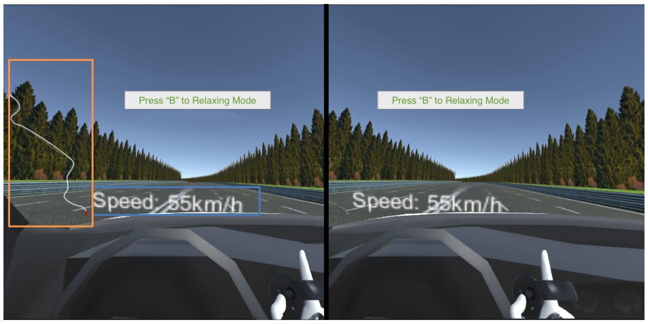

Figure 2: Automated Driving Mode: The UI displays vehicle velocity (blue box) and a navigation map (yellow box).

4.2.1 Attentional Function Index. The 13-item Attentional Function Index (AFI) [9] assesses perceived effectiveness in daily activities supported by direct attention. It is often used as a self-report of cognitive functioning. It applies a seven-point Likert scale, in which 1 represents *Not at all* and 7 represents *Extremely well*. In the questionnaire, questions 1-9 are positive questions, in which higher scores imply a higher level of attention, while questions 10-13 are negative ones, where lower scores imply a higher level of attention.

4.2.2 Positive and Negative Affect Schedule. The 20-item Positive and Negative Affect Schedule (PANAS) is a self-rating tool to measure the current mood state of subjects. The standardized questionnaire builds on the two-factor model of positive (PA) and negative affect (NA) for analyzing emotional states [42]. Study subjects are asked to rate the perceived intensity of ten positive (e.g., interested, alert, inspired) and ten negative adjectives (e.g., nervous, distressed, upset) on a five-point Likert scale. A higher score of PA and a lower score of NA imply a better subjective evaluation of mood.

4.2.3 Digit Span Backwards test. We used the Digit Span Backward test (DSB) [45] as a memory test. Participants hear digit sequences and have to recall them in reversed order by reciting the digits to a voice recorder. Depending on performance, participants move up a level or down a level. The test starts with two digits and for each correct answer the length of the sequence increases by one. Similarly, after two successive wrong answers the length of the sequence decreases by one. Assessment finishes after 14 trials. The following two variables are measured: i) Two Error Maximal Length (TEML): The maximum length of the correctly recalled sequence before two subsequent errors. ii) Mean Span (MS): The digit span that a participant was found to get correct 50% of the time.

4.3 VRE Prototype and Apparatus

Our VRE simulation provides two modes, one for automated driving (see Figure 2) and one for relaxing (see Figure 1). Users can switch from the automated driving mode to the relaxing mode by pressing a controller button, as shown on the notification bar in Figure 2. In the automated driving mode, users travel in the "driver" seat on a rather monotonous highway while hearing the environmental noise of vehicle traffic. On the front windshield, we designed two displays for the velocity of the vehicle and the navigation map (see Fig. 2), which communicate the vehicle speed and a progress bar of the current position to the passengers. In the relaxing mode, we staged the in-car VRE with a 360° video of live-captured natural scenery (©pandorama360)[1]. As a background sound, birds warble and wave along with light flute music (©321 Relaxing - Meditation Relax Clips)[2] in VR. We also adjusted video brightness for a more realistic user experience in the simulated environment.

In addition, we implemented 3D models of seagulls and a ship as two metaphors for vehicle velocity and the progress of the journey respectively (see Fig. 1). We designed three patterns for the flying rhythm of the seagulls to encode the velocity of the vehicle: a low-speed rhythm (0-60 km/h), a medium-speed rhythm (60-80 km/h), and a high-speed rhythm when the car speed exceeds 80km/h. As a visualization for the itinerary, the moving path of a ship from the furthest position at sea level to the closest one on the coast symbolizes the duration of the trip and the arrival at the destination. The predictable slowly-changing metaphors were located in the central vision and at the edge and beyond the peripheral area. They were designed to help users assess essential information about the journey with a lower cognitive load while relaxing in the in-car VRE. Our prototype was realised using the Unity game engine and installed on a standard VR PC connected to an Oculus Rift, two tracking sensors, and one handheld controller. We used an additional noise-canceling headphone for the audio output.

4.4 Procedure

Participants were invited to our university and introduced to the study with an explicit explanation on the meanings of the implement metaphors, namely the seagulls indicating the vehicle's speed and the ship as the journey's progress. Each participant was seated on a stationary chair and wearing an Oculus Rift headset. After signing consent forms, participants filled out a demographic questionnaire. At the start, they were asked to self-report current attention capacity and mood states by filling out the AFI and PANAS questionnaires. Next, participants were asked to complete the DSB test on a desktop computer. These measures were marked as the baseline. Participants then watched a 2–min traffic video clip (©dx7388)[3] to induce a context-specific type of stress [7] as the precondition of the restorative experience (debilitated attention). We subsequently repeated the same measurements as before to quantify the stress induction. After being instructed how to operate the VR system in an on-boarding session, each participant experienced either our in-car VRE or the control condition (closing the eyes) for eight minutes, followed by the same measurements again. In these eight minutes, participants were asked first to experience the automated driving mode for 30 seconds to expose them to the traffic scenario. They were then asked to follow the instruction displayed on the notification bar, i.e., *Press "B" to Relaxing Mode* in the VRE or *Please close your eyes to relax* in the control condition (auditory stimuli remain unchanged, namely the environmental noise of vehicle traffic). The results were recorded and later compared to the previous data. In the second round, the stress induction used different video material and the relaxation used the respective other condition (VRE vs. closing eyes), again followed by the same measurements.

[1] 360 Degree Cinemagraphs, *accessed: February 2021*
[2] Relaxing Pan Flute Music, *accessed: February 2021*
[3] Incredible Traffic, *accessed: February 2021*

Finally, the experimenter conducted a semi-structured interview asking participants to recollect and think aloud about their feelings during the VRE experience. The entire study took about one hour, in which each participant experienced both experiment conditions, namely in-car VRE and closing the eyes.

5 RESULTS

To verify the restorative effects of the in-car VRE on attention, mood, and working memory in comparison to the control condition of closing the eyes, we collected and compared the attention score in AFI, the PA and NA scores in PANAs, and the TEML and MS values in DSB before and after both restorative experiences. We used independent and paired samples *t*-tests for normally distributed data and the Wilcoxon signed-rank test and the Mann-Whitney test for a mixture of non-normally and normally distributed data in JASP [12] to determine whether there is a significant mean difference between the two sets of measures before and after each restorative experience. We used the one-way repeated measures ANOVA test to examine significance across the four sets of measures before and after both restorative experiences. Statistical significance is reported for $p \leq .05$. A large effect size is reported if it is > 0.5.

5.1 Attention Score

The attention score from the AFI reflects the participants' subjective evaluation of their attentional state at the moment. Figure 3 shows participants' attentional function for both conditions.

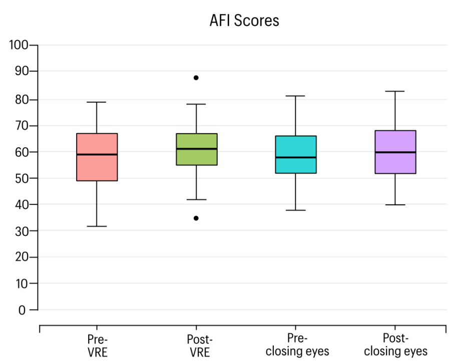

Figure 3: Differences in attention scores between pre- and post-relaxation in two conditions.

We observed a slightly (not significantly) stronger average increase in the VRE condition compared to the closing eyes condition. After the restorative experience in the VRE, participants on average gained 2.9 (SD = 7.6) points, compared to an increase of 1.4 (SD = 8.4) points after closing the eyes. In the VRE condition, also the absolute AFI score was slightly (not significantly) higher after the restorative experience (Mdn = 61, SD = 12.8) when compared to the pre-VRE measurement (Mdn = 59, SD = 12.2), W = 65, p = .31.

5.2 Mood Score

Figure 4 shows changes in mood before and after exposure to VR in both conditions. The VRE increased (but with no significant difference) positive affect (Mdn = 30, SD = 5.3) compared to pre-VRE

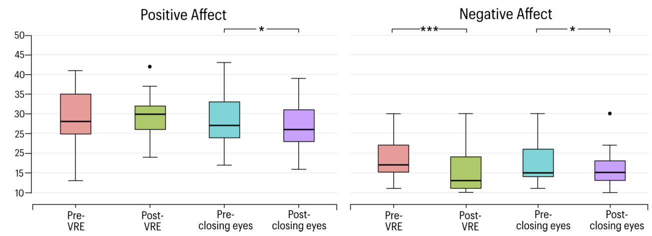

Figure 4: Differences in mood scores between pre- and post-relaxation across conditions. $*$ indicates a significant difference between the two conditions with $p \leq .05$. $***$ indicates a significant difference with $p \leq .001$.

(Mdn = 28, SD = 7.6) scores, W = 65.5, p = .39, r = -0.23. While closing the eyes significantly decreased positive affects (Mdn = 26, SD = 6.5) compared to pre-closing eyes (Mdn = 27, SD = 6.9) scores, W = 116.5, p < .05, r > 0.5. A Wilcoxon's signed rank test showed significance and a large effect size in the decrease of positive affect after closing the eyes. The VRE significantly decreased negative affect (Mdn = 13, SD = 5.5) compared to pre-VRE (Mdn = 17, SD = 4.7) scores, W = 166, p < .001, r = 0.94. The amount of decrease is larger than in the control condition, in which negative affect also significantly decreased from pre-closing eyes scores (Mdn = 15, M = 17.7, SD = 5.4) to post-closing eyes scores (Mdn = 15, M = 15.9, SD = 4.8), W = 132, p < .05, r = 0.54. The Wilcoxon's signed rank tests showed stronger significance and larger effect size in the decrease of negative affect after exposure to VRE compared to the control condition.

Across conditions, participants on average gained 1.3 (SD = 4.9) PA points in the VRE, compared to a decrease of 2.0 (SD = 4.7) PA points after closing the eyes. A Mann-Whitney test showed that this PA mean difference between before and after the restorative experience is significant across conditions, U = 118.5, p < .05.

5.3 Working Memory Span

The digit span examined by the DSB reflects the participants' working memory capacity as a measurement of their direct attentional capacity at that time. While the TEML measurement did not show much difference before and after the restorative experience in both conditions, we further examined the MS measurement. We observed a slightly (not significantly) stronger MS increase on average in the VRE condition compared to closing the eyes, $t(20)$ = -0.227, p = .822, d = -0.05. In specific, participants improved their short-term memory on average by 0.16 (SD = 0.7) digits in the VRE, compared to an increase of 0.11 (SD = 0.5) digits after closing the eyes. Moreover, in the test after exposure to the VRE participants achieved their best performance regarding working memory span (M = 5.11, SD = 1.0) compared to all other DSB tests. We used the one-way repeated measures ANOVA test and found no significant difference across conditions, $F(3, 60.0)$ = 0.721, p = .543, ω^2 = 0.0.

5.4 Subjective Reports and Comments

Participants were asked to think aloud after experiencing both relaxation conditions. Two experimenters developed a set of recurring themes, using thematic analysis on the original notes and recordings as demonstrated in [8]. The resulting themes are listed below along with direct quotes identified with user IDs.

5.4.1 In-Car VRE vs. Closing Eyes. Participants in both conditions were asked to rate the overall relaxation experience on a 5-point Likert scale with 1 indicating "not relaxing at all" and 5 "totally relaxing". Our participants preferred the in-car VRE experience(Mdn = 4.0, SD = 1.0) to simply closing the eyes (Mdn = 3.0, SD = 1.1). Many found the beach view with the wave patterns of a calming sea accompanied by a wave sound as auditory stimulus most relaxing in the VRE. In contrast, more than half of the participants reported opening the eyes more than once during the closing eyes experience. Many objected to relaxing by closing eyes, *"due to the fully black vision"-p8* and *"the darkness in which I can not help myself think over in my mind, while in the beach scenario I felt totally mentally occupied."-p5*. Meanwhile, some participants with limited prior experience in VR reported difficulties of relaxing in the current version of the VRE, such as *"too much to focus in the environment"-p20*, *"eye strains"-p11, p12*, and *"artificial simulation"-p7, p9*.

5.4.2 Individual Relaxation Preference. Consistent with the related work, many participants prefer to relax in a green space such as a forest in addition to the beach environment for in-car relaxation. Overall, they wish to relax during transit in a more dynamic virtual environment in terms of live beings such as *"a slide show of my favourite animal, seal"-p1*, magical experience *"of sitting on the top of trees"-p12* or *"traveling through the forest"-p5*, and multi-sensory stimuli like *"wind, fresh air, and forest smell"-p16, p13, p4.* Although we found no statistical correlation between the preference for relaxation and the restorative effects after the exposure to the VRE in the quantitative data, our qualitative data shed light on the impact individual relaxation preferences have on the restorative effects.

5.4.3 Metaphor Interpretation. For the metaphors of an incoming ship and circling seagulls in the VRE, we received neutral feedback. As some mentioned the regular movement of seagulls and the ship especially at the beginning *"effortlessly caught attention"-p3* and was *"good for focus"-p7*, several users complained about *"the approaching ship being too close"-p12* and an *"unrealistic simulation"-p9* as the metaphors were the only computer-animated objects in the VRE, which otherwise consisted of a captured 360-degree video clip of a real beach scenery. Regardless of its unclear restorative effects, the majority of the participants (n = 14) stated a clear demand for such a metaphor notification design during in-car relaxation. *"It informed me of vehicle states while relaxing in natural scenery"-p5* and *"helped me prepare for the end of relaxation and the journey"-p19* as well as *"emergency on roads"-p15.* Moreover, some users discussed *"the need for speed visualization might be lower than the one for destination during relaxation"-p7* and ideal use cases of *"short-distance driving"-p19*, *"business trips"-p4*, and *"commute from work to home"-p13.*

5.4.4 Demand and User Needs. Overall, more than half of the participants (n = 14) voted in favor of relaxing in such a VRE in future automated vehicles. Relaxing natural environments were rated as the major restorative factor, which is *"an unusual but nice place"-p7* and *"much easier to relax in"-p19.* In addition, some wanted a more active relaxation experience in the car, such as *"adventure games on the island"-p9*, *"watching videos or film on the beach"-p5*, and *"synchronized body sensation between real and virtual environments"-p4.*

6 INSIGHTS FOR FUTURE IN-CAR VRES

Our empirical results showed stronger improvements in mood compared to attention capacity and working memory after the exposure to an in-car VRE, compared to closing the eyes. Furthermore, we found indications that adapting VRE design to the automotive context calls for a more active relaxation, a multi-theme and multi-sensory virtual environment, as well as transferable ambient information. We also speculate on the possible VRE adaption to domestic VR usage especially in times of lockdown fatigue. These main insights allow us to formulate implications for future HCI research on in-car VR relaxation:

6.1 Active In-Car Relaxation

Compared to the passive relaxation provided by traditional restorative environments [29], VREs applied in the automotive context call for a more active relaxation. As we learned from our think-aloud study, in addition to purely viewing the beach, participants wanted an interactive environment such as an adventure game comprising various possibilities in the storyline, or a magical experience such as an extraordinary perspective to observe and travel through the environment, e.g., a bird's-eye view of a forest, or secondary activities while relaxing on the beach such as reading books or watching videos similar to how they would usually relax in reality. On the road, ever-changing vehicle motions could further provoke the active state. Deriving from this concrete feedback from users, we advocate considering a smooth transition between passive and active relaxation states when designing such in-car VREs.

6.2 Multi-Theme and -Sensory Environment

We reason from our qualitative data, that the individual relaxation preference influences the restorative effects of (virtual) natural environments. Although the majority of humans are inclined to relax in nature throughout evolutionary history, people living in cities are increasingly disconnected from nature and accustomed to relaxing actively, e.g., by playing games. We therefore propose multi-theme natural settings in virtual environments to include a wide range of user groups. In addition to the common green and blue space of forest and water [21, 43], the unique natural experience of exploring snow mountains or snowstorms was favored by some users especially for a fast-speed journey. To recreate the beauty of nature in a VRE to its full extent, a multi-sensory approach could consist of at least visual and auditory, but and potentially also of olfactory and haptic stimuli. An intelligent vehicle interior could be modified with such immersive technologies to enhance the driving experience and support in-car relaxation. When designing restorative stimuli, we subsequently need to think of the virtual environment and the vehicle interior together and whether the intended multiple stimuli are consistent across these two realities.

6.3 Transferable Ambient Information

Transferable ambient information visualization between VREs and cars plays a critical role in both pragmatic and hedonic ways, by carrying non-critical traffic information to keep people unobtrusively informed of vehicle states while immersed in relaxation on the road. Unlike frequent head movements found in the prior work [26], the visualization located at the edge and beyond the peripheral area with a gentle motion design was well received by our participants who performed limited and slow head movements. Some participants found that their experiences would have been more vivid and informative if there was a more realistic simulation in VR. This shows the existing mismatch between the captured real natural scenes and the computer-rendered metaphors as a practical challenge. One approach to avoid this discrepancy could be the computer-generated VRE by recreating the entire natural environment in a more abstract style to match the simulated and controlled artefacts. Furthermore, users extended the idea of such transferable interfaces to synchronized motion: They imagined real vehicle dynamics, such as the change of speeds or turns, mapped to their motions in VREs, as well as auditory ambient information such as designing traffic noise into beach sound effects.

6.4 Domestic VRE for Being Away

"Being away," as one character of soft fascinations [13], means that people can shut down direct attention and are shortly engaged in gently moving elements with indirect attention during a VRE exposure. At first, we focused on expanding the scope of VRE usage from the clinical to an everyday mobile context of passenger experience. Our study showed promising restorative effects, especially on affect aligned with the prior work [3], and novel challenges such as an active relaxation state voiced for an in-car VRE adaption. It implies that the everyday application scenario shapes the user needs of a VRE design involving soft fascinations. Here, facing the worldwide lockdown fatigue, we'd like to speculate on the future context of domestic VRE applications. In a limited activity space such as a single apartment, people could "be away" in an adapted VRE design. One example combines i) the well-established simulation recapturing nature beauty (e.g., an exotic travel destination) and ii) metaphor design of beloved living beings (e.g., preferred animal or faraway friends) in VR. We see the opportunity of domestic VREs for escaping from the stress under monotonous, limited household space to a dynamic virtual natural environment while immersed in a journey through nature with on-demand social contacts.

7 LIMITATIONS AND OUTLOOK

There is a learning effect in the DSB test, due to the repetitive measures throughout the study which followed a so-called sandwich paradigm widely adopted in previous VRE studies [25, 35]. In our work, each DSB test started with two trials and the first test took place the beginning of the study. Participants were thus familiar with the DSB test before their exposure to any relaxation conditions. We calculated the mean difference across two conditions to counterbalance the effect and found relevant support of a higher increase of restoration as measured by working memory capacity. We found the most distinct restorative effects in mood through in-car VREs. However attention capacity and working memory only achieved a slight restoration in in-car VREs compared to the control group. To further verify the validity of restorative effects of in-car VREs, future studies could leverage physiological measures in connection to attention, stress, and emotion, such as speech signals, heart rate, or skin conductance level. We will actively explore these opportunities in the near future and have already collected speech signal data during this study. Since a small sample size of users experienced relaxation in an automated ride in a static lab study, we have to acknowledge that our results can only be generalized to a limited extent to real driving cars. Vehicle dynamics such as acceleration or deceleration might change the user's reactions to the used metaphors, e.g., the speed of the seagulls. However, as an initial step, our focus was to find out whether the novel concept of in-car VRE rooted in environmental psychology can promote restorative effects and outperform the baseline (closing the eyes). In this exploratory study, we tested a multi-modal VRE, including visual and auditory stimuli [29]. Together, the implemented nature sounds and visualizations contribute to the restorative effects. We call for future specialized studies to differentiate the auditory influences on restorative effects from the visualization. Finally, we reflect on the implemented prototype, especially the perceived unrealistic simulation and proximity awareness in the virtual world. The former implies that we could render the natural scenes in a more abstract way to diminish the contrast between artificial and real elements. The proximity awareness reveals another influence factor on relaxation in VR, i.e., the relaxing distance between the subject's view and other moving objects. This calls for future work to investigate the size, movement range, and intensity of gentle movements that could trigger restorative effects in VREs. In a future study, we plan to explore design variations of virtual natural settings and metaphor cues in a moving car, considering motion-sickness, situation awareness, and system distrust. We advocate to further explore the extension of VREs for counteracting daily stress in a wide range of contexts, e.g., domestic VREs.

8 CONCLUSION

There is a growing interest in promoting well-being in HCI, specifically when introducing new technologies. In this work we created an in-car VRE using a captured natural environment in an HMD together with simulated and controlled artefacts, which convey non-critical vehicle information to the driver during relaxation. In a user study (N = 21) we found that the proposed in-car VRE strongly improved the subjective ratings of mood, along with a slight restoration in the attentional capacity and the objectively measured performance in a working memory test, compared to the control condition of closing the eyes. We discussed certain implications of our observations for applying VREs in the automotive context, by the adaptation of active relaxation, multi-theme and multi-sensory environments, transferable ambient information, and the general research paradigm. We want to inspire both researchers and practitioners to apply these implications to their work on in-car VR relaxation, so we can soon benefit from the time in intelligent cars for our personal well-being. Future research can build upon our insights to improve the restorative experience of their in-car VR experiences. Finally, we see potential in exploring domestic VRE variations for empowering people to "be away" with on-demand social contacts, especially under the present global lockdown fatigue.

ACKNOWLEDGMENTS

We thank our study participants for their time and effort, and our anonymous reviewers for their constructive and insightful feedback. J.L.'s contributions were funded by the China Scholarship Council (CSC), grant number 201908080094.

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