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Ruben Schlagowski, Fabian Wildgrube, Silvan Mertes, Ceenu George, Elisabeth André

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Flow with the Beat! Human-Centered Design of Virtual Environments for Musical Creativity Support in VR

Ruben Schlagowski
Chair for Human-Centered Artificial Intelligence, University of Augsburg
Augsburg, Germany
ruben.schlagowski@uni-a.de

Fabian Wildgrube
Chair for Human-Centered Artificial Intelligence, University of Augsburg
Augsburg, Germany
fabian.wildgrube@uni-a.de

Silvan Mertes
Chair for Human-Centered Artificial Intelligence, University of Augsburg
Augsburg, Germany
silvan.mertes@uni-a.de

Ceenu George
Chair for Human-Centered Artificial Intelligence, University of Augsburg
Augsburg, Germany
ceenu.george@uni-a.de

Elisabeth André
Chair for Human-Centered Artificial Intelligence, University of Augsburg
Augsburg, Germany
elisabeth.andre@uni-a.de

ABSTRACT

As previous studies have shown, the environment of creative people can have a significant impact on their creative process and thus on their creations. However, with the advent of digital tools such as virtual instruments and digital audio workstations, more and more creative work is digital and decoupled from the creator's environment. Virtual Reality technologies open up new possibilities here, as creative tools can seamlessly merge with any virtual environment the user finds himself in. This paper reports on the human-centered design process of a VR application that aims at supporting the user's individual needs to support their creativity while composing percussive beats in virtual environments. For this purpose, we derived factors that influence creativity from literature and conducted focus group interviews in order to learn how virtual environments and 3DUI can be designed for creativity support. In a subsequent laboratory study, we let users interact with a virtual step sequencer UI in virtual environments that were either customizable or fixed/unchangeable. By analyzing post-test ratings from music experts, self-report questionnaires, and user behavior data, we examined the effects of such customizable virtual environments on user creativity, user experience, flow, and subjective creativity support scales. While we did not observe a significant impact of this independent variable on user creativity, user experience or flow, we found that users had specific individual needs regarding their virtual surroundings and strongly preferred customizable virtual environments, even though the fixed virtual environment was designed to be creatively stimulating. We also observed consistently high flow and user experience ratings, which promote human-centered design of VR-based creativity support tools in a musical context.

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CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**; **Empirical studies in HCI**; **User interface design**; **User centered design**.

KEYWORDS

Creativity, Creativity Support Tools, Virtual Reality, Musical XR, User Centered Design, User Interface Design, Generative Adversarial Networks

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1 INTRODUCTION

Several great thinkers and productive minds in history were fastidious about their creative environment. Famous examples include Kant's window providing a view on a church tower, Proust's cork-lined room, and Kipling's cluttered desk [48]. Prior work investigated the role of the physical environment in the creative process. In the 1960s, Rhodes et al. included the physical environment into his four-fold model of creativity [66]. As claimed by Dubos et al., people that are limited to a 'featureless environment' suffer intellectually and emotionally [23], and Kaplan et al. pointed out that creativity can be enhanced by contact with natural elements [39].

As creative work became more technologically driven and digitized in the computer age, research in the field of human-computer interaction (HCI) is often focused on user interface design of digital applications that provide productive functionality. These applications have specific goals, such as optimal usability or user experience in mind. The environment that the user finds himself in while being productive or creative, however, is often regarded as an uncontrollable variable. Creative tools and applications that utilize virtual reality (VR) technologies provide the unique opportunity to break this paradigm and rethink how virtual environments (VEs), such as virtual landscapes, work places or venues, can be designed and utilized in order to support the user's creativity. This idea is strongly encouraged by the psychological state of *presence* in a virtual 3D environment, an increased subjective feeling of actually 'being there' [46], which can be achieved with appropriately designed VR applications [69].

This paper reports on a research project that explores the potential of virtual environment design and customization for creativity support in VR. To ensure that our test apparatus did not bias the empirical study, we used a human-centered design approach [38] to develop a VR-based prototype that allows users to be creative in a virtual environment as unhindered as possible. To achieve this, we first derived factors from literature that are known to influence creativity in the physical world and could be translated to design choices for creativity support tools and VEs in VR.

Based on these findings, we developed multiple design concepts and a prototype for a VR application that enables users to compose drum beats and design drum sounds for a selection of songs within customizable virtual environments that aim to foster their creativity. These drum beats can be created by using a 3DUI for a virtual drum sequencer that utilizes a generative adversarial neural network (GAN) for drum sound creation and UI modules that allow customization of these sounds. To ensure a good user experience while being creative, we considered feedback and requirements from our target group (beginner and expert musicians) in early development and conceptualization. In this regard, evaluated design concepts in focus group studies during which we also asked participants for their preferences regarding creative environments. As these preferences varied widely, we included the idea of customizable virtual environments into our design, a feature that lets users adjust certain environmental parameters such as daytime, visual complexity or ambient sound according to their indiviual preferences.

Within a laboratory study, we compared such customizable VEs with a fixed environment configuration that was designed to be creatively stimulating in regards to user creativity (as rated by music experts), user experience, flow, and subjective creativity support scales. As a major factor influencing creativity is personality [2, 66], we investigated correlations between these scales and the personality traits of participants. Our results, both from the focus group and laboratory studies, encourage the use of customizable virtual environments for VR applications that aim to support creativity and indicate that VR can benefit the state of flow [20] while being creative.

2 RELATED WORK

Our work can be located in the realm of 'Musical XR' as defined by Turchet et al. [79], as our VR prototype incorporates a virtual reality musical instrument (VRMI) that makes use of virtual elements, spatial persistence, interactivity, and provides means for sonic organization. However, since our primary focus is to research means for supporting user creativity in VR, it could also be regarded as a creativity support tool (CST). Related work in the fields of VRMIs and CSTs are addressed in subsections 2.3 and 2.2. To give a foundation for the conceptualization and development of a system that supports creativity through 3DUI and VE design, subsection 2.1 first focuses on creativity definitions and factors that were found to support creativity.

2.1 Creativity Definition and Support Factors

The most prominent definition of creativity (first brought up by Stein et al. [75]) requires creative output to be both useful and novel. Thus, the creative process is "the production of appropriate novelty" [62]. Webster, on the other hand, described creativity as a process alternating between divergent ("brainstorming") and convergent (single goal focused) thinking [84] and in the musical context as "engagement of the mind in the active, structured process of thinking in sound for the purpose of producing some product that is new for the creator" [84]. Simonton noted that "Creativity has the characteristics of constrained stochastic behavior. Creativity is to a certain degree predictable, but far from deterministic." [72].

2.2 Creativity Support Tools

While general overviews on creativity support tools (CSTs) can be found in the literature reviews from Frich et al. [30], Gabriel et al. [31] and Wang and Nickerson [82], this subsection focuses on CSTs in the context of (either) music or mixed reality.

In the musical domain, Eaglestone et al. [24] investigated requirements of composers for software that facilitates their creative composing process and found that composers liked randomized recommendations provided by software. Further, a variety of concepts for harmonization in the context of musical composition were explored, for instance by automatized harmonization [16, 67] or chord recommendations [35]. Tsandilas et. al. [78] and Farbood et. al. [27] presented systems that use drawing input modalities for music composition.

Yang et al. [85] built and evaluated a VR-based creativity support system for a (product-) design task and found that the VR-based system scored better than a pen-and-paper approach with regards to creativity and flow. Chang et al. [14] conducted a study with 138 seventh-grade students investigating the potential of VR in a teaching scenario. They observed more creative designs and problem solving in the VR group than the classical media (presentations, videos) group. Valer et al. [80] built an AR app that translates 3D phone motion and touch pressure into 3D sculptures as well as sound. In their study, participants received good scores on the creativity support index (CSI). Overall, it emerges that the influence of environmental factors are predominantly neglected in common CSTs.

2.3 Virtual Reality Musical Instruments

Early work on Virtual Reality Musical Instruments (VRMIs) was primarily focused on novel interaction techniques such as gesture tracking [63], gloves [58] and hand gestures or movement [47, 57]. Musical instruments that were realized in VR are usually suited to the chosen input modalities, e.g. theremins for gesture or posture-driven interaction [12, 47]. Percussive instruments such as xylophones [47] or drums [34] were used prominently as metaphors for VRMIs. More complex musical instruments that enable compositions include collaborative virtual music sequencers [53], VR interfaces for DAWs [4], looping systems [6, 7] and modular spatial representations of notes or instruments such as 'wedges' [56] or manipulable virtual planet systems [19].

On a more general level, Berthatu et al. [5] and Serafin et al. [70] gave some general guidelines and design recommendations

Table 1: Summary of creativity support factors

Category	Factors	Description	Sources
Priming	Visual positive metaphors	E.g. illustration of lightbulb	[49]
	Embodied Metaphors	E.g. breaking a wall in VR	[83]
	Instructions	E.g. "Be creative!"	[61]
Body Movement/ Body Posture	Walking	User walks through the VE	[29, 62, 86]
	Large movements	E.g. user has to perform large gesture interactions	[36]
	Fluid arm movement	E.g. curved movements instead of angular movements	[37, 73]
	Open/expansive posture	E.g. arms and legs uncrossed	[3, 54]
	Exercise	E.g. cycling	[18, 76]
Sound	Moderate ambient sound	E.g. sound of coffeehouse	[51]
Indoor	Contextual cues	Furniture, paintings, things to do with the task	[33, 59]
	Windows	View into nature	[13, 33, 50]
	Open space	E.g. high ceilings	[8, 55]
	Visual detail	Patterns, "untidiness"	[8, 50, 81]
	Random objects	"Inspiring" decorative elements	[8]
	Indoor plants		[71, 77]
	Colors	Green/blue for calming, red/orange for stimulating	[45, 50, 52, 77]
Outdoor	Being outdoors		[17]
Lighting	Brightness and Color temperature	Dimmed and warm	[43, 74]
	Accent lights	Blue and red	[41, 52]
Misc	Surprise		[28]
	Avatars	Embodied creativity	[10, 32]

for VRMIs. While VEs have been designed and used in a variety of projects, they have rarely been considered as an important design consideration. One exception here was Çamcı et al. [11] who integrated environment features such as walls and ceilings into their VRMI design.

3 CONCEPTS AND VIDEO PROTOTYPES

Our goal when choosing a use case for creative work in VR was to find a balance between creative freedom for the creators while also maintaining comparability of the creative output for studies and keeping the amount of required a priori knowledge (regarding both music theory and sound design) fairly low. To achieve this, we chose the use case of percussive composition to existing audio tracks/compositions, which can serve as a reference for creative assessment. We excluded composing melodies, harmonies, and chord progressions as we did not want to require participants to have extensive knowledge of music theory in future laboratory studies. As a metaphor for our 3DUI, we chose a step sequencer (compare for instance [26]). Step sequencers are a well-known UI paradigm for creating cyclical musical ideas or phrases, called 'loops', by providing the possibility to visually arrange single strokes of various drum instruments in a timely manner. Since our step sequencer UI can only be used to create rhythmical patterns, it is referred to as 'drum sequencer' in the rest of this document. As literature did not provide a hint on how, or to what extend the third dimension can benefit composition tasks in VR, we developed three design concepts for a drum sequencer 3DUI that make use of the third dimension to different extent (see Section 2.1). We used these concepts as a starting point for discussion and feedback within a focus group study with musicians, as described in Section 4. The three concepts were implemented in video prototypes and presented to participants of a focus group study as described in Section 4. The three developed 3DUI concepts (see Fig. 1) are:

(1) *Grid:* This concept is a direct translation of a 2D quantisation grid (as typical in DAWs and drum sequencers) onto a plane in 3D space. Each sample has its own 'track' onto which notes can be placed.
(2) *Literal Loop:* In this approach, the 'Grid' is bent into a cylinder and surrounds the user. 3D sound sources for each note add to the surround sound effect by rendering the audio of each sample from its unique position in space.
(3) *Multiple Loops:* Each sample is placed in space as a separate loop where notes can be freely placed. A note can be marked as the starting point for a loop and each note is connected to at least one other note, similar to a linked list. The distance between two adjacent notes maps to their timing. Each loop can have a unique length, determined by the sum of the distances between all notes.

In order to give users the opportunity to creatively designing the drum sounds themselves, we included 3D vector-manipulation modules (VMM) as described in [68] that can be used to interact with a GAN that was trained to generate drum sounds (*WaveGAN*

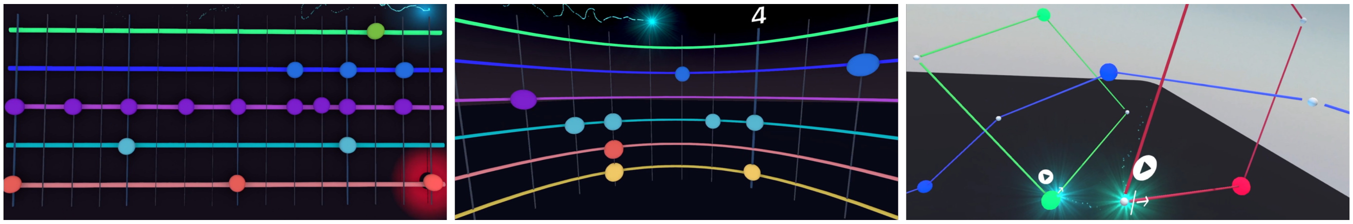

Figure 1: Stills from the video prototypes that were shown to the focus group participants. F.l.t.r.: 'Grid', 'Literal Loop' and 'Multiple Loops'

architecture by Donahue and colleagues [22]). We chose this system, as it provides both features for convergent and divergent parameter exploration, without requiring any a priori knowledge in the field of sound design and music production. Two of such VMM modules can be seen left and right in Figure 3.

Additionally, all design concepts (see Figure 3) were designed to foster creativity by including spatially distributed 3DUI layouts that require open and expansive user postures, large movements, fluid arm movements and physical walking (compare Table 1).

4 FOCUS GROUP STUDY

Following the initial phase of paper- and video prototype production described in Section 3, feedback and ideas from active musicians were gathered. Eight musicians from different demographic and professional backgrounds were recruited via mailing lists and social media channels. The participants were aged between 24 and 62 years ($\overline{M}$: 36.75, SD: 15.9). The participants came together in two separate online conference sessions, the first one including five participants (two female, three male) and the second one three participants (two female, one male). Each participant played at least one instrument or sang actively in choirs. Instruments played ranged from piano, guitar, and organ to saxophone and various types of flutes. All participants except one had little or no experience with VR. Both sessions had a duration of 120 minutes and followed a protocol outlining several topics.

4.1 Procedure

After a brief introduction, the first set of questions aimed to identify the definition of creativity in general and in the context of music. It also addressed individual creative processes and preferences for environments in which participants felt creative by describing situations and places that felt most creative to them. This first block of questions was followed by a brief presentation of virtual reality concepts by the moderator. This included two videos introducing the interaction principles of head-mounted displays and VR controllers. Participants were then asked how they envisioned VR supporting creativity and were asked to explain their ideas. The next block began with two short screencasts explaining the basics of a drum sequencer interface. Users were then asked for their spontaneous ideas for VR versions of the presented 2D interface. Finally, video prototypes of the three design concepts (see Section 3) were shown and reactions were examined using a traffic light scale (red, orange or green lights, according to approval, see [25]). Then, each participant was asked to justify his or her decision.

4.2 Results

The following sections present the results of an inductive thematic analysis [9] of the focus group study.

4.2.1 Creative User Types. As could be expected from the numerous definitions of musical creativity found in the literature (see Section 2), participants had varying definitions of musical creativity. For all participants, the main component of (musical) creativity was 'novelty' or 'originality'. One participant mentioned the similarity of 'create' and creativity and said that for her creativity is "to create something from nothing". Notably, only three participants actively mentioned things similar to the concept of 'usefulness' in the literature. One participant said, creativity had to be 'productive' and another mentioned what was being created should be of 'high level' while a third mentioned 'beauty' as a goal to aim for.

Comparing statements from the participants revealed two main tendencies: creativity as a mostly structured process versus creativity as a spontaneous, experimental process. This division into 'structuralists' and 'experimentalists' could be observed across the different thematic blocks of the sessions.

4.2.2 User Requirements for Creative Virtual Environments. To find out more about the environments in which the participants could feel creative, they were asked to imagine their ideal creative environment. These were very individual in the specifics, however, on a more abstract level, the two groups of 'structuralists' and 'experimentalists' emerged as well. While the former tended to favor abstract and minimalistic environments, the latter had very concrete ideas for their ideal creative setting. However, some common preferences across the groups emerged as well. As depicted in Figure 2, all relevant factors that were mentioned by the participants were aggregated into thematic clusters, which are as follows:

- *Atmosphere:* A common theme running through all the participants' needs and requirements for an ideal creative environment is an atmosphere of concentration, calm and attention. Almost all of them stated that they needed an environment without major distractions, especially of an acoustic nature. Complete silence or, at most, a quiet background noise ("a little river") was the general consensus.
- *Utility:* Another important aspect for participants in all observed groups ('structuralists'/'experimentalists') was the sense of utility. They described the need for various tools or devices at their disposal. Quick access to a variety of tools, whether musical or technical, seemed to be a high priority. But again, the two groups split, with one structuralist

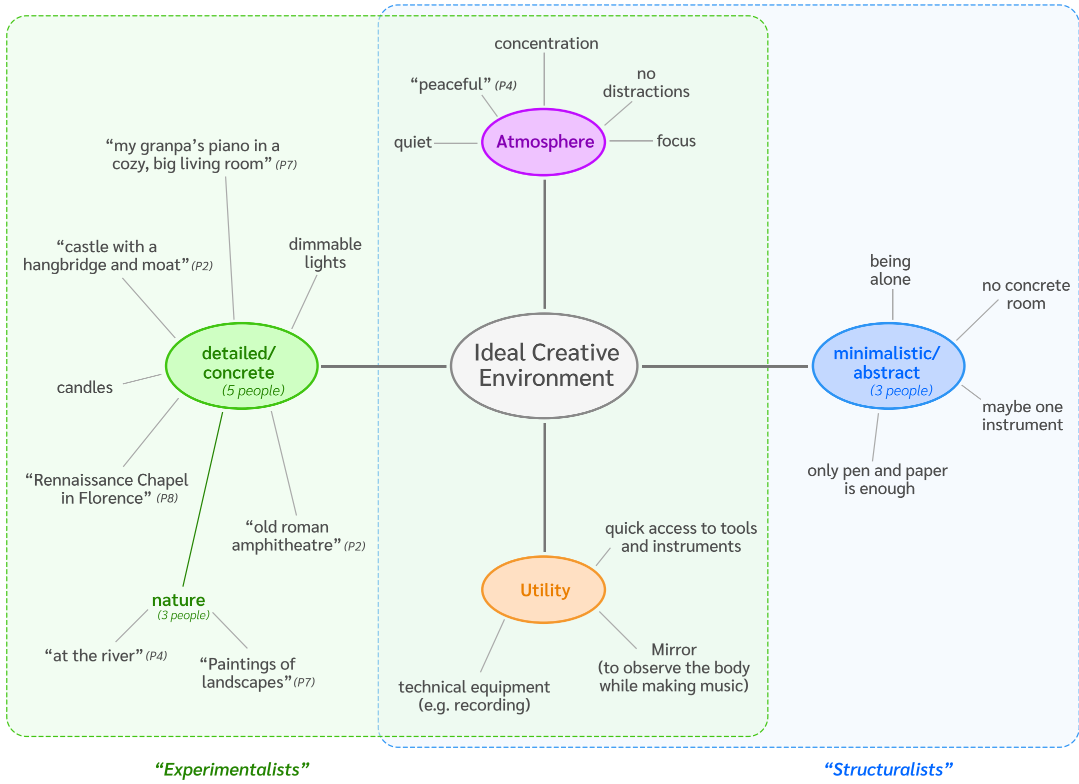

Figure 2: Wishes and ideas of the participants for an imagined ideal creative environment. The translucent green and blue boxes highlight the statements given by the 'experimentalists' and 'structuralists' respectively.

saying that "one instrument would be enough." While an 'experimentalist' said he wanted "a range of instruments with different sounds" to try different things and get inspired.

- *Minimalistic and Abstract:* The same three individuals who took a structured, organized, and planned approach to their musical creativity indicated very similar preferences for abstract and minimalist environments. They indicated that a simple room would suffice as long as they could be alone and had an instrument, a pencil, and some paper at hand.
- *Detailed and Concrete:* The five 'experimentalists' wanted inspiration from outside in their creative environment. They thought, for example, that "the sound of nature through the window" could stimulate creativity, as could different colors in the room. Others had very specific places in mind, such as "my grandfather's piano in a cozy living room" or "a medium-sized chapel in Florence overlooking a lush garden". These places had personal meaning, but also offered inspiration, e.g. through pictures, books, and candles, or because the place was "the most inspiring in the world."

4.2.3 Concept Evaluation and Design Implications. Feedback on 3DUI concepts: The three ideas for the main loop interface presented in Section 3 received mixed feedback from the participants. The 'Multiple Loops' concept (see right picture in Fure 3) turned out to be confusing for most users except one person who had extensive experience with sequencers.

Therefore, the 'Multiple Loops' concept was discarded right away as it did not appeal to any of the seven sequencer novices in the focus group. The remaining two concepts – 'Literal Loop' and 'Grid' – both received positive and negative ratings. While 'Literal Loop' was more immersive for some, it made others feel dizzy. By contrast, the 'Grid' concept was viewed as very clear and easy to understand for most participants. However, concerns were voiced that it did not utilize the potential of the third dimension available for interactions in VR. Since no clear favourite could be identified, the 'Grid' concept was chosen to be pursued for the implementation of the VR prototype since it was perceived as being familiar and clear even for novices.

Individual needs for creativity: While participants agreed on some main tendencies (e.g. peacefulness, playful attitude, creativity as an active process, etc.), specific individual needs still differed widely – especially with regards to the ideal environment. The preferences for colorful, inspiring environments are diametrically opposed to the preferences for quiet, simple rooms with no ornamentory elements and a focus on the essential. As a result, we considered a single VE to appropriately meet all of these expectations at the same time to be hard to conceptualize, if even impossible. The design implication we derive from this observation is to provide the users with the ability to customize their VE according to their own needs (see Section 5). However, since customizability comes with complexity (which might contradict the needs for simplicity of some

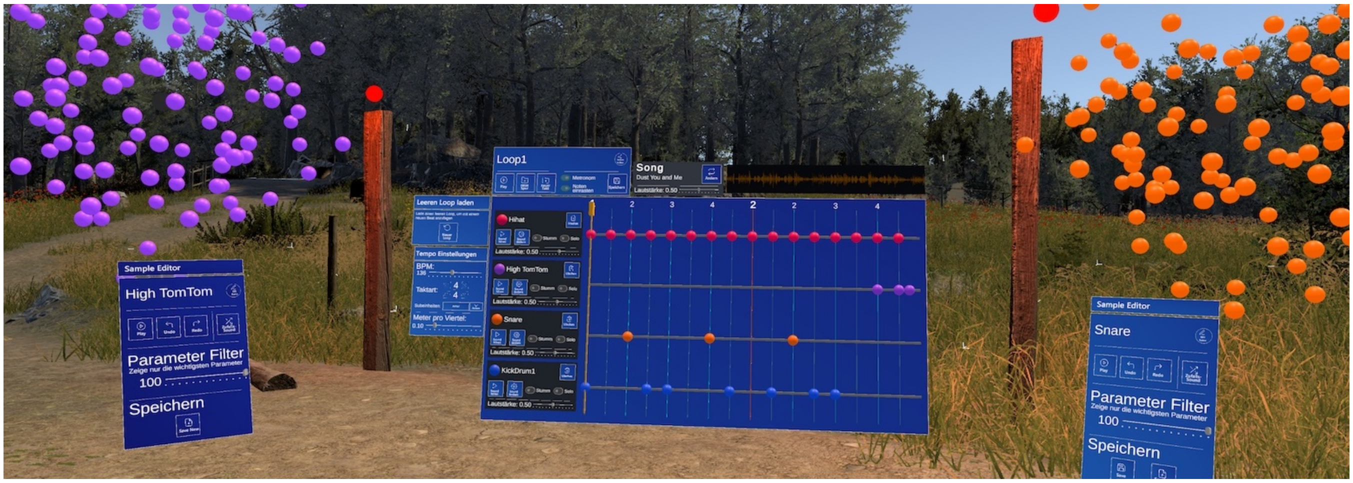

Figure 3: The main loop editing interface of the final prototype with two Vector Manipulation Modules (VMMs) in the fixed environment condition ('Meadow').

participants), we decided to conduct an experiment (see Section 6) investigating whether this idea performs better than a predetermined (fixed) environment which we designed to be creatively stimulating according to findings from literature (compare Table 1).

5 VR PROTOTYPE

The VR prototype we developed uses a HTC Vive Pro VR head-mounted display and Vive Pro controllers. During the development phase, feedback was gathered in iterations by letting musicians interact with the prototype and encouraging them to think out loud and give feedback on usability and their overall user experience. The resulting prototype provides users with two main 3DUI components, a main drum loop editing interface (see Figure 4) and Vector Manipulation Modules (VMMs) (see modules on the left and right side in Figure 3). Both components can be used to design custom drum beats in customizable VEs.[1]

As participants of the laboratory study only have limited time to familiarize themselves with the prototype, we chose the grid based layout (see left image in Figure 1) for the main drum loop editing interface, since it was regarded to be the most beginner friendly by focus group participants. Our implementation of the grid can be used to create drum beats by placing spheres on individual drum tracks. Further, it enables users to configure quantization (or disable it if desired), tempo (in bpm) and measure, and to choose from a variety of audio tracks (not featuring drums) that cover a wide range of musical genres. If a specific song is selected, predefined tempo and measure settings are loaded that fit the selected song. Users can also add and delete drum tracks as desired. If a user wants to customize a drum sound, a vector manipulation module (VMM) can be used to alter the drum sound that is assigned to the track. These UI modules allow the editing of drum sounds which are generated by a Generative Adversarial Network (GAN). This is achieved by allowing the user to manipulate spheres that correspond to the vectors of the input latent space of a GAN which was trained to generate realistic drum sounds. By using a VMM-manipulatable GAN for drum-sound generation instead of typical drum libraries, users are able to customize drum sounds according to their artistic vision instead of being limited to a selection of samples. Furthermore, these modules do not require any a priori knowledge regarding music production or sound design from users, which has the potential to benefit the creative experience for non-expert musicians. For a more detailed explanation of these modules, refer to [68].

The environment in which the user is located while creating drum patterns can be selected and customized. First, users can select between four environment types: *Space*, *Meadow*, *Concert Hall* and *Music Studio* (see figure 5). Second, a variety of parameters can be configured for the environment:

- *Ambient Sound Volume:* The Sound was chosen fittingly to the location (e.g. soothing sci-fi drone sound, birds, pre-concert ineligible crowd conversations, office ambience sound).
- *Visual Complexity:* The amount of pre-placed (color-neutral) objects that fit into the location (e.g. rocks, tree-logs, leaves in meadow, chairs, stage light equipment in concert hall) was configurable. Additionally, their positions could be interpolated between 'tidy' and 'untidy' positions.
- *Colorfulness:* The amount of pre-placed colorful objects that fit into the context of the location (e.g. flowers, painted walls, colored curtains and floors) was customizable. The color could be chosen between red/orange [50] and green/blue [45, 52].
- *Main Lighting:* Both brightness and color temperature of the main spotlight illuminating the whole scene could be adjusted.
- *Accent Lights:* Users were able to control the amount of pre-placed accent lights that were integrated into the environment (e.g. spotlights on the wall in concert hall, ceiling lights and led ceiling in studio) and choose their color between red, green, and blue (following the work of [41] and [77]).

[1]The source code for the demonstrator is publicly available on Github at *https://github.com/FabianWildgrube/vrdrumsequencer*.

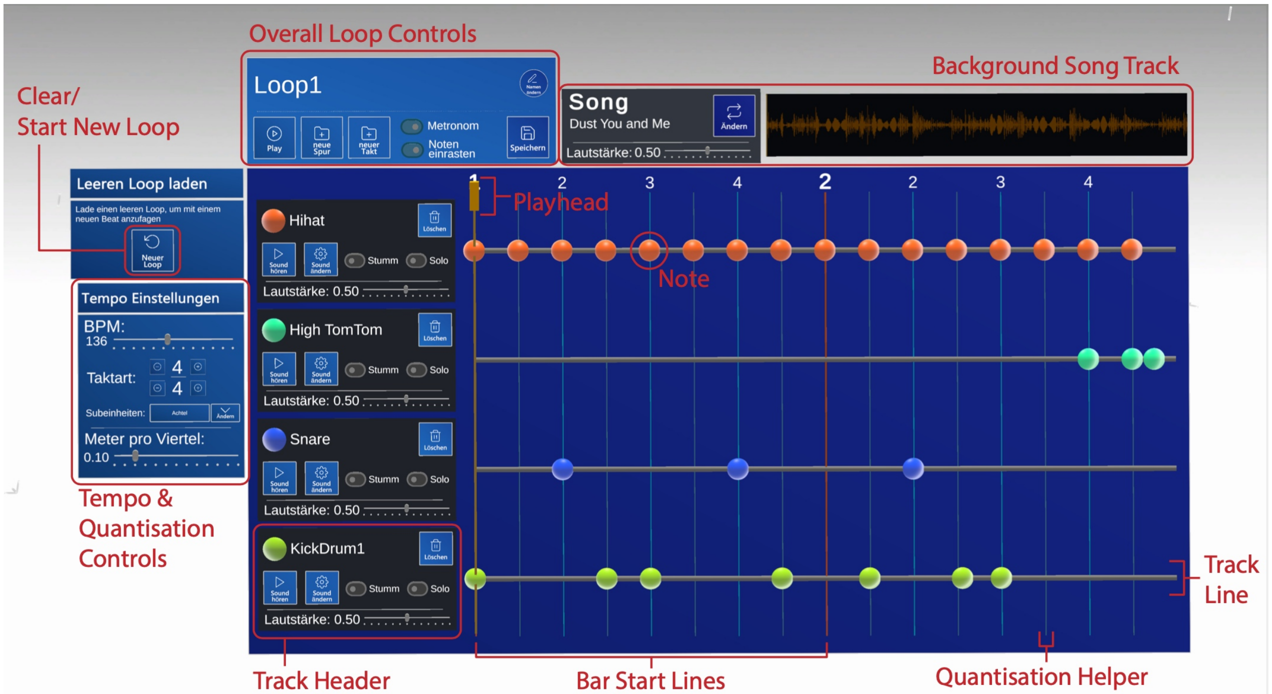

Figure 4: The main loop editing interface of the sequencer.

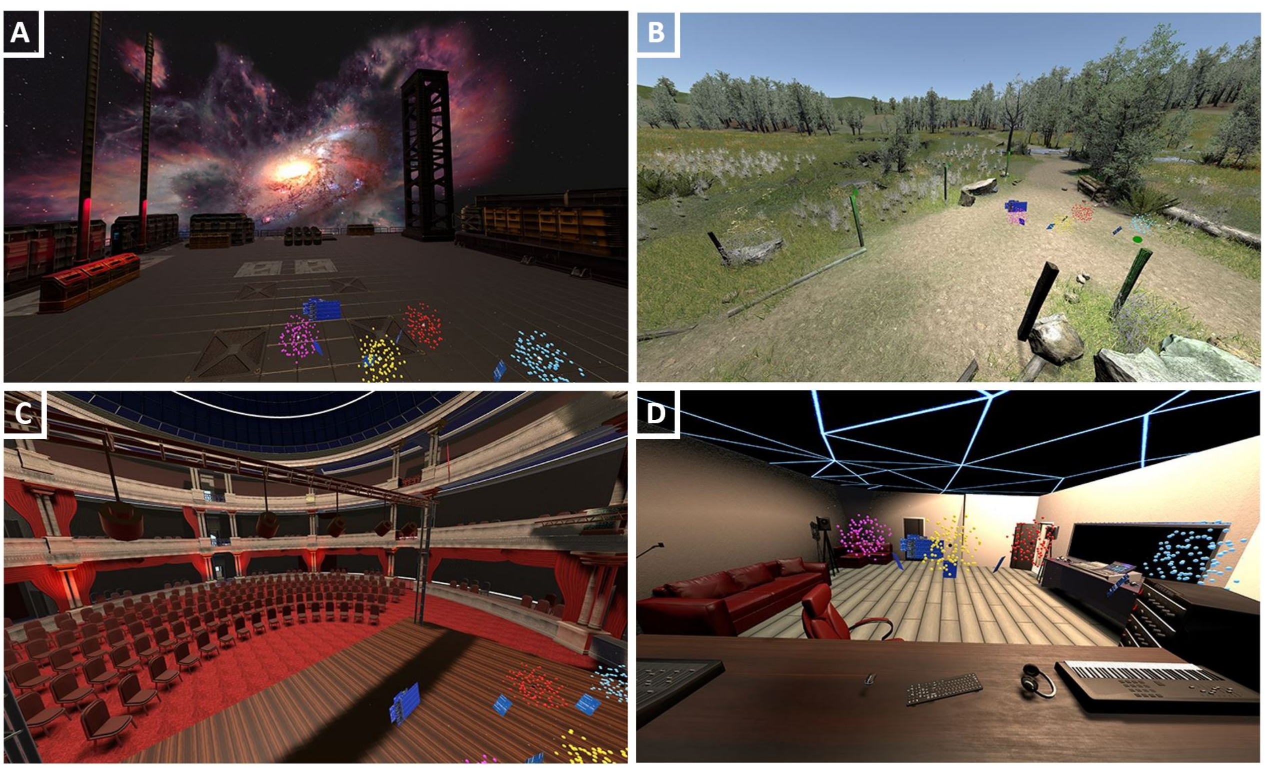

Figure 5: The four virtual environment (VE) types: (A) Space, (B) Meadow, (C) Concert hall, (D) Music studio.

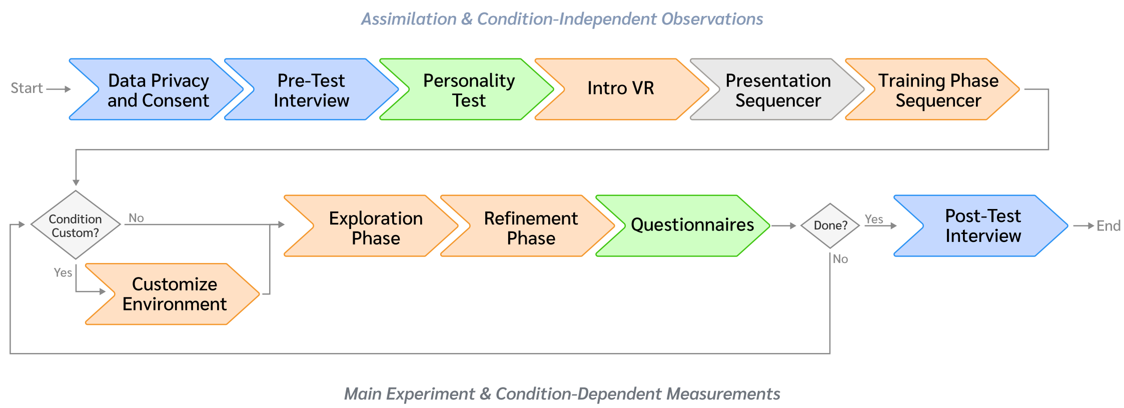

Figure 6: A visualisation of the study procedure.

In addition to the customizable VEs, we implemented a preset (fixed) environment (see environment in Figure 3) that we designed to be creatively stimulating according to the findings in the literature (see table 1). For that fixed VE configuration, users found themselves in the 'Meadow' environment type (see option B in Fig.5). Other VE types (options A, C and D in Fig.5) were made unavailable in that condition. We chose this over e.g. a randomized VE type selection, as nature-related factors (which are omnipresent in the 'Meadow' VE type) were found to have a positive impact on creativity [13, 17, 33, 50]. Medium chaos was integrated into the scene [81] and a late-day setting was applied. Further, red accent lights for dimmed, warm and not too bright lighting were integrated [43, 74].

In the laboratory study described in Section 6, we compared the two conditions, the customizable and the fixed VE design paradigm, using a within-subjects study design.

6 LABORATORY STUDY

Using the VR prototype introduced in Section 5, we conducted a laboratory study. The research questions this laboratory study addresses are:

- **RQ1**: How well does the prototype perform in regards of user experience, flow and creativity support (see Table 2, No. 1-3)?
- **RQ2**: Are the experts' creativity ratings (ACR, see Table 2, No. 5), or the self-assessment measures (see Table 2, No. 1-4) affected by the integration of either a customizable or predefined VE ('custom' vs. 'fixed', compare Section 5)?
- **RQ3**: Are there correlations between personality traits of participants, musical experience, environment configuration metrics, and the independent variables listed in Table 2?
- **RQ4**: Do participants prefer the customizable or the fixed VE when asked directly and is this reflected in the time they take for creative tasks in the respective VE?

16 participants (8 identified as women, 8 as men), recruited via mailing lists and social media, took part in the study which was conducted as within-subjects experiment. Each participant had an individual open-ended time slot (approximately 2 hours). Participants ranged in age from 20 to 62 ($\overline{M}$: 29, SD: 11). The first two participants experienced technical difficulties, so they were excluded from the judges' creativity assessment (see Section 6.1). Participants' musical activity, as indicated by pretest interviews, ranged from approximately two years of amateur playing to 10 or more years of professional experience. The level of activity was coded in a 7-point Likert scale that ranged from 'no experience' to 'professional musician'. To rate the beats produced by the main study's participants after the study (in order to answer RQ2), five (4 male, 1 female) professional musicians aged between 26 to 58 years ($\overline{M}$ = 40.4, SD = 11.2) were recruited.

6.1 Experiment Design and Process

In a short semi-structured interview that was conducted prior to the experiment (see block 'Pre-Test Interview' in Figure 6), participants were questioned about their musical background, their individual creative processes and preferences. Afterwards, a short personality test was administered by using the NEO-FFI-30 questionnaire by Korner et al. [42] for later correlation analysis (cf. RQ3). After a short introduction to the VR application and hardware, participants were asked to familiarize themselves with the drum sequencer interface.

Subsequently, the within-subject experiment was conducted in order to answer RQ2. For this experiment, each participant had to perform two creative task sections, one within the customizable and one within the fixed VE (this serves as the independent variable). The order of these conditions ('custom' and 'fixed') was randomized. For both task sections, participants were asked to produce beat tracks for short instrumental songs using the drum sequencer interface in the respective VE condition. Each task section was split into two phases: 'Exploration' and 'Refinement' (following the divergent and convergent phases of creativity [84]). During the 'Exploration' phase, the users were instructed to select three instrumental songs from a list of 20 songs from different genres. For each of the three chosen songs they were instructed to create an accompanying beat. It was emphasized that this beat does not need to be finished, but rather was meant to be just a first idea

Table 2: Dependent Variables

No.	Abbr.	Name/Description/Subscales	Range	Assessment Method
1	UX	**User Experience**, Experience while using the application, subscales: 'Attractiveness', 'Perspicuity', 'Efficiency', 'Dependability', 'Stimulation', 'Novelty'	1-5	User Experience Questionnaire (UEQ) [44]
2	FSS	**Flow**, Psychological state of being immersed in a task [20]	1-7	Flow Short Scale (FSS) [65]
3	CSI	**Creativity Support**, Feeling of being creatively supported	0-100	Creativity Support Index [15]
4	CESR	**Creative Experience**, How creative users felt, subscales: 'Competence', 'Autonomy', 'Task Enjoyment'	0-9	Creativity Experience Self Rating Questionnaire [21]
5	ACR	**Average Creativity Rating** by experts, mean of 'Creativity', 'Rhythmic Interest' and 'Personal Preference' ratings [64], "Creative Quality"	1-7	Consensual Assessement Technique [1]
6	–	**User Preference**, preferred VE paradigm ('custom' vs. 'fixed', compare Section 5)	custom, fixed, none	Questionnaire item (selection)
7	–	**Task Completion Time**, Time participants took for beat creation in the refinement stage	0-inf.	Direct measurement during experiment

which could be refined later. During the 'Refinement' phase, the users were allowed to select one of the three beats they had created during the preceding 'Exploration' phase. This beat was then to be refined to a point were the users felt it was finished.

After each of the two refinement phases (one for each condition), participants filled out the questionnaires measuring dependent variables No. 1-4 (see Table 2), namely user experience, flow, creativity support and creative experience by filling out the corresponding questionnaires [15, 21, 44, 65].

The Consensual Assessment Technique devised by Amabile [1] was chosen to serve as the measurement technique for the dependent variable ACR (expert's creativity ratings, cf. RQ2 and Table 2). Here, a number of professional musicians and music educators were recruited. Independently, each of these experts judges the creativity of the products produced by study participants. A definition of creativity was not given to the experts. All judges were instructed to use their personal definition of what is creative in their rating decisions. As the products of this study are pieces of music, three rating scales, as proposed by Priest et al. [64], were used: 'creativity', 'rhythmic interest', and 'personal preference'.

6.2 Results

As participants conducted creative tasks (both exploration and refinement stages) twice in the within-subjects experiment (in randomized condition order), we evaluate correlations as well as measures from self-report questionnaires and the expert ratings separately. For the following subsection and corresponding graphs, we report on these iterations with the terminology 'first' and 'second'.

6.2.1 Dependent Variable Analysis. User Experience (UEQ): The scales 'Attractiveness' (*fixed*: $\overline{M}$: 2.18, SD: 0.71; *custom*: $\overline{M}$: 2.21, SD: 0.76), 'Stimulation' (*fixed*: $\overline{M}$: 2.13, SD: 0.67; *custom*: $\overline{M}$: 2.20, SD: 0.66), and 'Novelty' (*fixed*: $\overline{M}$: 1.98, SD: 1.12; *custom*: $\overline{M}$: 2.08, SD: 0.71) were rated at or above 2 in both conditions, which is very high and thus very unlikely to be observed [44]. The scores of the other scales ('Perspicuity', 'Efficiency', 'Dependability') were well above 1.2 in both conditions, which can be interpreted as positive evaluations [44]. This indicates a very good overall user experience (cf. RQ1). However, no significant differences were found between the two VE conditions 'custom' and 'fixed' (cf. RQ2).

Creative Experience (CESR): As it can be seen in Figure 7, the 'task enjoyment' and 'autonomy' scales have relatively high scores, while 'competence' is ranked lower. Central tendencies of all three scales are roughly equal in both conditions. The same is true when grouping the data by experiment iteration (see Figure 8). Due to non-normality within the groups (Shapiro-Wilk's tests were computed for every scale; none exhibited normality), Wilcoxon tests were performed. After p-value correction (Benjamini-Hochberg procedure), no significant differences could be found. However, the competence scale did exhibit a significant difference before p-value correction with the custom condition having greater values than the fixed condition ($p = 0.019$).

Flow (FSS): Results of the flow scale exhibit very high scores (cf. RQ1) with little variance across both conditions and experiment iteration, as shown in Figure 9. When comparing both conditions statistically (cf. RQ2), no significant difference was detected.

Creativity Support (CSI): The Creativity Support Index (CSI) produces scores between 0 and 100. Since the VR prototype tested in this study does not include any collaborative features, the collaboration scale was defaulted to 0, as suggested by the authors of the CSI [15]. As illustrated by Figure 10, CSI score does differ between the two conditions (cf. RQ2, *fixed*: $\overline{M}$: 59.9, SD: 17.17; *custom*: $\overline{M}$: 72.8, SD: 20.23). However, ratings for first and second iteration are quite similar (*first*: $\overline{M}$:68.9, SD: 19.5; *second*: $\overline{M}$: 68.1, SD: 17.94). A trend can be seen, suggesting that creativity support was rated greater in the *custom* condition while at the same time the central tendencies do not suggest an order effect. Student's t-tests were

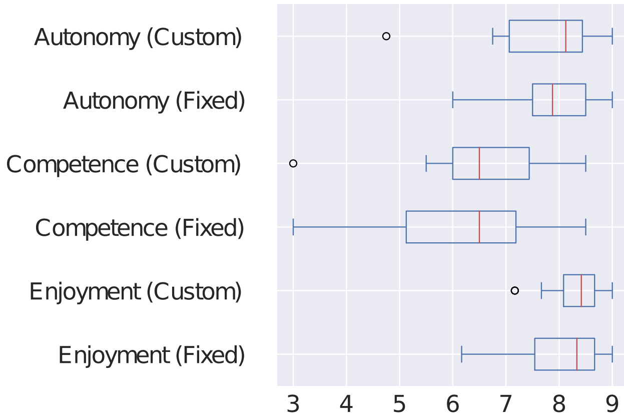

Figure 7: Central tendencies of the creative self experience items (CESR), grouped by condition.

Figure 8: Central tendencies of the creative self experience items (CESR), grouped by iteration.

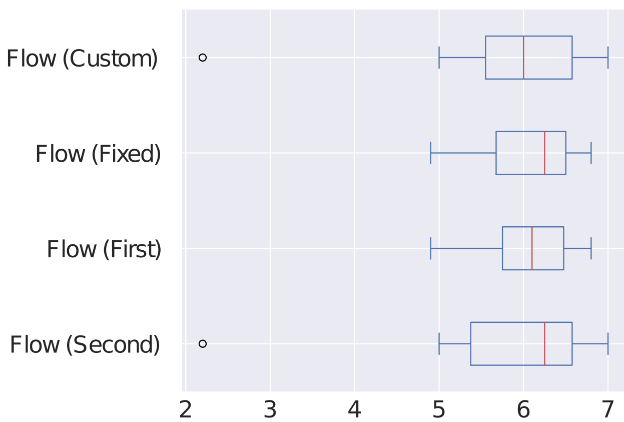

Figure 9: Central tendencies of the flow score, grouped once by condition and once by iteration.

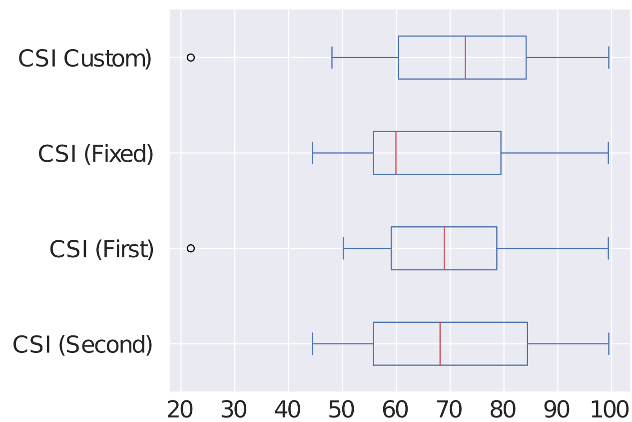

Figure 10: Central tendencies of the creativity support index (CSI), grouped by iteration and by condition.

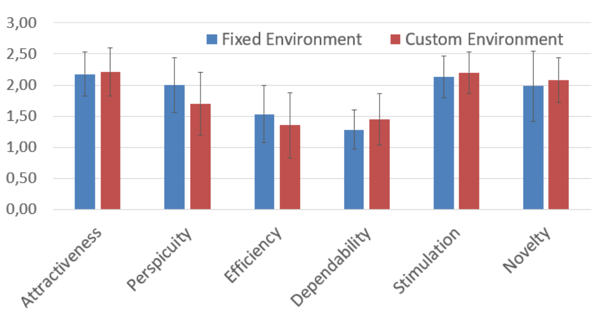

Figure 11: Comparison of UEQ scale means - Custom vs. Fixed condition.

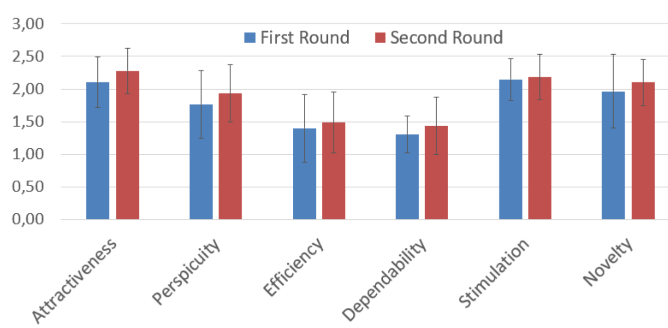

Figure 12: Comparison of UEQ scale means - first vs. second run.

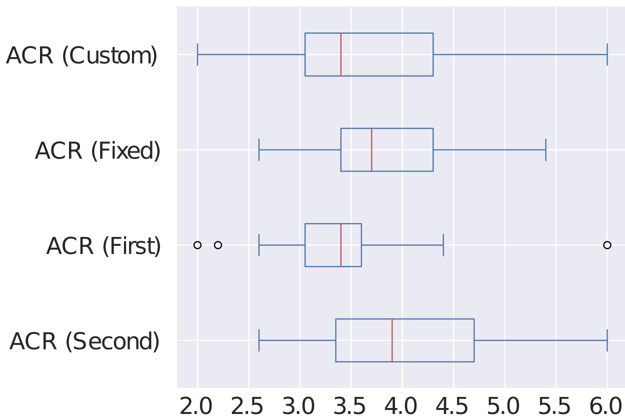

Figure 13: Central tendencies of the average creativity ratings (ACR) grouped by condition and by iteration.

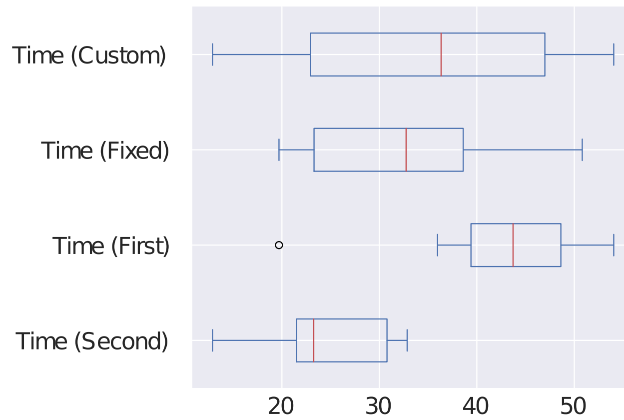

Figure 14: Central tendencies of the time (in minutes) spent in each condition and iteration (first/second).

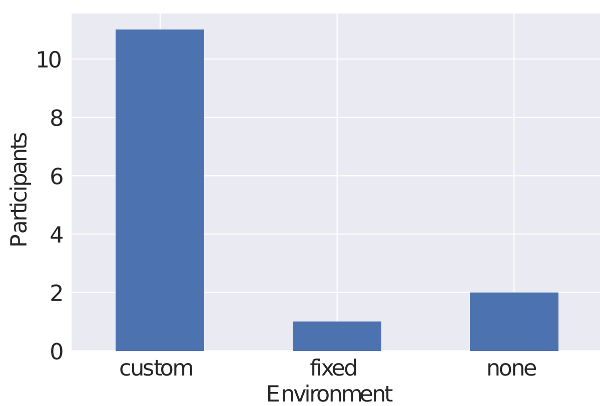

Figure 15: Participants' preferences for the different VEs.

Table 3: Results of interjudge reliability analysis of creativity ratings (data: 5 judges with 28 ratings per scale).

	Creativity	**Rhythmic Interest**	**Personal Preference**
Mean	3.77	3.57	3.11
SD	1.04	1.07	1.10
Cronbach's α	0.737	0.546	0.712

calculated, as normality within groups and equal variances were confirmed with Shapiro-Wilk's and Levene's tests. Despite the observable tendencies, no statistically significant differences could be observed.

Average Creativity Rating (ACR): To ensure that the individual ratings of creativity given by the judges (cf. RQ2) could be combined into a single score for each song, interjudge reliability analysis was performed. Thus, Cronbach's α was computed for the scales 'creativity', 'rhythmic interest' and 'personal preference' [40, 64]. The results of this analysis are presented in table 3. The scores for creativity and personal preference show an α score >0.7, which is considered an acceptable level [1, 40, 60]. Therefore each song could be assigned a single rating, computed as the average of the individual judges' ratings, resulting in an averaged creativity rating (ACR). These ratings were compared for the two experimental conditions as well as the iteration (first/second) in which they were seen by the participants.

The assumptions of normality within the groups and equal variances were tested using Shapiro-Wilk's test and Levene's test respectively. Normality within groups *fixed* ($p = 0.894$) and *custom* ($p = 0.206$) as well as *first* ($p = 0.130$) and *second* ($p = 0.690$) was given. Equally, homogeneity of variances was affirmed by the scores for *fixed*/*custom* ($p = 0.145$) and *first*/*second* ($p = 0.509$). Consequently, Student's t-tests for paired data were calculated for both pairings as the requirements of normality and equal variances were met. Comparing creativity ratings of the conditions 'custom' and 'fixed' with the hypotheses that ratings from *custom* were greater than ratings for fixed, produced no statistically significant result. When comparing creativity ratings by their temporal order/iteration, it was shown that ratings for the second song were greater than for the first song to a statistically significant level ($p = 0.032$ before p-value correction). However, after p-value correction no statistical significance remained. *Condition Preference:* To explicitly assess which condition the participants preferred (cf. RQ4), they were asked which one they liked better after they finished the whole experiment. Further, they were asked to fill out a free text form to justify their decision. As illustrated in Figure 14, most participants preferred the customizable environment. While some did not state a clear preference, only one person explicitly liked the fixed VE better. One reason for their disliking of the *fixed* environment mentioned by multiple people were environmental features distracting them.

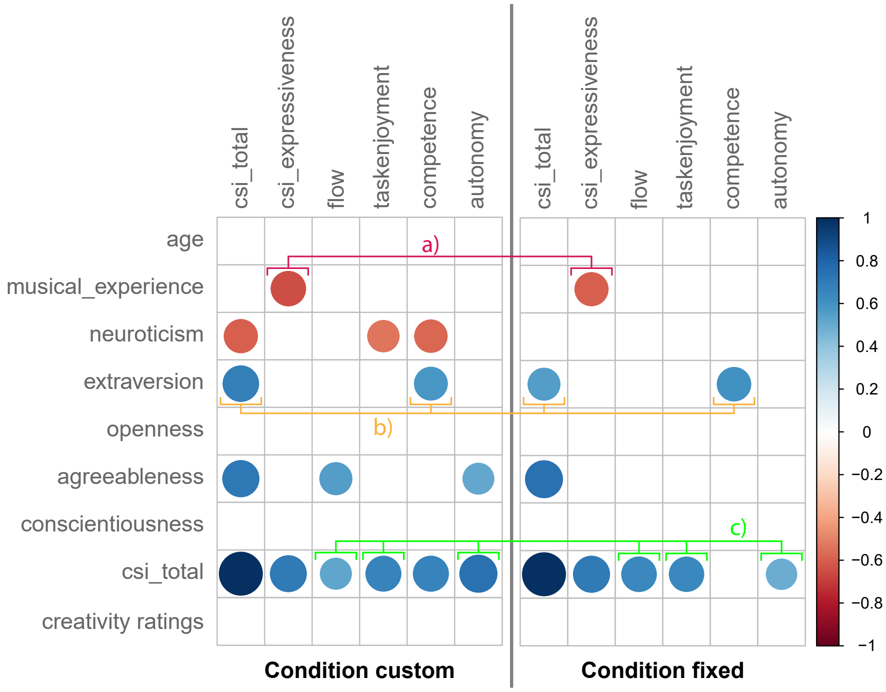

Figure 16: Excerpt of pearson-correlations between independent and dependent variables for both VE conditions.

Time spent in VEs: Participants spent roughly equal amounts of time in each condition, when comparing 'custom' and 'fixed' conditions (cf. RQ4). However, a relatively clear bias towards the first iteration was observed. With 44 minutes on average, participants spent almost twice as much time in the first iteration than in the second iteration of creative tasks (*first*: $\overline{M}$: 43.7, SD: 8.75; *second*: $\overline{M}$: 23.2, SD: 6.0), as can be seen in Figure 15.

6.2.2 *Correlation Analysis.* To discover possible patterns with regards to demographic and personality data, correlations were computed. Since the demographic and personality data was not part of the experimental setup with two conditions, correlations were calculated for each condition separately. Figure 16 shows an excerpt of the results in matrices with significant correlations indicated by colored circles. Data from all 16 participants was included in this correlation analysis. Notably a negative correlation between the musical experience and evaluation of expressiveness (a subscale of the creativity support index) can be observed in both conditions (Figure 16*a*). Also, 'Extraversion' correlates positively with the CSI score and the Competence scale (Figure 16*b*). Lastly, strong positive correlations between the Creativity Support Index, the flow score and the scores from the Creativity Experience Self Rating questionnaire (CESR) can be observed in both conditions (Figure 16*c*). Another correlation we found (not depicted in Figure 16) was a negative correlation between neuroticism and the number of environmental objects (compare 'visual complexity' in 5) that were configured by participants within the custom condition.

7 DISCUSSION

Users preferred customizable environments: We observed a substantially higher mean creativity support index (CSI) for the customizable virtual environments. After p-value correction, however, this difference turned out to be insignificant, which can be explained by our rather small sample size. The difference we observed is highlighted by the data we gathered when asking participants directly for their preferred condition: Here, 11 out of 14 participants preferred customizable environments (see Figure 14). Participants stated that this was mostly due to features of the fixed environment configuration that distracted them. For instance, falling leaves or birds in the ambient soundtrack were perceived to be "annoying". The customized environment configurations of these participants differed strongly from the fixed environment configuration: The time of day was often chosen to be at midday or night, the ambient sound level was configured to be lower and accent lights were only used sparingly. These results, combined with the results of our focus groups, which showed that users have widely differing preferences for creative environments, lead us to conclude that VEs that support creativity should be customizable and/or designed according to specific user needs (just as creative people do with their own environments in the physical world). However, since our participants were not only able to customize certain environmental parameters (e.g. light color) but also select between four different virtual environment types (see Figure 5) in the custom environment condition (compared to just the 'meadow' VE in the fixed condition), it is hard to pinpoint exactly which of these two paradigms (VE selection or customization) had the greatest impact on the strong user preference for customizable VEs.

Personality traits revealed potential biases: When analyzing the correlations between personality traits and the choice of customizable environments, we found negative correlations between neuroticism and the visual complexity users configured for their environments (see Section 5), as well as the CESR subscales task enjoyment and competence in the custom VE condition (see Figure 16). However, all other correlations with personality traits were independent of the virtual environment configurations. Instead, we observed that agreeableness and extroversion correlate positively with CSI scores across all environment conditions. While the correlation with agreeableness can most likely be explained with an increased tendency for positive feedback regarding the creativity support tool, the correlation with extroversion was unexpected. Following these observations, we encourage researchers to be careful when evaluating creativity support systems with CSI, as personality traits, such as extroversion and agreeableness, can significantly bias the results.

There lies vast potential in designing VR setups for flow: We observed a correlation between flow and CSI/CESR across both conditions (custom and fixed environment). Thus, we encourage researchers and developers who aim to design creative support tools to optimize their systems specifically for user flow. Further, the overall high flow ratings across both conditions and creative task iterations (both first and second task sections) suggests that participants did not need much practice to familiarize themselves with the drum sequencer UI and that VR technology can be promising for fostering flow during creative tasks in virtual environments.

Early feedback from musicians was crucial: Besides flow, our prototype received high ratings regarding creativity experience (CESR) and the UEQ subscales 'attractiveness', 'perspicuity', 'stimulation', and 'novelty'. We interpret these observations as a success of the human-centered design approach we followed, as it took user requirements into account when designing the 3DUI and VE capabilities. For instance, our initial ideas that made use of the third dimension for the main sequencer UI (see Figure 3) were dropped as a result of the focus group session. Instead, we used the more traditional grid-based layout to minimize the entry barrier for users. Decisions like this were crucial to providing musicians with a 3DUI that did not disturb their workflow, suited their needs, and did not negatively interfere with creativity ratings when the impact of customizable virtual environments was investigated during the laboratory study.

The environment is connected with creative mood: While the results of the laboratory study did not reveal any impact of features of the virtual environments on creative quality or creative experience, the post-test interviews (see Figure 6) revealed a link between the choice of VE types (see Figure 5, A-D) and the participants' creative mood. Multiple participants stated that they felt more inclined towards certain genres of backing tracks in one environment than the other. Examples included a preferred selection of Country songs in the 'Meadow' environment and more beat-driven songs in the 'Outer Space' environment. A possible implication of this observation is, that there might not even be one 'ideal' virtual environment for a single creative person. Rather a wide selection of different environments that can be interchanged in flexible ways might be a promising approach. Future work should asses whether temporal factors, such as creative mood or sentiment, shall be utilised to adjust VEs appropriately.

Expert musicians lack expressiveness: Another notable observation is that musical experience and expressiveness are negatively correlated in both conditions. One explanation is that experienced musicians are accustomed to achieving such a high level of musical expression using the instruments they are proficient in, that a similar effect could not be achieved with our step sequencer UI. This problem could be addressed by focusing on experts in future participatory studies. A technical approach might be to develop systems that allow musicians to use their familiar/main instruments in VEs, e.g., by using augmented reality or augmented virtuality technologies.

8 CONCLUSION

This paper explored the potential of designing and customizing virtual environments (VEs) to foster creativity in VR.

First, we extracted and listed factors that can positively influence creativity from literature and related research. From these factors, we developed design concepts for a VR application including

(1) a 3DUI for a virtual drum sequencer that allows users to create drum tracks and design drum sounds without demanding substantial a priori knowledge about music theory or audio production and
(2) virtual environments that can be customized by users to fit their individual needs while being creative in VR.

Following a human-centered design process, we conducted a focus group study to let musicians review our design concepts and gather user requirements regarding 3DUI design and creativity supporting environments. Considering the findings from literature and our focus group study, we developed a prototype that achieved high user experience and flow ratings. During a laboratory study, we used this prototype to compare two design paradigms: Customizable virtual environments (VEs) and a static/fixed VE configuration that was designed to foster creativity based on findings from literature. As dependent variables, we looked at creative quality (as rated by experts), flow, user experience, creative experience, and subjective creativity support. Further, we investigated and discussed correlations between these measures and the personality traits of the study participants.

Our results from the laboratory study show that participants predominantly preferred customizable VEs over a predetermined or static environment configuration that was designed to be optimal for creativity support. From the quantitative data analysis, however, we did not observe a significant impact on creativity ratings of experts and self-assessment creativity scales. However, as we did observe high participant scores for flow and found positive correlations between subjective creativity support and flow, task enjoyment, feeling of competence, and autonomy, we conclude that there lies great potential in developing VR-based creativity support tools that focus on flow in creative contexts. Furthermore, we observed that users chose musical genres that fit to their surroundings, and argue that developers should not only consider fixed parameters such as personality traits, but also consider temporal parameters such as creative mood when designing virtual environments for creativity support.

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