# Usability, Learnability and Human Factor Evaluation in a Multi-Browser Virtual Environment

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*Abstract: The multi-browser Virtual Environment (VE) is designed for desktop VR to simulate a multi-screen arrangement to enhance productivity in internet activities. Various evaluation models must be used to assess the feasibility of early-stage software development. Initially, pilot evaluations will focus on factors within the developed VE and human factors to measure this VE. The System Usability Scale (SUS) is a well-known evaluation technique that measures usability and learnability. Additionally, human factor evaluation models will be used to assess changes in the user's mental state, such as fatigue, stress, and physical discomfort. The study found no significant differences in SUS, usability, or learnability among experienced and inexperienced users of the multi-browser VE. Both groups found the system equally usable and learnable. The evaluation of human factors revealed no significant differences in fatigue, stress, or physical discomfort before and after using the multi-browser VE. For the browsing experience, there was a clear preference for multi-browser VE over traditional browsing experiences. Overall, multi-browser VE was well received and had no noticeable effect on users' mental states.*

*Keywords: Usability; Learnability; SUS; Human Factor; Multi-browser; Virtual Environment*

# 1 Introduction

The rapid progression of Virtual Environments (VE) / Virtual Reality (VR), alongside the Cognitive InfoCommunications (CogInfoCom) paradigm, has notably impacted user perception, interaction and management of digital information [1] [2]. Immersive environments can enhance engagement and spatial comprehension; however, they may also present cognitive challenges that affect usability and learnability. Thus, systematic usability evaluation is crucial when introducing new interaction paradigms based on VE [3] [4].

Web browsers have transformed from basic document viewers into multifunctional platforms that facilitate complex, parallel tasks via tab-based interaction [5] [6]. Despite their origins as 2D platforms, current browsers have evolved into versatile settings for various online operations, demonstrating their adaptability and effectiveness in facilitating human activity [7]. In a 2D environment, the browser's tabs often require clarification for users and are considered less than optimal [8]. Managing multiple tabs within a two-dimensional interface can diminish clarity of overview and elevate cognitive load. This limitation drives the investigation of spatialized, multi-browser methods that utilize 3D environments to enhance information access and navigation [9-11].

However, usability, which encompasses user convenience and the effectiveness of a system, is an essential factor in the successful development of a VE. Learnability is also a factor that focuses on understanding and navigating the system quickly [12]. Since users are the leading actors in the user-centered system, they have different mental and physical conditions each time [13]. The intersection of VE and CogInfoCom, usability, learnability, and human factors provides an exciting study perspective and can revolutionize how humans interact in VE [14].

Moreover, the System Usability Scale (SUS) is a model for evaluating usability and learnability. The SUS evaluation, which consists of ten questions, does not measure usability alone. Two questions from the SUS, which are aspects of learnability, are "I think that I would need the support of a technical person to be able to use this system" and "I needed to learn many things before I could get going with this system" [15] [16]. Next to human factors is an evaluation model to measure users' mental and physical conditions. Previous research proposed an evaluation model for human factors to assess mental states, including changes in stress and fatigue, before and after using the VE [13].

Apart from immersive HMD-based VR, an increasing amount of research has focused on desktop 3D VE as effective "virtual workspaces" that can facilitate information-intensive tasks without the need for specialized VR hardware. An illustrative case is MaxWhere, a desktop 3D VR platform characterized as a 3D browser/workspace. Previous research indicates that MaxWhere enhances task efficiency in workflow sharing and management contexts, demonstrating quicker completion times and reduced user operations relative to traditional 2D workflows.

Additionally, its mouse-based navigation methods are found to be accessible to a diverse user base [17-19].

By developing multi-browser VE, this research investigates the impact of spatialized multi-window browsing within a desktop VR-like workspace on usability, learnability, and human-factor outcomes. This study diverges in its interaction design, browser arrangement strategy, and evaluation focus, specifically addressing SUS usability/learnability separation and pre- and post-human-factor comparisons. This positioning clarifies how our contribution enhances existing desktop 3D workspace platforms and provides further evidence for multi-browser VE designs in routine browsing activities [19] [20].

This research evaluated multi-browsers in VE using usability, learnability, and human factors. We have developed a multi-browser VE along with a navigation model. The stress, fatigue, usability, and learnability levels will be measured to assess the user experience and mental state. After this research is completed, justification will be obtained regarding the impact of the multi-browser on users, so that further studies can be carried out to improve the user experience in carrying out all their work by utilizing 3D VE. This paper presents related work on VE usability and measurement approaches, followed by a system description, experimental methodology, results, and a discussion of the implications.

# 2 Literature Review of Usability, Learnability, and Human Factors

This section examines research on the usability and learnability of the SUS instrument, as well as studies addressing human factors associated with fatigue, stress, and physical discomfort. The study concludes by referencing previous research on multi-browser VEs, thereby establishing both the theoretical and empirical foundation for the current investigation.

## 2.1 System Usability Scale

The System Usability Scale (SUS) is a widely used tool for evaluating perceived usability in various interactive systems, including VEs [21]. Previous studies have shown that the SUS can be divided into two dimensions: usability and learnability. This decomposition provides a clear and robust foundation for evaluating both the immediate effectiveness of a system and the ease with which users can become familiar with it [22]. This framework renders SUS especially appropriate for preliminary assessments of innovative interaction paradigms.

The SUS can be used to measure the usability of VE systems, considering characteristics such as ease of use, learnability, and overall user satisfaction in VEs. Its standardized questionnaire style and scoring system make it an adaptable instrument for assessing the user experience in VR applications, providing significant insights into the usability and learnability of VE. However, Lewis and Sauro [22] They explained that there are two factors in SUS: usability and learnability. The usability aspects are represented in questions 1, 2, 3, 5, 6, 7, 8 and 9, while the elements for measuring learnability are 4 and 10. Various studies have also used this to assess usability and learnability in interactive systems and VEs [15] [16]. Usability and learnability in VE have different perspectives from experienced and inexperienced users. Experienced and inexperienced VE users may have varied perceptions of usability and learnability. While experienced users emphasize efficiency and advanced capabilities [23], inexperienced users choose ease of use and guidance [24].

## 2.2 Human Factor Study

The evaluation of human factors in VEs typically focuses on fatigue, stress, and physical discomfort, especially concerning the use of task-oriented systems [25]. This study employs a framework consistent with work- and task-based VE evaluation, emphasizing short-term alterations in user state instead of long-term clinical outcomes [26]. Evaluating VE users' stress levels of VE users is critical for a successful user experience.

Moreover, various researchers have measured mental states using multiple questionnaires. Another research study by Wei et al. measured fatigue in four aspects (physical, motivational, affective, and cognitive fatigue) using a tourism fatigue questionnaire [26]. However, the aim of some of this research does not lead to a job/task/training/learning. Tschoerner et al. conducted another study that analyzed human factors by mental states (stress and fatigue). [13]. That research aims to work/train/learn, which is similar to the objective of this research. They developed several questionnaires considered suitable for evaluating human factors in train shunting training, so we used the model from their proposed questionnaire in this study. This instrument is used in this research because it provides an initial assessment of the VE development process. The number of questions used was 9, using a 1-5 Likert scale. Then, from the same reference, slight relevant modifications were made to assess or justify the user's advantages and disadvantages when using multi-browser VE.

## 2.3 Multi-Browser in 3D Virtual Environment

The development of 3D VE has transformed how people engage with and browse internet-based content [27]. Researchers investigated the integration of 3D VE with regular web browsing, developing multi-browser systems that enable users to perceive and interact with web pages in immersive 3D spaces [28]. These systems allow users to interact with multiple web pages within an immersive 3D environment, offering a more engaging and immersive experience than traditional browsing. Previous research on spatialized desktop VR systems suggests advantages for overview and task coordination, warranting additional exploration of multi-browser interaction in VE. Various environments can be developed for user needs, such as MaxWhere [10]. The growing interest in and improvements to multi-browser 3D VE aim to enhance internet browsing and collaboration by leveraging its benefits.

Desktop 3D VR workspaces have been explored as alternatives to traditional 2D desktop configurations, especially for tasks that require handling multiple digital content and frequent context switching. MaxWhere has been examined as an environment that facilitates the interactive arrangement of content in three-dimensional space, allowing users to engage in digital workflows within a spatially structured virtual room. Controlled studies demonstrate that these environments can decrease the number of operations and the time allocated to overview-related tasks compared to traditional 2D workflow execution, indicating possible advantages for information organization and monitoring in multi-content tasks [17] [18]. Thus, experimental findings on MaxWhere indicate that its navigation and task execution are practical for users with varying spatial abilities. This supports the notion that desktop VR navigation can be accessible without extensive prior experience with VR [2]. Additional evidence beyond MaxWhere indicates that converting traditional 2D layouts into 3D dashboard-like environments may decrease cognitive load while preserving performance, thereby supporting the overarching rationale for spatialized desktop VR interfaces [19].

To align the background with the study aims, the literature review is confined to two closely related areas: (i) empirical usability evaluation of virtual/extended reality and VE, focusing on desktop/3D workspaces where applicable; and (ii) validated usability measurement utilizing the SUS, encompassing its recognized usability–learnability framework. This study retains foundational work on CogInfoCom solely to the extent that it informs the human–technology coupling perspective pertinent to VE interaction and evaluation [1, 11, 29-31]. In this study, we incorporate MaxWhere as a conceptual comparator and position our multi-browser VE as a targeted implementation aimed at internet browsing behavior, with an evaluation focused on SUS-derived usability and learnability, as well as human-factor stability, including fatigue, stress, and physical discomfort [13, 19, 20].

# 3 Materials and Methods

This section discusses the materials and methods used in this research. The first part discusses the creation of a multi-browser VE and its features. The second part describes testing scenarios. Next, the third part describes the experiment's procedure and how participants fill out the questionnaire in the fourth part. The final part discusses the research Question and hypothesis of this study.

## 3.1 Multi-Browser VE Development

The developed multi-browser VE is a room with several browser windows that can be used as a medium for internet activities. The browser arrangement is made in a row, like when people work using monitor screens and form a semi-circular pattern on a desk or in a room. The entire browser/whiteboard can be seen from a single point in the center. For illustration, the room is shown in Figure 1. The VE in this research was created using Unity 2022.3.10f1 and the C# programming language.

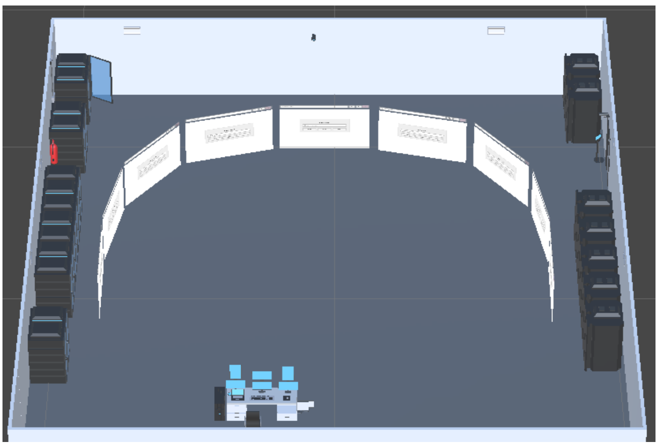

Figure 1
The entire room with multi-browser VE

The multi-browser VE environment consists of two forms: the first is fully 3D, and the second is a 2D view. In the first form of 3D view, the user can interact with the room entirely, viewing it from a broader perspective, and simultaneously use more than one browser, as shown in Figure 2. The environment will change to a 2D view if the user selects one of the whiteboards, as in Figure 3.

Furthermore, various developers have provided web browsers with standard features, such as Meta Quest Browser [32] or those offered by the Unity Asset Store [32]. However, in this research, the browser is open-source and uses a Chromium engine [33]. A browser's primary features include the ability to display URLs and web pages. It provides interactive visual browsing of files/video recordings through mosaics and targeted playback, which can also be accessed from the back-and-forth pages, as seen in Figure 3. We also added a close-focus view feature to exit 2D mode and return to 3D mode.

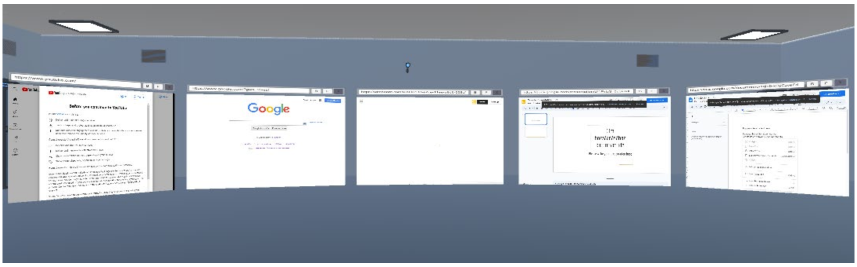

Figure 2
Multi-browser 3D VE view

Navigation within the multi-browser VE was achieved through standard mouse and keyboard inputs, facilitating forward, backward, and lateral movement via intuitive control mappings. This design aimed to strike a balance between accessibility and spatial freedom, while minimizing the need for specialized hardware or prior experience in VR.

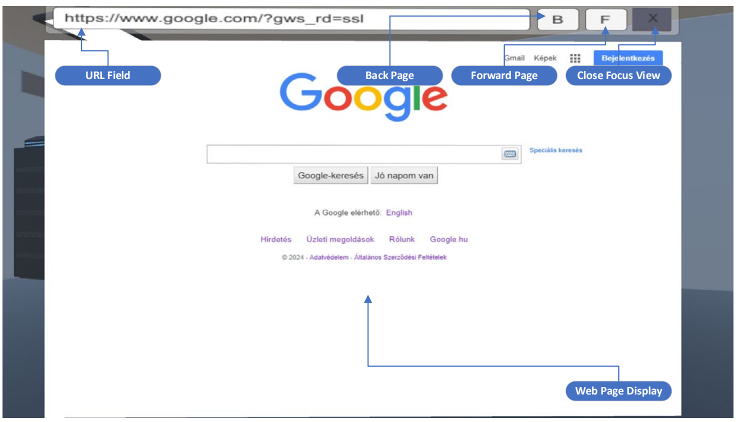


Figure 3
2D whiteboard view

Therefore, we optimized the control design using only the keyboard and mouse. The keyboard enters instructions in characters, text, letters, or symbols according to its standard function. For user movement in 3D view mode, the player's movement is entirely using the computer mouse (walking forward, backward, and along the right or left side). In the 3D view, we use a middle click on the mouse roller to navigate and move to different places based on the x- and y-axis of the mouse.

The right-click is used to rotate the camera view, and the left-click is used to select the browser and enter 2D view. Meanwhile, in a 2D view, the computer mouse only navigates web pages. In a 2D view, the user cannot move, or in a static view.

## 3.2 Testing Scenario Description

The testing scenario is conducted in six stages for each user/participant, as outlined in Table 1. The equipment device used in the development and testing stage is a ThinkPad X1 Extreme Gen 2 laptop and a standard computer mouse. The testing procedure followed the six stages summarized in Table 1, encompassing preparation, familiarization, task execution, and post-experiment evaluation.

Table 1
Testing scenario phase

| No. | Duration (mins) | Activity | Action | Equipment |
|---|---|---|---|---|
| 1 | 10 | VE Preparation | Set up computer devices and questionnaires. | Testing environment, VE, and device |
| 2 | 10 | Participant arrival | Briefly inform participants about the experiment and distribute the pre-experiment questionnaire. | Questionnaire |
| 3 | 5 | VE Demo | Demonstrate how to navigate and interact with the VE for participants. | VE and computer device |
| 4 | 10 | VE Testing Scenario | Participants conduct testing and internet activities on VE. | VE and computer device |
| 5 | 5 | Questionnaire completion | Participants fill out the post-experiment questionnaire. | Questionnaire |
| 6 | 5 | Experiment closing | Clean up the testing environment. | All Equipment |

## 3.3 Experiment Procedure

The process is discussed in Part 4 of the testing scenario. Initially, participants adapt to the navigation model for their movements in 3D VE mode. Afterwards, participants can choose one of the browsers to carry out a task. The next stage is to switch between browsers and work on a task until the testing time runs out. In both tasks carried out, participants enter 2D mode, several tasks/jobs that can be done online, such as reading a website page, watching video/music, drawing on a whiteboard/blackboard, working on a spreadsheet, document editing, creating slide show until reading the portable document file or other work that is usually carried out by participants who use a web browser. In the middle or end of the browser task, participants can also do/review what can be done by viewing the multi-browser in

3D mode. The duration of each task is flexible, and participants can attempt to work on more than two tasks; however, the total time allocated to each participant remains fixed.

## 3.4 Questionnaires

Participants filled out the questionnaire twice: before the experiment by filling in the pre-experiment questionnaire and after the experiment by filling in the post-experiment questionnaire. For the pre-experiment questionnaire, participants filled in their email address, sex, age, experience with computer peripherals, internet activities, experience with 3D VE, mental state, and the advantages and disadvantages of using VE. Participants also completed a handedness questionnaire to determine their preference for the hand they used to perform the activity. Although the mouse is designed to be used with the right hand, justification of handedness in computer-generated VE is necessary [46]. After the participants had completed their experiments, they filled out a questionnaire that included their email addresses (for data identification and unification purposes), the mental states questionnaire, and the SUS. The Mental State Questionnaire was completed twice, before and after the experiment. This aims to determine and assess the impact of using VE on the participant's mental condition.

## 3.5 Participants

The rationale for the pilot study and the determination of sample size. This experiment served as a preliminary pilot evaluation of the multi-browser VE to establish baseline evidence for (i) perceived usability and learnability assessed through the SUS and (ii) the stability of selected human-factor indicators, including fatigue, stress, and physical discomfort, before the planning of a larger confirmatory study. The study was not designed to detect minor effects between subgroups; instead, it aimed to generate preliminary effect estimates, identify potential usability risks, and evaluate the feasibility of the protocol and measures. The implementation of a pilot design adheres to the recommendation that pilot studies should determine sample size based on feasibility and estimation objectives, rather than on formal hypothesis-testing power criteria [34] [35]. A total of 30 participants were recruited to facilitate initial subgroup comparisons between experienced and inexperienced VE users. In technology and training evaluation research, sample sizes typically range from 11 to 30, especially in early-stage empirical evaluations [36].

## 3.6 Research Questions and Hypothesis

Based on the above ideas, we have identified three Research Questions (RQ) that will guide the efforts described in this study. The RQs are:

**RQ1** How usable and learnable was the multi-browser VE for experienced or inexperienced users?

**RQ2** Does multi-browser VE cause fatigue/stress and physical discomfort for users?

**RQ3** Do users/participants prefer using multi-browser VE over a traditional browsing experience?

This research poses three main hypotheses that should be validated by attending to our usability, learnability, and human factor premises:

**Hypothesis 1 (H1)** SUS, usability, and learnability are the same between experienced and inexperienced users on multi-browser VE.

**Hypothesis 2 (H2)** There was no significant difference in fatigue/stress and physical discomfort between before and after using multi-browser VE.

**Hypothesis 3 (H3)** The advantages and disadvantages of using certain technologies in internet browsing are the same.

# 4 Results and Discussion

In this section, before explaining the results obtained in this research, the characteristics of the participants will first be described. In this study, the sample consisted of 30 participants, comprising 22 men and eight women. Participant handedness was measured by EHI (Edinburgh Handedness Inventory) [37], with the result being 27 right-handed and three left-handed. The youngest participants were 19 years old, and the oldest was 42, with a mean age of 29.67 and a standard deviation (SD) of 5.79. In the context of browser use or internet use by participants, an assessment was conducted of their experience with the internet, as was done in previous research [38].

The profiles of all users/participants vary in their activities, utilizing the internet as a medium for interaction. Their activities, as shown in Figure 4, include social media, browsing (information gathering), entertainment (watching movies, listening to music, etc.), learning (reading, accessing e-learning, etc.), working (using online documents, spreadsheets, and online meetings, etc.), and gaming. Overall, their experience using the internet spanned a minimum of 5 years and a maximum of 24 years, with an average of 14.4 years and a SD of 5.4. In one day, they spend at least 6 hours actively using the internet and a maximum of 15 hours, with an average time of 9 hours and a SD of 2.9 every day. A total of 20 participants have experience with VE (Virtual Reality, Mixed Reality, Augmented Reality, 3-D Environment, 3-D Gaming, etc.), and 10 participants have no experience at all.

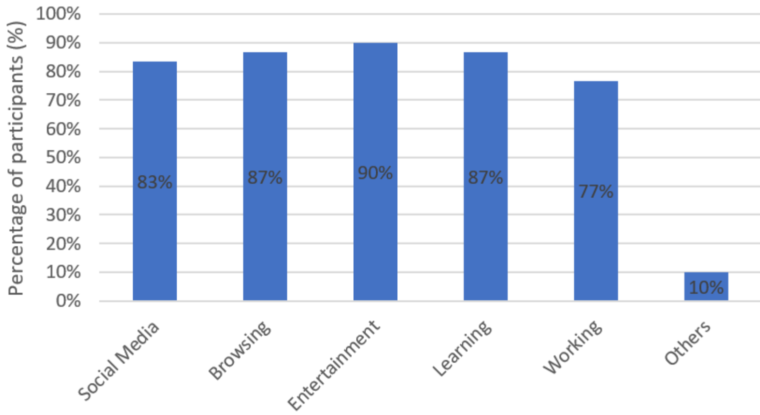


Figure 4
Participants experience activities using the Internet

## 4.1 Usability and Learnability

The first evaluation carried out was related to usability and learnability. As previously explained, SUS is used to provide an assessment [21]. In general, the results obtained for the multi-browser created can be seen in Figure 5. This figure presents the average values of SUS, Usability, and Learnability. Each data set is divided into three parts: the average of all users/participants in blue, the average of experienced users in orange, and the average of inexperienced users in grey. Based on this data, evaluations from users with VE experience can yield better evaluation results than those from inexperienced users.

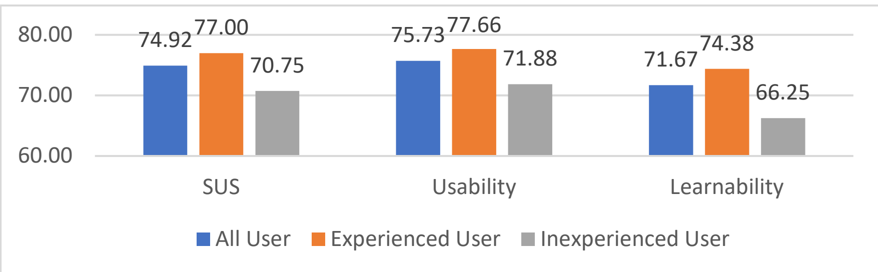


Figure 5
SUS, Usability, and Learnability overall testing result

Two perspectives on SUS are well known to justify SUS: Sauro et al. [22] And Bangor et al. [39]. Justification based on the assessment by Bangor et al. for multi-browser is "C," or in the "Good" range; in this case, both experienced and inexperienced users fall within the same range. Meanwhile, based on the perspective of Sauro et al., they got a grade of "B" based on the average rate of all experienced users. In contrast, inexperienced users give a grade of "C." However, the percentile range for all users (experienced and inexperienced) is 70 – 79. Overall, the justification results are presented in Table 2.

Table 2
SUS scale grade according to Sauro and Bangor

| User Result | SUS Score | Sauro | | | Bangor | | |
|---|---|---|---|---|---|---|---|
| | | Range | Adjective | Percentile Range | Range | Grade | Adjective |
| **All** | 74.92 | 74.1 – 77.1 | B | 70 – 79 | 70 – 80 | C | Good |
| **Experienced** | 77.00 | 74.1 – 77.1 | B | 70 – 79 | 70 – 80 | C | Good |
| **Inexperienced** | 70.75 | 65.0 – 71.0 | C | 70 – 79 | 70 – 80 | C | Good |

To answer RQ1, we conducted several statistical analyses to validate our findings. The first step we took was checking the data distribution. Overall, the data distribution is not normal. Then, we conducted a comparative analysis using the Shapiro-Wilk test to see the normality of the data. The SUS for experienced users has a p-value of 0.041, which is smaller than 0.05, indicating that the results of the SUS are statistically significant. Still, for inexperienced users, the p-value of 0.539 is less significant than 0.05, indicating a normal distribution. This contrasts with when the parameters are separated between usability and learnability. In terms of usability and learnability, all p-values obtained are more significant than 0.05, indicating that the distribution is normal. The next step is to carry out data homogeneity validation. All p-values for SUS, usability, and learnability are greater than 0.05, indicating homogeneous variance in the data obtained.

The final step in answering RQ1 is to validate each aspect (SUS, usability, and learnability). Since the data distribution for usability and learnability was normal, the validation test was conducted using two t-tests comparing samples of experienced and inexperienced users. For SUS, analysis was carried out using the Wilcoxon rank sum test. The median data for experienced users is 77.50, and for inexperienced users is 71.25. The p-value result from the Wilcoxon rank-sum test for the SUS aspect is 0.164. In Table 3, the p-values of the t-test (for usability and learnability) and Wilcoxon rank-sum test (for SUS) are all greater than 0.05. So, based on these results, H1 is accepted because there is no significant difference in SUS, Usability, and Learnability scores between experienced and inexperienced users on multi-browser VEs.

Overall, the usability and learnability results in Table 3 indicate that the multi-browser VE can be effectively used by both experienced and inexperienced users, supporting intuitive initial interaction without requiring extensive prior familiarity.

Table 3
Results of statistical tests when comparing Experienced and Inexperienced Users

| Variables | SUS | Usability | Learnability |
|---|---|---|---|
| t-test | - | -1.209 | -1.175 |
| p-value | 0.164 | 0.236 | 0.249 |

The comparable learnability scores among user groups indicate that the multi-browser VE facilitates intuitive first-time use, including for participants lacking prior VE experience. This finding is consistent with studies in VR and interactive system design, which indicate that spatial consistency, familiar interaction metaphors (such as mouse-based navigation), and clear visual organization can alleviate the initial learning burden. The findings suggest that the system's interaction logic does not create extra cognitive barriers for users in the initial stages, indicating its appropriateness as a general-purpose browsing environment rather than being limited to expert users. In other words, there is no difference between experienced and inexperienced users in SUS, Usability, and Learnability assessments. These results answer RQ1 and accept H1, indicating that the multi-browser VE has a relatively good level of usability and learnability.

## 4.2 User's Mental States before and after Experiments

A mental state assessment was conducted to evaluate fatigue and stress using a questionnaire. With these questions, participants completed the questionnaire twice, both before and after the experiment. The results of the questionnaire are presented in Table 4. In Table 4, mean differences are calculated by averaging the results from both the post-experiment and the pre-experiment. Then, the average results from the post-experiment are reduced by the pre-experiment. The mean differences between post- and pre-experiment show that the difference between the two is relatively small and not significant.

To answer RQ2, we analyzed the Wilcoxon signed-rank test because the data did not follow a normal distribution. Table 4 shows that the p-values of all items obtained using the Wilcoxon signed-rank test were not significant at the general significance level of 0.05. Based on these results, there is not enough evidence to reject H2. Thus, this confirms H2 that using multi-browser VE does not cause significant differences in users' levels of fatigue/stress and physical discomfort.

Table 4
Mental States between Post- and Pre-Experiment

| No | Items | Mean differences between post- and pre-experiment | p-value between post- and pre-experiment |
|---|---|---|---|
| 1 | Overall Tiredness | 0.133 | 0.646 |
| 2 | Overall Tension | 0.067 | 0.839 |
| 3 | Eye Fatigue | 0.133 | 0.691 |

| | | | |
|---|---|---|---|
| 4 | Vision (visual sensitivity) | 0.1 | 0.796 |
| 5 | Eyestrain | 0 | 0.829 |
| 6 | Backpain | 0.067 | 0.788 |
| 7 | Neck pain | 0.067 | 0.875 |
| 8 | Headache | -0.067 | 0.932 |
| 9 | Sleepiness | -0.067 | 0.823 |

## 4.3 User's Feedback on Multi-Browser VE

Feedback from users, based on the percentage of all users, regarding the advantages of using multi-browser VE rather than traditional browsing is shown in Table 5, while the disadvantages are listed in Table 5. In the advantages aspect, around 90% or 27 participants considered that the multi-browser VE "creates interest" or are very interested in this VE. Other elements have scored in the range of 40% to 57%. However, another exciting thing is that around 70% or 21 participants think that the multi-browser VE concept increases the accessibility of internet activities.

Table 5
Advantages of using Multi-Browser VE

| No. | Advantages Aspects | Participant Feedback | |
|---|---|---|---|
| | | Total | Percentage |
| 1 | Provide outstanding visualizations that aren't possible in a traditional browser | 14 | 47% |
| 2 | Create interest | 27 | 90% |
| 3 | Increase engagement | 12 | 40% |
| 4 | Increase browsing accessibility | 21 | 70% |
| 5 | Immersive browsing | 15 | 50% |
| 6 | Safe physical effort | 16 | 53% |
| 7 | Convenience | 17 | 57% |

The second set of feedback examines the perceived drawbacks of multi-browser support. Table 6 indicates that a limited number of participants reported negative experiences, with around 3% (one participant) experiencing motion sickness or misleading interaction, and 7-13% (two to four participants) noting other minor issues. Conversely, the majority of participants, approximately 67% (20 participants), indicated no perceived disadvantages. To address RQ3, a McNemar's test was utilized to compare the proportions of reported advantages and disadvantages, as both measures were derived from the same user group. The findings reveal a statistically significant difference ($\chi^2 > 3.84$, $df = 1$, $\alpha = 0.05$), indicating that the proportion of reported advantages significantly exceeds that of the disadvantages. The alternative hypothesis is accepted, indicating a distinct preference for the multi-browser VE among users.

Table 6
Disadvantages of using Multi-Browser VE

| No. | Disadvantages Aspects | Participant Feedback | |
|---|---|---|---|
| | | Total | Percentage |
| 1 | Artificiality | 2 | 7% |
| 2 | Motion Sickness | 1 | 3% |
| 3 | Dizziness | 3 | 10% |
| 4 | Eyestrain | 4 | 13% |
| 5 | Unrealistic Interaction | 3 | 10% |
| 6 | Misleading | 1 | 3% |

## 4.4 Qualitative Thematic Analysis of User Feedback

The analysis of open-ended user feedback employed a thematic grouping approach, wherein responses were coded and organized into recurring themes that represent perceived strengths and weaknesses of the navigation control. This qualitative analysis complements the quantitative findings, providing a contextual understanding of user perceptions beyond numerical scores.

Positive feedback was gathered into four primary themes. The primary theme identified was Ease of Use and Intuitive Control, which was the most commonly reported. Participants noted that navigation was characterized as “easy,” “smooth,” and quickly learnable, even for first-time users, primarily attributed to familiar mouse-based interactions. The second theme, Familiarity and Game-Like Experience, indicated that comparisons to established 3D VE (such as sandbox or first-person games) suggested that previous exposure to 3D navigation metaphors enabled swift adaptation. The third theme, Support for Multitasking and Overview, emphasized the benefits of simultaneous viewing of multiple screens, which users linked to increased productivity, particularly in monitoring information such as data dashboards or live graphs. The fourth theme, Engagement and Novelty, reflects user perceptions of the system as “new,” “interesting,” and motivating, suggesting heightened engagement during task execution.

Negative feedback, although less frequently reported, was categorized into three primary themes. The initial theme, Input Mapping and Interaction Consistency, addressed issues of confusion or discomfort associated with the use of middle-click and right-click functions for navigation, which are frequently intensified by hardware constraints such as substandard mouse devices. The second theme, Visual and Interaction Feedback, encompassed requests for enhanced animations, opacity transitions when nearing objects, auditory cues (e.g., footsteps), and more distinct exit affordances, reflecting expectations influenced by modern immersive systems. The third theme, Cognitive Load and Physical Comfort, indicated instances of confusion arising from the simultaneous opening of multiple pages and mild hand fatigue experienced during extended use.

The multi-browser VE was developed utilizing a desktop-based 3D VE, emphasizing mouse and keyboard interaction to enhance accessibility and minimize hardware reliance. A significant technical challenge was designing intuitive navigation mappings that strike a balance between flexibility and user familiarity. Middle-click and right-click interactions facilitated efficient control of 3D movement; however, user feedback indicated that variations in mouse hardware and unfamiliar input mappings may diminish comfort for specific users.

A further challenge involved visual and interaction feedback, including object occlusion, animation smoothness, and distinct exit affordances, which are essential for sustaining orientation and minimizing confusion in multi-window 3D VE. The challenges influenced design trade-offs between system simplicity and immersive richness, directly motivating the iterative refinement directions presented in the Future Work section.

Analyzing outcomes within the framework of a pilot evaluation. The pilot study primarily contributes initial evidence indicating that the system demonstrates "Good" usability and acceptable learnability, without observable pre–post deterioration in the assessed human-factor indicators. The findings indicate the necessity of advancing to a larger confirmatory study aimed at (i) assessing minor effects with sufficient statistical power, (ii) incorporating a broader range of participant profiles, and (iii) analyzing performance-based outcomes (e.g., task completion time and error rates) in conjunction with SUS and human-factor measures [34].

## 4.5 Structured Evaluation of Research Questions

The evaluation of the research questions is explicitly structured in accordance with the relevant statistical analyses and outcomes to enhance clarity. RQ1/H1 investigated the differences in perceived usability and learnability of the multi-browser VE between experienced and inexperienced users. This inquiry was examined through SUS-based usability and learnability metrics, supplemented by normality assessments, homogeneity evaluations, and intergroup comparisons. The findings revealed no statistically significant differences between the two groups, indicating that participants across varying experience levels shared similar perceptions of usability and learnability.

RQ2/H2 examined the impact of the multi-browser VE on users' mental states, focusing on fatigue, stress, and physical discomfort. The evaluation of this question was conducted through pre–post comparisons utilizing non-parametric tests. The analysis revealed no significant changes in the assessed mental-state dimensions, indicating that short-term use of the system does not hurt user well-being.

RQ3/H3 examined user preferences and subjective evaluations of browsing within the multi-browser VE in contrast to traditional browsing methods. This inquiry was analyzed using quantitative preference data and qualitative user feedback. The results indicated a distinct preference for the multi-browser VE, with the advantages significantly surpassing the disadvantages, thus reinforcing favorable user acceptance of the proposed system.

## 4.6 Limitations and Future Work

This study was designed as a pilot evaluation of the multi-browser VE to assess feasibility and generate preliminary estimates for usability, learnability, and human-factor stability, rather than to conduct a fully powered confirmatory test for minor subgroup effects. The multi-browser VE was developed as a desktop-based 3D VE to reduce hardware limitations and enhance accessibility. The findings suggest that lightweight VE configurations can serve as a transitional phase, between conventional 2D interfaces and fully immersive VR systems, particularly in contexts where usability, swift onboarding and user comfort are crucial.

Pilot studies serve primarily to evaluate feasibility parameters and guide the design of subsequent primary studies. Effect-size estimates derived from pilot studies should be interpreted with caution and not regarded as definitive evidence [40-43]. Thus, although N = 30 facilitates stable descriptive estimation and protocol validation, it restricts statistical power for identifying minor differences between experienced and inexperienced users and limits generalizability to wider populations and contexts. Consequently, we regard non-significant group comparisons as preliminary and present the current contribution as a baseline evidence point, aligning with early-stage evaluations in VR and training research, where comparable sample sizes frequently occur [36] [44].

A second limitation is that outcomes primarily rely on self-report measures, such as the SUS and brief pre– and post–human–factor ratings. The SUS is extensively utilized, and its two-factor structure is well recognized; this offers a valuable yet imprecise indication that could be enhanced through triangulation with supplementary measures [22]. Furthermore, human-factor effects in VE exhibit multi-dimensional characteristics, such as visual fatigue, workload, and discomfort related to cybersickness [44]. Variations in exposure durations and task types may result in distinct patterns [36] [44]. Future research should incorporate both objective and behavioral indicators, such as task time, error rate, and interaction counts, as well as longer or repeated sessions and validated complementary instruments when applicable, including workload or VR-specific symptom measures. This approach will enhance the understanding of learning dynamics and ergonomic safety in sustained multi-browser VE [36] [44].

Future work will advance in two phases. Initially, a confirmatory study will be conducted utilizing a larger and more diverse sample, considering factors such as age, occupational background, and familiarity with gaming/3D navigation [40, 42, 43]. Secondly, we will expand the technical and comparative framework by benchmarking the multi-browser VE against established desktop 3D workspace paradigms, such as MaxWhere-style spatial “smartboard” arrangements, and systematically assess the impact of navigation and spatial layout decisions on performance and user experience [19, 45, 46]. This structured program is consistent with existing research on desktop 3D VR workspaces and establishes a clear progression from initial usability validation to comprehensive design recommendations for multi-browser VE.

## Conclusions

This study delivers a preliminary pilot evaluation of a desktop-based, multi-browser VE, emphasizing usability, learnability, and specific human-factor indicators. The SUS and pre–post assessments of fatigue, stress, and physical discomfort indicated that the proposed system demonstrated good overall usability and acceptable learnability, with no statistically significant differences observed between experienced and inexperienced users of the VE.

Moreover, the short-term utilization of the multi-browser VE did not result in notable alterations in users' mental states, suggesting that the system can be engaged with safely and comfortably under the evaluated conditions. The evaluation of the research questions indicates that spatially organized multi-browser interaction facilitates intuitive first-time use and promotes user well-being.

In addition to quantitative results, qualitative feedback indicated that users found the system to be user-friendly, engaging, and conducive to multitasking through a simultaneous multi-screen overview. Reported drawbacks primarily pertained to interaction refinements rather than fundamental usability concerns. This pilot study provides baseline empirical evidence supporting the feasibility of the multi-browser VE concept and warrants further investigation.

Future research will incorporate larger and more diverse participant samples, evaluations based on task performance, and improved interaction design to enhance generalizability and deepen the understanding of learning dynamics.

This work advances the fields of VE and human-computer interaction by illustrating the effectiveness of a lightweight, desktop-based multi-browser VE in achieving a balance among usability, learnability, and human-factor considerations, thereby providing a viable approach to enhancing the accessibility of virtual workspaces.

## Acknowledgements

The research presented in this paper was supported by the Hungarian Research Network (HUN-REN) and was carried out within the HUN-REN Cognitive Mapping of Decision Support Systems research group. This work has been implemented by the TKP2021-NVA-10 project with the support provided by the Ministry of Culture and Innovation of Hungary from the National Research, Development and Innovation Fund, financed under the 2021 Thematic Excellence Program funding scheme. The authors would like to thank Prof. Peter Baranyi for the valuable advice.

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