Exploring Older Adults' Experience of Neurorehabilitation in Virtual Reality within a University of the Third Age

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***Abstract*—One of the areas where the commercially available contemporary immersive virtual reality technologies can be used for the common good is the neurorehabilitation of patients after events such as a stroke. The L-NeRVEn distributed software system represents a solution where a patient, under the supervision of a therapist, may undergo training involving motor imagery tasks with a disabled upper limb and electroencephalography to determine the success of the task. During the development of such system, an extensive user–experience–oriented testing is necessary. Here, an interesting group of potential users is older people, especially in the role of the patient. To obtain a relatively consistent and enthusiastic group of such users, this paper proposes to combine the testing with activities of University of the Third Age study programs. The paper also reports on a pilot implementation of such testing with n=12 participants and presents the results based on direct observation, video recordings, Igroup Presence Questionnaire, and Virtual Reality Sickness Questionnaire.**

***Index Terms*—neurorehabilitation, virtual reality, motor imagery, electroencephalography, user experience, University of the Third Age, testing, IPQ, VRSQ**

I. Introduction

Recent technological advances have made Virtual Reality (VR) accessible to the masses. This is especially true for VR headsets, which provide a satisfying immersive VR experience for a price of around 500 EUR. The areas where the VR utilization is seriously considered and experimented with include neurorehabilitation, where positive results have been achieved with patients with cerebral palsy [1], after a stroke [1], [2], or after a spinal cord injury [3], [4]. One of the contributions to this effort is the L-NeRVEn (LIRKIS NeuroRehabilitation in Virtual Environment) software system [5], [6], developed at the LIRKIS laboratory of the Technical University of Košice (TUKE). It offers a shared virtual environment (VE), where a patient, under a therapist's supervision, may undergo training sessions.

To test the suitability of L-NeRVEn for its potential users, extensive testing, focusing on the User Experience (UX), has been carried out with the system. Within the testing, a particular interest was in older adults, as they are more likely to need the services of the system in the patient's role. To obtain a group of engaged older adults, it was decided to perform a part of the testing within the University of the Third Age (U3A) framework at TUKE[1]. In contemporary higher education, U3A are important parts of lifelong education, focusing on older adults, primarily pensioners. According to [7], the first U3A was established in 1973 in France, and in Slovakia, such activities started after the revolution in 1989. Nowadays, U3A programs are provided by virtually all major Slovak universities.

The L-NeRVEn testing with older adults, which is the primary focus of this paper, involved nine second-year students of the "Informatics and Information Technologies" U3A program. The rest of the paper first provides a short overview of the L-NeRVEn system (Section II). Section III describes the testing procedure and participants and Section IV presents and discusses the results. In Section V, the paper concludes by stating the mutual benefits of the testing activity, a summary of interesting findings, and plans for L-NeRVEn future development, derived from them.

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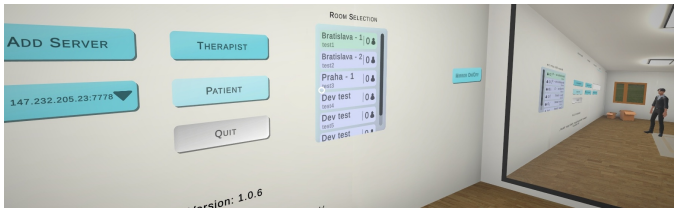
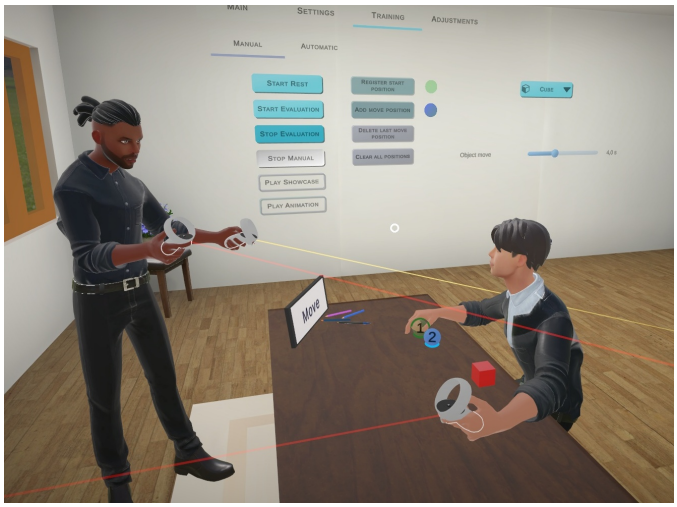
[1]https://tuke.sk/en/the-university-of-the-third-age

II. L-NeRVEn Neurorehabilitation System

L-NeRVEn is a prototype solution for post-stroke neurorehabilitation of patients who have lost control of their upper limb. It is a distributed software system, with a client-server architecture, developed using the Unity[2] game engine and the Mirror [8] networking library. L-NeRVEn supports multiple training sessions, each with one patient and one therapist. The essential part of the therapy sessions is a motor imagery (MI) task, where the patient is instructed to imagine a movement with the disabled arm. The success of the MI task is evaluated according to the patient's brain activity, measured using electroencephalography (EEG). The EEG signal processing and evaluation is performed by a separately developed component, called *P-EEG*, which utilizes the procedure described in [9], [10]. L-NeRVEn is primarily designed for the Meta Quest family of VR headsets, but can also be used on a personal computer running the Microsoft Windows operating system.



a)



b)

Fig. 1. L-NeRVEn virtual environment: lobby (a) and training room (b).

The VE of L-NeRVEn consists of two separate spaces. The first one is a lobby (Fig. 1 a), where the user occurs after starting the system. In the lobby, the user chooses a server, which will maintain the patient–therapist communication and connection to P-EEG, and a training room. Finally, he or she clicks on the "Therapist" or "Patient" button and enters the selected training room in the corresponding role. The training room is the second type of space and can be seen in Fig. 1 b).

[2]https://unity.com

The system offers different training rooms to support multiple simultaneous sessions; however, these rooms are identical in appearance and functionality.

Compared to other solutions, such as [11]–[14], the original features of L-NeRVEn are the collaborative nature of its VE, where both the therapist and the patient are present in the form of animated full-body avatars and its distributed architecture, allowing the users to join from different physical locations. In addition, the P-EEG component is loosely coupled with the rest of the system and can be replaced by another one, following the same communication protocol. An interested reader can find more information about L-NeRVEn in [5], [6].

A. Basic Training Procedure

A therapy session in L-NeRVEn consists of one or more repetitions of a basic training procedure, each with one MI task. These procedures can be managed "manually" by the therapist or automated with preset durations of individual periods. In what follows, the manual version of the procedure is described as this is the one used in the testing.

Before the procedure, the patient should already wear an EEG cap and experience the VE via a VR headset. In addition, he or she should be seated at a table with the disabled arm resting on the table.

The procedure starts with the *pause* period, where the therapist adjusts the position of the patient's avatar and the virtual table to match the positions of the real ones. The therapist also selects an object and its movement to be imagined by the patient.

By pressing the corresponding button in the wall menu that can be seen in the background of Fig. 1 b), the therapist switches to the *resting* period, where the patient is instructed not to think about anything particular, especially not about the movement of the arm. The EEG signal from this period is used by P-EEG to determine a baseline, crucial for the MI recognition.

After a while, the therapist changes the period to *MI*, again by pressing the corresponding button. Fig. 1 b) captures the VE during this period, with the therapist's avatar on the left and the patient's avatar on the right. The text "Move", displayed on a tablet placed at the virtual table, indicates to the patient that he or she should imagine the arm movement. If the P-EGG component evaluates the MI task as successful, an animation of the movement with the virtual representation of the arm is performed as a reward for the patient. After the animation, the procedure ends. If the patient is not able to imagine the movement successfully within a reasonable time, the therapist ends the procedure manually. In both cases, the end of the procedure means entering the *pause* period, where a subsequent procedure can start.

III. Materials and Methods

The UX testing of the L-NeRVEn system with older adults focused solely on the patient role. The participants experienced the training procedure through the Meta Quest 3S VR headset in a seated position. The Quest 3S VR headset was chosen

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due to its favorable price–performance ratio and the seated position because of the fact that many older users in need of such therapy will have limited mobility. An assistant, who managed the testing, took the role of the therapist.

Before the testing, each participant was informed about the purpose of the system and the testing, the testing procedure, the basic operation of the VR headset, and the amount of data collected. After that, he or she signed an informed consent form. Subsequently, the participant was seated at a table and the VR headset was placed on their head. The assistant communicated with the participant and adjusted the headset to ensure that they experienced the VE comfortably and appropriately. The participants started their VE experience already in the training room.

The testing began with the assistant entering the same training room as the participant. First, the assistant asked the participant to look around the training room, using head movements, and also to move, using controller joysticks or teleportation. This was necessary for the participant to get familiar with the VE. Subsequently, the assistant performed four repetitions of the basic training procedure with the participant. The repetitions differed in the object and movements to be imagined. The procedure was carried out as described in Section II-A with one exception: The participants did not wear an EEG cap. Instead of the P-EEG component recognizing the success of the MI task, the assistant sent a corresponding message to L-NeRVEn manually. In this way, an illusion of the movement imagination recognition and corresponding reward (the arm animation) has been delivered to the participants. For further analysis, the participant's performance has been recorded in the form of the VR headset's audiovisual output.

After completing all the basic procedure repetitions, the assistant asked the participant to remove the helmet and share their impressions and thoughts on the experience. The participant also filled out two questionnaires, focusing on specific aspects of the VR experience.

A. Questionnaires

The first questionnaire used was *IPQ* (Igroup Presence Questionnaire) [15]. It allows for assessing the subjective sense of presence in a VE, experienced via immersive VR. IPQ contains 14 items, focusing on the general feeling of presence in the VE (category G) and 3 dimensions: spatial presence (SP), involvement (INV), and experienced realism (REAL). The items are rated on a 7-point Likert scale (1 = Strongly Disagree, 7 = Strongly Agree). For each category, the score is calculated as the average of the ratings of its items. The final score is the average over all dimensions. Scores close to 1 mean a very low presence, scores around 4 a moderate presence, and scores close to 7 a high presence. According to recent analyses, [16], [17], IPQ can be considered as an effective and reliable tool.

The second one was *VRSQ* (Virtual Reality Sickness Questionnaire) [18], where the participants expressed their perception of nausea caused by the immersive VR experience. VRSQ is a modification of the Simulator Sickness Questionnaire (SSQ) [19], from which Kim et al. [18] excluded 5 items. The VRSQ is specifically designed for VR experienced through VR headsets. A 4-point Likert scale is used for responses, with the meaning "not at all" (0), "slightly" (1), "moderately" (2), and "very" (3). Using formulas defined in [18], the final score is computed from the answers as a percentage, where 0% means no sickness perceived and 100% means severe sickness. Although SSQ is still widely used for VR [20] and some shortcomings of VRSQ have been identified [21], VRSQ was chosen because of the lower number of questions (9 compared to 14 in the SSQ) and taking into account the results of the study [22], which shows that from a psychometric point of view, the VRSQ is better than the SSQ. This decision was also supported by the increasing number of VRSQ utilization cases in scientific studies, such as the evaluation of educational VE enabling embodiment in a tree [23] or the comparison of teaching using immersive VR and slides [24]. From the perspective of L-NeRVEn, its use in research [25], focused on the effects of motor-cognitive training in VR for seniors, is also relevant.

For both questionnaires, a Slovak translation introduced in [26] was used. Normally, the L-NeRVEn UX testing also includes the System Usability Scale (SUS) [27], [28] and NASA Task Load Index (NASA-TLX) [29] questionnaires. However, in this case, they were excluded as the patient's role, which the participants experienced, is relatively simple and passive. Therefore, it did not provide enough room to assess the overall functionality and usability of the system (SUS) and present a significant workload (NASA-TLX).

B. U3A Integration

A seamless integration of the testing into the "Informatics and Information Technologies" U3A program was possible thanks to the similar topic of the program and its informal nature, which, according to [30], is common in IT-oriented U3A courses. The program is realized in three–hour–long sessions every two weeks and the testing was incorporated into three subsequent sessions.

During the first session, the L-NeRVEn system was shortly introduced to the students and they were asked whether they would like to participate in the testing. As the response was very positive, it was decided to perform the testing during the second session.

For the testing, a classroom next to the one where the sessions are usually held was reserved. Two assistants were involved, one performing the testing scenario in the therapist role and one assisting in acquiring feedback, including the questionnaires. Thanks to this, it was possible to process two participants simultaneously. The participants were called one by one while the rest of the group had a usual session. This "usual" part of the session focused on reinforcing the already acquired knowledge and dealing with individual issues, so no participant missed anything new while performing the testing.

The third session was used to test those participants who were not present during the second one. In addition, some participants desired to try the role of the therapist.

C. Participants

In total, there were 12 older adults involved in the testing, eight females and four males, aged 60 to 86.

TABLE I
TESTING PARTICIPANTS. THE COLUMN "E.VR" PRESENTS EXPERIENCE WITH VR, AND "HEALTH" LISTS HEALTH ISSUES.

ID	*Age*	*Gender*	*E.VR*	*Health*	*Education*	*Height*
P01	63	F	1	My	HS, Med	163
P02	86	F	1		HS, Serv	160
P03	60	M	1		HS, Serv	178
P04	69	F	2		Uni, Med	168
P05	73	F	1		Uni, Med	169
P06	69	M	3		HS, ME	186
P07	74	F	1		Uni, Ecn	165
P08	73	F	1	Eye s., My	HS, CE	170
P09	71	F	1	MS	HS, IT	170
P10	67	M	1	My	Uni, ME	167
P11	64	F	1		Uni, ME	160
P12	69	M	1		Uni, Edu	191

The list of the participants and corresponding details are provided in Table I. The participants' previous experience with VR (the "*E.VR*" column) is expressed on a 5-point scale, from no experience (1) to daily use (5). The abbreviations used in Table I are listed in Table II.

The first three participants (P01 to P03 in Table I) were outside of U3A and performed the testing a few weeks before the first session. This was done to evaluate the testing procedure before being executed with the U3A students. As the procedure remained the same in both cases, it was decided to include the results of these participants to the U3A ones.

TABLE II
LIST OF ABBREVIATIONS.

Abbreviation	*Meaning*
Eye s.	Eye surgery
MS	Motion Sickness
My	Myopia
HS	High School
Uni	University
CE	Civil engineering
Ecn	Economics
EDU	Education
IT	Information Technologies
ME	Mechanical Engineering
Med	Medicine
Serv	Services

IV. RESULTS AND DISCUSSION

As can be seen in Table I, all the participants, except for P04 and P06, reported no previous experience with VR. This lack of experience initially posed a significant obstacle during testing, as the controls felt unnatural. However, about 80% of the participants learned to interact with the system during testing, which resulted in a better UX, as respondents were not forced to focus on the controls too much. The controls proved to be the most difficult to handle for P02 and P03.

When interviewed, the participant P02 stated that she had absolutely no experience with this technology, the controls were unintuitive, the headset was uncomfortable, causing itching around her forehead and temples. In addition, P02 experienced very blurred vision and general disorientation. For P02, it was hard to use the controls even after being instructed several times, and her hand and finger movements were jerky and unnatural. "I don't understand which button does what" or "Why this particular button does what it does" were statements indicating that the button functionality was not intuitive for P02. It is important to note that P02 had no experience with controllers (a gamepad or joystick), keyboard, or mouse, and was by far the oldest member of the group. During the testing, P02 moved as little as possible, which caused complications in tasks where it was required to visually follow an object moving in front of them. Although these can be considered as signs of a potential hidden discomfort, P02 stated that she did not feel any discomfort, only a slight itching of the head. She also claimed that she does not mind being in virtual space and could endure it for longer periods of time. On the other hand, controlling the application was a major problem, which significantly limited her UX.

The participant P03 had no problem understanding controllers, as he has used to play console games. However, P03 has significantly limited movement in his upper front limb as a result of a serious injury. This complication significantly limited his experience, meaning that whenever he wanted to interact with objects or perform various application settings, his hand movement was limited, and he had to struggle considerably more than other participants. During the post–test interview, the participant stated that he did not feel any physical exertion. We assume that, as the respondent is accustomed to his condition, he is unable to judge the complexity of the movement and this complexity was more objectively assessed by the test assistant.

TABLE III
IPQ AND VRSQ QUESTIONNAIRE RESULTS.

ID	*IPQ*					*VRSQ*
	GP	*SP*	*INV*	*REAL*	*Total*	
P01	4.00	7.00	3.00	4.00	4.5	14.17
P02	4.00	4.67	4.00	4.33	4.3	3.33
P03	3.25	4.67	4.00	4.00	4.0	6.67
P04	4.00	7.00	1.50	6.00	4.6	0.00
P05	5.75	7.00	1.50	2.67	4.2	0.00
P06	5.75	6.67	5.00	6.33	5.9	10.83
P07	4.00	6.67	1.00	5.00	4.2	0.00
P08	5.00	5.67	3.00	5.67	4.8	10.83
P09	4.25	7.00	1.00	2.67	3.7	0.00
P10	5.25	5.67	4.00	6.00	5.2	0.00
P11	4.00	5.33	4.00	3.67	4.3	6.67
P12	5.50	7.00	7.00	5.33	6.2	15.83
Avg.	4.56	6.19	3.25	4.64	4.66	5.69

Regarding the questionnaires, Table III holds the results

for each participant, with the average values in the last row ("*Avg.*"). Considering the VRSQ results, they do not support our assumption that older people may experience stronger discomfort than younger ones because of age and lack of previous experience with VR technology. For example, from the rest of the testing, a sample of the same size (12) of participants under the age of 30 can be selected, where more than half felt mild nausea and could not imagine working in a VE for a long period of time. In addition, four of these younger participants were forced to remove the headset due to discomfort. In comparison, no respondent over 60 reported any serious feelings of discomfort. Comparing the VRSQ scores, the average in this group (over 60) is only 5.69 while in the rest of the testing (below 60) it was 23.16.

The IPQ results show that, on average, the participants P01–P12 considered the presence as moderate (around 4) in the general presence and the dimensions of realism and involvement. The spatial presence was considered high. In addition to the aforementioned specifics of the group, the moderate results can be attributed to a significant difficulty when reading the texts in the VE, especially the wall menu. This may have been caused by the age–related myopia and the fact that, due to its limited resolution, the graphical output of the headset did not provide a sufficiently sharp image.

As we mentioned earlier, one task of the test scenario was to move around the training room. Here, two ways of movement were presented to the participants to choose from: continuous movement using joysticks on the controllers and teleportation to the location pointed out by a raycaster, emitted from the left controller in the VE. While teleportation is, in general, preferred because it does not cause as much nausea as continuous movement, almost all participants preferred continuous movement to teleportation. The participant P10 explicitly stated that teleportation seems too unnatural and strange to him, as he suddenly finds himself in a different place. This causes brief disorientation, which leads to feelings of frustration. On the other hand, it can be assumed that the reason why older respondents do not feel uncomfortable when moving continuously may be that their senses are somehow "dulled" due to age, compared to young people. Therefore, older respondents had almost no problem interacting in the VE or moving around it.

V. Conclusion

The integration of the L-NeRVEn UX testing with the IT-oriented U3A classes turned out to be mutually beneficial. On one hand, it provided us with a relatively consistent sample of older adults who were engaged and enthusiastic about the topic of the testing. On the other hand, it added a special and highly attractive content, closely tied to research and development activities at the institution providing the U3A classes. Almost all participants were very pleased and honored by the opportunity to be a part of such research. For most of them, it was the first opportunity to try immersive VR and the information that such technologies are used in the neurorehabilitation was new to all of them.

The results provided some unexpected revelations. Namely, the moderate to high perception of immersion in the VE and the preference for continuous movement over teleportation. However, due to the relatively small size of the sample (n=12), it is not possible to draw general conclusions from the findings. The results revealed several possible improvements that should be implemented in the future versions of L-NeRVEn, namely, enhanced visibility of the VE parts crucial for the patient and a modified workflow where the patient starts their experience already in the seated position in the therapy room.

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References

[1] G. andMohamed Nasser, Z. M. Ahmed, A. S. El-Husseiny, A. R. Youssef, and A. Al-Kabbany, "Immersive virtual reality games in neuromotor rehabilitation with brain-computer interfaces: A scoping review," *medRxiv*, pp. 2024–01, 2024.

[2] F. Arcuri, C. Porcaro, I. Ciancarelli, P. Tonin, and A. Cerasa, "Electrophysiological correlates of virtual-reality applications in the rehabilitation setting: New perspectives for stroke patients," *Electronics*, vol. 10, no. 7, 2021.

[3] E. Yeo, B. Chau, B. Chi, D. E. Ruckle, and P. Ta, "Virtual reality neurorehabilitation for mobility in spinal cord injury: a structured review," *Innovations in clinical neuroscience*, vol. 16, no. 1-2, p. 13, 2019.

[4] Y. He, Y. Xu, M. Hai, Y. Feng, P. Liu, Z. Chen, and W. Duan, "Exoskeleton-assisted rehabilitation and neuroplasticity in spinal cord injury," *World Neurosurgery*, vol. 185, pp. 45–54, 2024.

[5] S. Korečko, P. Nehila, and B. Sobota, "Game engine based application for neurorehabilitation in collaborative virtual reality," in *International Conference on Emerging eLearning Technologies and Applications (ICETA)*, 2023, pp. 313–317.

[6] S. Korečko, B. Sobota, P. Nehila, and D. Chmura, "Architecture, enhancements and perspective of the l-nerven virtual environment for neurorehabilitation," in *IEEE International Scientific Conference on Informatics (Informatics)*, 2024, pp. 152–156.

[7] A. Nowicka and P. Kopinec, "Education of elderly people on the example of students of the third age universities in poland and slovakia," *Rocznik Lubuski*, vol. 46, no. 1, pp. 121–134, 2020.

[8] D. Engelbrecht, *Building Multiplayer Games in Unity: Using Mirror Networking*. Springer, 2021.

[9] R. Rosipal, S. Korečko, Z. Rošťakova, N. Porubcová, M. Vankó, and B. Sobota, "Towards an ecologically valid symbiosis of bci and head-mounted vr displays," in *IEEE International Scientific Conference on Informatics (Informatics)*, 2022, pp. 251–256.

[10] R. Rosipal, Z. Rošťakova, and L. J. Trejo, "Tensor decomposition of human narrowband oscillatory brain activity in frequency, space and time," *Biological Psychology*, vol. 169, p. 108287, 2022.

[11] T. Karácsony, J. P. Hansen, H. K. Iversen, and S. Puthusserypady, "Brain computer interface for neuro-rehabilitation with deep learning classification and virtual reality feedback," in *Augmented Human International Conference*. New York, USA: ACM, 2019.

[12] E. J. McDermott, J. Metsomaa, P. Belardinelli, M. Grosse-Wentrup, U. Ziemann, and C. Zrenner, "Predicting motor behavior: an efficient eeg signal processing pipeline to detect brain states with potential therapeutic relevance for vr-based neurorehabilitation," *Virtual Reality*, vol. 27, no. 1, pp. 347–369, 2023.

[13] C.-J. Lin and T.-Y. Sie, "Integration of virtual reality-enhanced motor imagery and brain-computer interface for a lower-limb rehabilitation exoskeleton robot," *Actuators*, vol. 13, no. 7, 2024.

[14] C. S. Choy, Q. Fang, K. Neville, B. Ding, A. Kumar, S. S. Mahmoud, X. Gu, J. Fu, and B. Jelfs, "Virtual reality and motor imagery for early post-stroke rehabilitation," *BioMedical Engineering OnLine*, vol. 22, no. 1, p. 66, 2023.

[15] T. Schubert, F. Friedmann, and H. Regenbrecht, "The experience of presence: Factor analytic insights," *Presence: Teleoperators and Virtual Environments*, vol. 10, no. 3, pp. 266–281, 06 2001. [Online]. Available: https://doi.org/10.1162/105474601300343603

[16] M. Melo, G. Gonçalves, j. Vasconcelos-Raposo, and M. Bessa, "How much presence is enough? qualitative scales for interpreting the igroup presence questionnaire score," *IEEE Access*, vol. 11, pp. 24 675–24 685, 2023.

[17] T. Q. Tran, T. Langlotz, J. Young, T. W. Schubert, and H. Regenbrecht, "Classifying presence scores: Insights and analysis from two decades of the igroup presence questionnaire (ipq)," *ACM Trans. Comput.-Hum. Interact.*, vol. 31, no. 5, Nov. 2024. [Online]. Available: https://doi.org/10.1145/3689046

[18] H. K. Kim, J. Park, Y. Choi, and M. Choe, "Virtual reality sickness questionnaire (vrsq): Motion sickness measurement index in a virtual reality environment," *Applied Ergonomics*, vol. 69, pp. 66–73, 2018. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S000368701730282X

[19] R. S. Kennedy, N. E. Lane, K. S. Berbaum, and M. G. L. and, "Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness," *The International Journal of Aviation Psychology*, vol. 3, no. 3, pp. 203–220, 1993. [Online]. Available: https://doi.org/10.1207/s15327108ijap0303_3

[20] N. Tian, P. Lopes, and R. Boulic, "A review of cybersickness in head-mounted displays: raising attention to individual susceptibility," *Virtual Reality*, vol. 26, no. 4, pp. 1409–1441, Dec 2022. [Online]. Available: https://doi.org/10.1007/s10055-022-00638-2

[21] J. Josupeit, "Cybersickness as the virtual reality sickness questionnaire (vrsq) measures it!? –an environment-specific revision of the vrsq," *Frontiers in Virtual Reality*, vol. 4, 2023. [Online]. Available: https://www.frontiersin.org/journals/virtual-reality/articles/10.3389/frvir.2023.1291078

[22] V. Sevinc and M. I. Berkman, "Psychometric evaluation of simulator sickness questionnaire and its variants as a measure of cybersickness in consumer virtual environments," *Applied Ergonomics*, vol. 82, p. 102958, 2020. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0003687019301759

[23] P. Spangenberger, S.-C. Freytag, and S. M. Geiger, "Embodying nature in immersive virtual reality: Are multisensory stimuli vital to affect nature connectedness and pro-environmental behaviour?" *Computers & Education*, vol. 212, p. 104964, 2024. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0360131523002415

[24] A. P. Lawson and R. E. Mayer, "Individual differences in executive function affect learning with immersive virtual reality," *Journal of Computer Assisted Learning*, vol. 40, no. 3, pp. 1068–1082, 2024. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1111/jcal.12925

[25] R. Y. C. Kwan, J. Liu, O. S. K. Sin, K. N. K. Fong, J. Qin, J. C. Y. Wong, and C. Lai, "Effects of virtual reality motor-cognitive training for older people with cognitive frailty: Multicentered randomized controlled trial," *J Med Internet Res*, vol. 26, p. e57809, Sep 2024. [Online]. Available: https://www.jmir.org/2024/1/e57809

[26] S. Korečko, J. Mathes, and B. Sobota, "On slovak translation of questionnaires for measuring user experience in virtual reality," in *Electrical Engineering and Informatics*, vol. 16, 2025, pp. 582–587, in Slovak. [Online]. Available: https://eei.fei.tuke.sk/wp-content/uploads/2025/07/EEI_16.pdf

[27] J. Brooke, "Sus: A "quick and dirty" usability scale," in *Usability Evaluation in Industry*, P. W. Jordan, B. Thomas, B. A. Weerdmeester, and I. L. McClelland, Eds. London: Taylor & Francis, 1996, pp. 189–194.

[28] J. R. Lewis, "The system usability scale: Past, present, and future," *International Journal of Human-Computer Interaction*, vol. 34, no. 7, pp. 577–590, 2018.

[29] "Nasa task load index," https://digital.ahrq.gov/health-it-tools-and-resources/evaluation-resources/workflow-assessment-health-it-toolkit/all-workflow-tools/nasa-task-load-index, accessed on: 25. February 2025.

[30] S. R. Sobral and M. Sobral, "Computer education and third age universities: A systematic review," *International Journal of Environmental Research and Public Health*, vol. 18, no. 14, 2021. [Online]. Available: https://www.mdpi.com/1660-4601/18/14/7390