Collaborative Virtual Reality BCI Post-Stroke Neurorehabilitation Using HMD

Roman Rosipal[1,2], Nina Evetović[1], Zuzana Rošťáková[1], Arina Polyanskaya[1], Martin Vankó[1], Štefan Korečko[3], Branislav Sobota[3], Natália Porubcová[1], Leonardo Jose Trejo[2]

(1) Institute of Measurement Science, Slovak Academy of Sciences, Slovakia
(2) Pacific Development and Technology, LLC, CA, USA
(3) Department of Computers and Informatics, Technical University of Košice, Slovakia

BCI 2025, JUNE 2-5, 2025, Banff, Canada

Main Objective

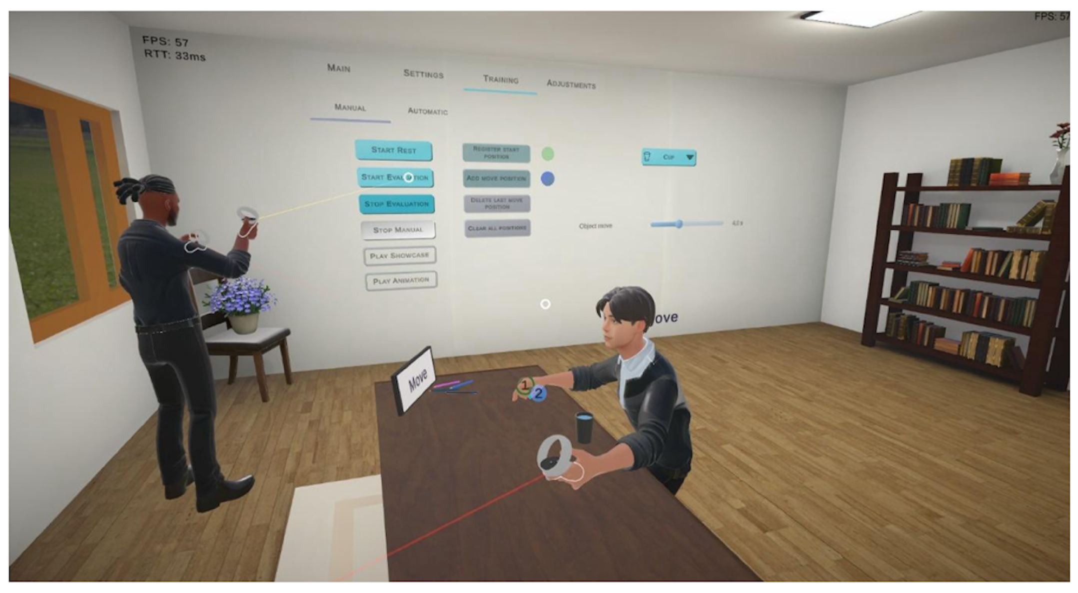
While virtual reality (VR) BCI systems offer promising avenues for post-stroke rehabilitation, most current solutions focus on single-user experiences. This limits opportunities for social interaction, which is a key factor in motivation, engagement, and recovery. Introducing collaborative BCI in shared VR environments can address this gap by enabling real-time interaction, cooperation, and competition with peers or therapists. Such socially enriched rehabilitation has the potential to enhance neural plasticity and improve functional outcomes.

A. Scientific and technological developments

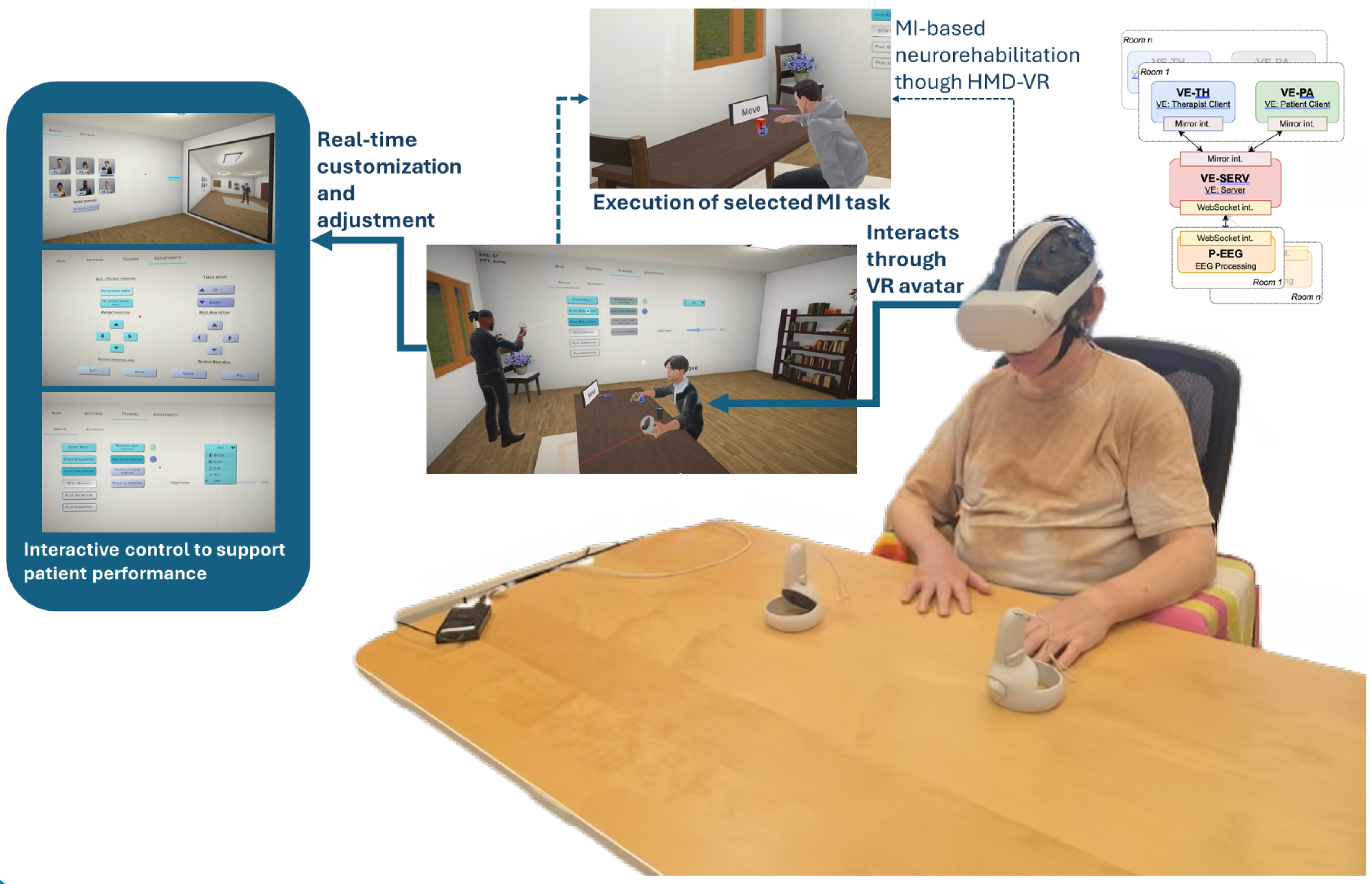
- We designed and developed a series of HMD-based virtual reality occupational therapy protocols
- Advanced ML and AI tools combine active and passive BCI into a compact algorithmic procedure that enables seamless human-computer and human-to-human interaction
- We specifically focus on training neurophysiological rhythms that are closely associated with motor activation

B. Clinical targets

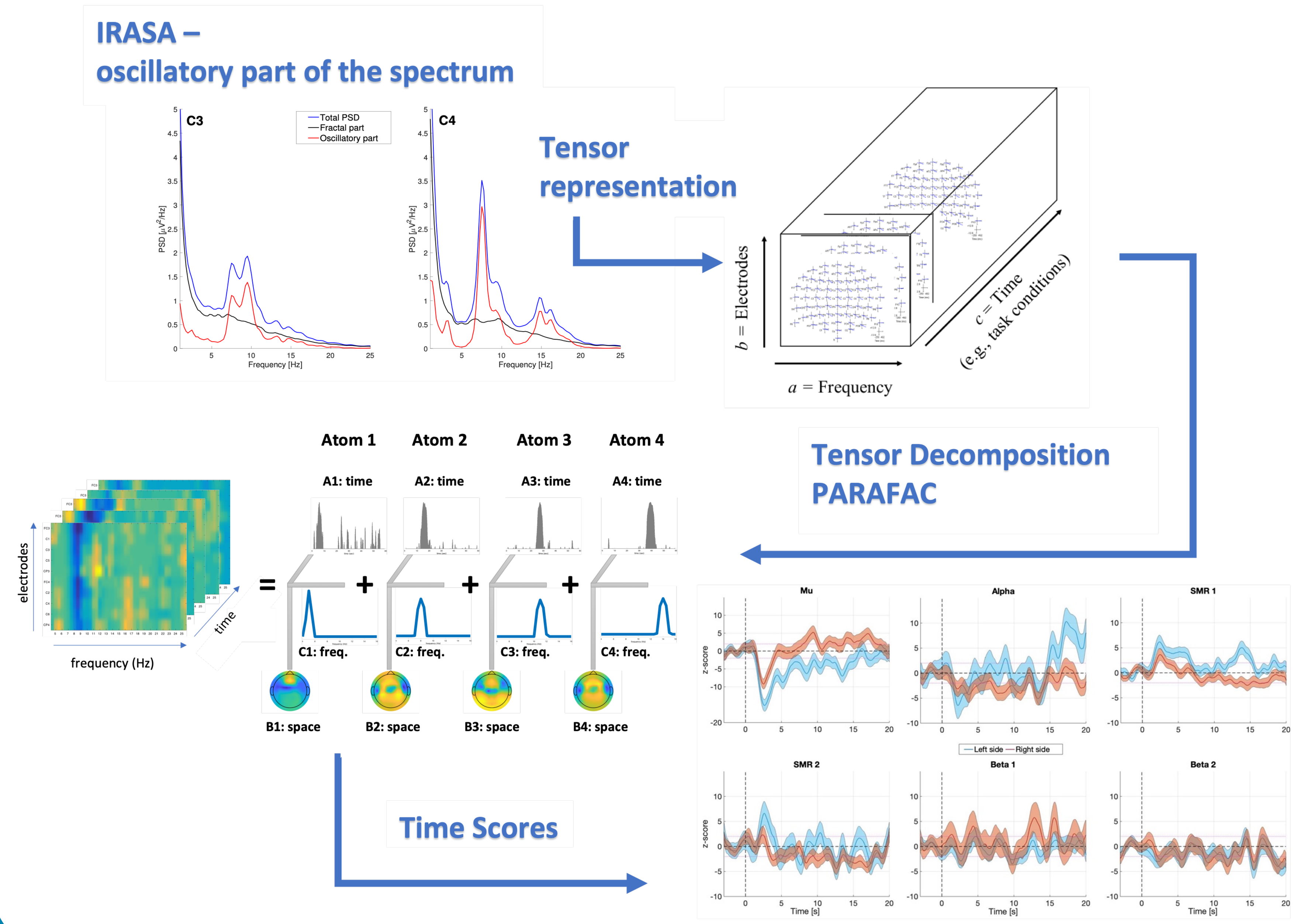
- We carried out a series of pilot, clinically well-controlled neurorehabilitation experiments. A larger clinical study starts in autumn 09/25.
- A supportive passive BCI system assists a therapist by monitoring the patient's mental state, performance, and engagement, guiding both decision-making and training strategies.
- We validate end-user acceptability and comfort of use of the tested system



Collaborative Virtual Reality Component



Brain-Computer Interface Component

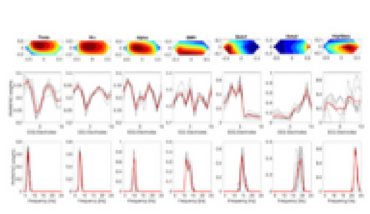


Experimental Setting and Results

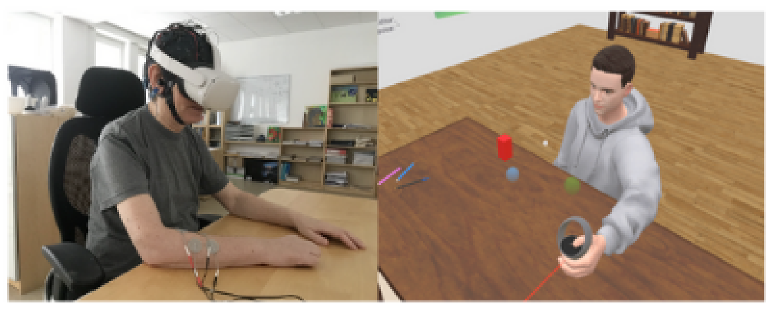
sub 207, 84 yrs. old male, left-hand hemiplegia

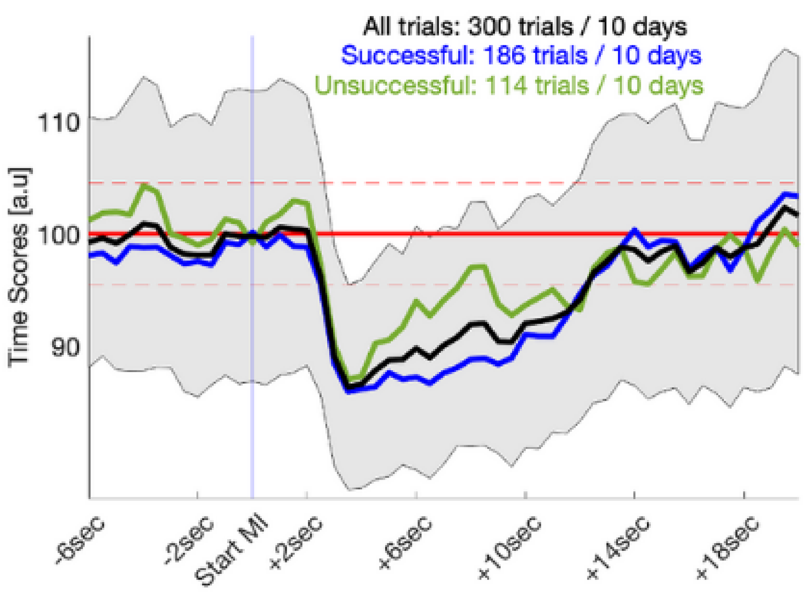
Step1: Train with Mirror-Box

Step 2: Extract PARAFAC Atoms



Step 3: Train in VR





The Nine-Hole Peg Test

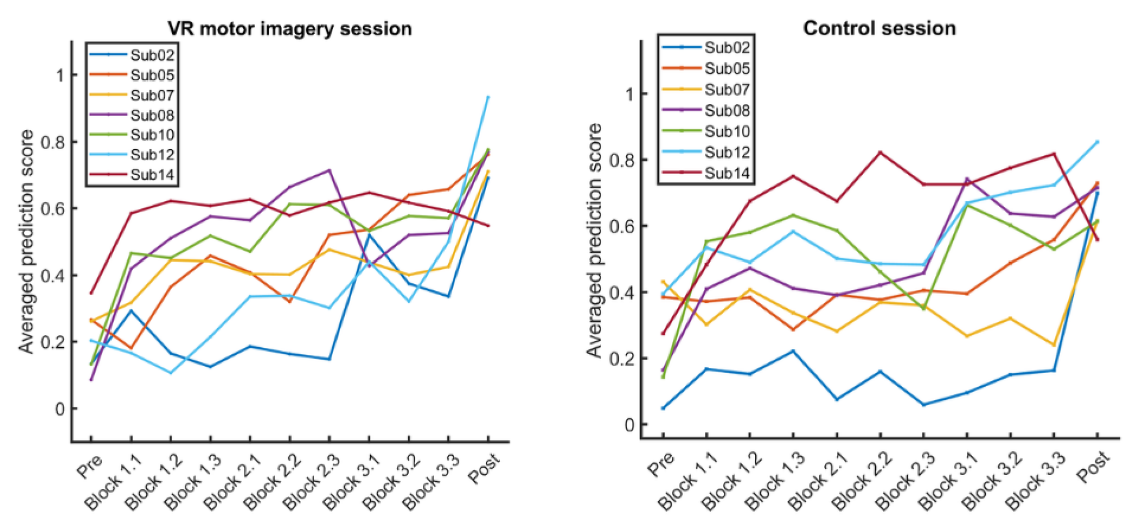
Date	Left	Right
Prior Mirror Box	78 sec	33 sec
Prior BCI-VR	66 sec	29 sec
After 11. sessions of BCI-VR	45 sec	30 sec

The Box and Block Test

	Left	Right
Prior Mirror Box	18 per min	32 per min
Prior BCI-VR	25 per min	37 per min
After 11. sessions of BCI-VR	26 per min	38 per min

Mental Fatigue - Passive BCI Component

- EEG and **N-way Partial Least Squares (N-PLS)** were used to classify fatigue states during extended BCI-HMD sessions.
- Achieved **82.4%** classification accuracy.
- Fatigue-related changes observed in alpha activity over occipital and sensorimotor areas.
- Temporal analysis revealed progressive fatigue accumulation.
- Supports real-time fatigue monitoring for adaptive neurorehabilitation.



Other Components Development and Work In Progress

- The study on the system's usability, acceptability, and user experience has started and is ongoing with a broader cohort of young and elderly participants.
- The collection of graphical scenarios is being expanded to enhance VR immersion and support social interactions, with an emphasis on two-person tasks.
- Exploration of latent space and explainable AI approaches is in progress to achieve stable representations of EEG motor activity-related components.
- The newly developed tensor-based artifact removal algorithm, SPECTER, has been validated and integrated into the processing pipeline.

References

[1] Cichocki et al. *Nonnegative Matrix and Tensor Factorizations*, John Wiley & Sons, 2009.
[2] Rosipal et al. *Biological Psychology*, 169:108287, 2022.
[3] Korecko et al. *Open Computer Science* , (under review).

Acknowledgement

The work was supported by the EU NextGenerationEU through the Recovery and Resilience Plan for Slovakia under project No. 09I03-03-V04-00443 (R.R.), the project No. 09I03-03-V04-00205 (Z.R.), the HORIZON-MSCA-2022-DN, 101118964-DONUT (N.E.), the Slovak Research and Development Agency project APVV-21-0105-TInVR, by the EU CHIST-ERA-20-BCI-004 project, and by Pacific Development and Technology, LLC.