Final Report

The Motor Learning and Neurorehabilitation (MLN) laboratory at the ARTORG Center for Biomedical Engineering, University of Bern, is an interdisciplinary group that gathers the knowledge and expertise of mechanical and biomedical engineers, computer scientists, neuroscientists, and psychologists. Our goal is to gain a better understanding of the underlying mechanisms associated with the acquisition of novel motor skills to develop innovative technology to improve the rehabilitation of neurological patients.

Our research focuses on human-machine interfaces and biological learning, and, specifically, on the use of robotic assistance to aid people in learning motor tasks and rehabilitate after neurologic injuries. Within our group, we develop innovative intelligent controllers that modulate movement errors based on patients’ special needs, age, and training task characteristics using a wide selection of robotic devices. We complement the research on robotics with the use of immersive virtual reality (VR) and augmented reality (AR) to enhance patients’ motivation and reduce their cognitive load during training. To get a better insight into brain-related intrinsic factors during therapy, electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) are used to identify neurocognitive markers underlying motor learning.

The aim of the B.Braun project titled: “Modulating sensorimotor errors to improve neurorehabilitation” was to study the use of novel immersive visualization technologies and immersive virtual reality (VR) games to improve stroke recovery during robotic therapy. In particular, we aimed to investigate the use of head-mounted Virtual Reality (VR) and Augmented Reality (AR) displays to enhance motor learning and neurorehabilitation. To that extent, we requested budget to purchase a computer screen, two VR goggles (HTC Vive; HTC, Taiwan & Valve, USA), a pair of AR goggles (Meta 2; Meta View, USA), and a computer. We also budgeted the salary of a project assistant (at 20%) and a postdoc (10%) to support the development of the virtual rehabilitation games/environments to be used in the experiments with the different VR apparatus and run the experiments.

Shortly after receiving the equipment, we started working in the design and development of the VR/AR environments (Figure 1) to run the first study to evaluate the impact of more state-of-the-art virtual and augmented reality tools vs classic screens on movement quality, participants’ cognitive load, and other psychologic aspects (e.g., usability, embodiment, and motivation).

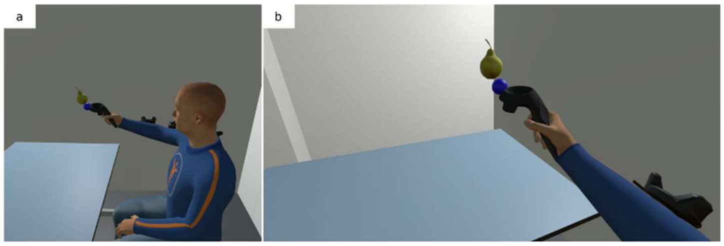

Figure 1: *Virtual environment (VE) that included the virtually reproduced table, walls, fruits, spheres, controller, and the avatar. A. Third-person perspective. B. First-person perspective (participants’ point of view).*

In January 2019, we received approval from the Ethics Committee of the Canton of Bern (KEK-Nr. 2018-01179) and Swissmedics (10000432) to perform experiments with human subjects using VR and our robotic devices. In collaboration with Prof. Dr. med. René Müri (head of the University Neurorehabilitation at the University Hospital in Bern, Switzerland), we performed a first experiment to compare the impact on movement quality and cognitive load of novel vs standard visualization technologies (Figure 2), namely i) Immersive VR head-mounted display (HMD), ii) Augmented reality HMD, and iii) Computer screen. Twenty healthy young participants performed a motor (i.e., reaching in 3D space) and cognitive tasks (i.e., counting task) simultaneously. We found that the movement quality improved when visualizing the movements in immersive VR compared to the computer screen, especially for movements in several vs single dimensions. A trend suggested better movement quality in augmented reality compared to the computer screen and worse than immersive VR. We did not find significant differences across visualization technologies for the cognitive task accuracy. These results were presented in the 16th IEEE/RAS-EMBS International Conference on Rehabilitation Robotics (ICORR 2019), Toronto, Canada [1].

Figure 2: Display modalities. Left: Immersive virtual reality (IVR). Middle: Augmented reality (AR). Right: 2D Screen. In all modalities, participants hold a controller and wear three trackers placed on the shoulder, the upper arm, and the lower arm. In AR, a fourth tracker was attached to the HMD.

The cognitive load, assessed by the accuracy in the counting task, did not show differences across modalities, probably because participants prioritized (good) performance in the counting task over the motor task. In contrast, subjective reports (i.e., through questionnaires) may better reflect the (experienced) cognitive load. Therefore, we performed a second analysis based on questionnaire data to evaluate whether visualization technology impacted cognitive load (using the NASA Task Load Index) and other aspects relevant to therapy, namely motivation, usability, and embodiment. In line with our previous findings, subjective reports on cognitive load did not significantly differ across visualization technologies. However, immersive VR was reported as more motivating and usable than AR and computer screen, and both, immersive VR and AR reached higher embodiment values than the screen (Figure 3). Although no significant differences in cognitive load were observed, results from the other questionnaires support our previous finding that immersive VR HMD seems to be the most suitable visualization technology to train motor tasks in VR. These results were submitted for presentation at the "International Conference on Disability, Virtual Reality & Associated Technologies (ICDVRAT 2020)" (postponed to 2021 due to the COVID-19 pandemic). A paper was submitted (upon invitation) to a special issue of the journal "Virtual Reality" by Springer entitled "Virtual Reality for Therapy, Psychological Interventions, and Physical and Cognitive Rehabilitation" [2].

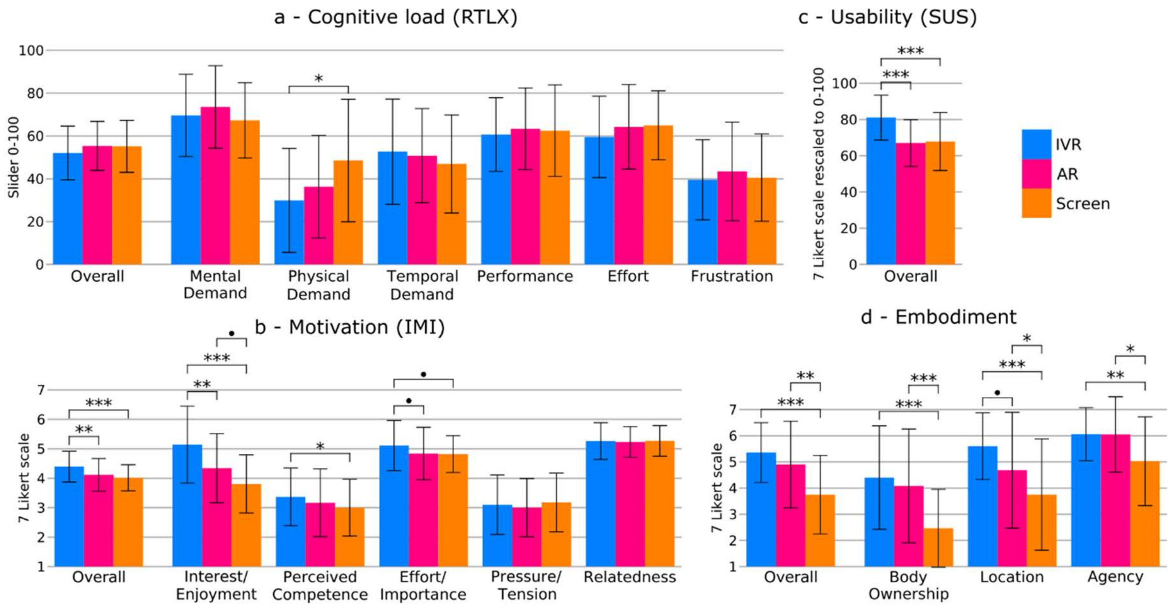

*Figure 3: Mean scores reported after the immersive virtual reality (IVR), augmented reality (AR), and screen modalities. a – Cognitive load (RTLX) and its subscales. b – Intrinsic motivation (IMI) and its subscales. c – Technology usability (SUS). d – Embodiment and its components. *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, · $p < 0.1$. Error bars: ±1 SD*

We conducted a follow-up experiment to study the effect of visualization technologies on cognitive load and motor performance in 20 healthy elderlyparticipants (> 59 y.o). We found that, in line with the results observed in the young group, the movement quality improved in immersive VR compared to the screen (Figure 4). We also found that the movement quality with AR was worse than immersive VR and better than the screen. We did not observe significant differences across visualization technologies in the cognitive task accuracy. Importantly, elderly participants did not report differences in usability between immersive VR and the screen. We are preparing a new publication with results from the elderly population.

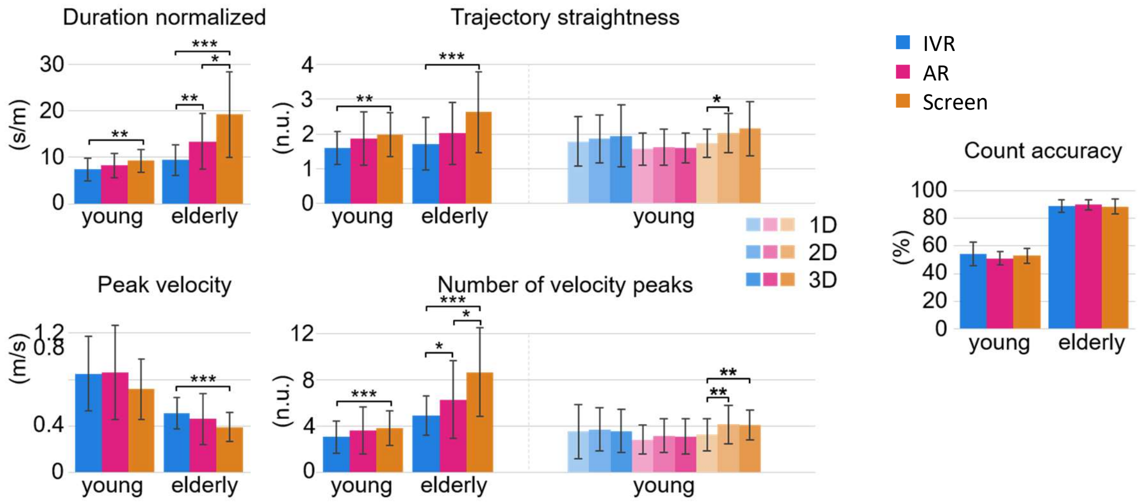

*Figure 4: Mean movement performance across modalities in young and elderly participants. Error bars: ±1 SD. ***p < 0:001, **p < 0:01, *p < 0:05, . p < 0:1*

We also incorporated our VR/AR setup in the clinic at the University Hospital in Bern to perform a feasibility study with stroke patients using the commercialized rehabilitation robot Armeo®Spring from our industrial partner Hocoma AG (Switzerland). However, patient recruitment was significantly delayed due to coronavirus-related interruptions and restrictions on patient recruitment. Results from the ongoing experiment with stroke patients and elderly participants will be published as a journal paper by fall 2021.

Figure 5: Experimental setup with Delta.3 robot (Force Dimension, Switzerland).

The B.Braun project aimed to explore the influence of the history of visual and proprioceptive errors on motor adaptation and neurorehabilitation. Within the above-summarized experiments, we first aimed to evaluate if the new visualization techniques are suitable for clinical use. In parallel, we also advanced in the design of novel robotic controllers that modulate the history of errors to enhance motor learning. We propose that Model Predictive Controllers (MPC) can promote movement variability with flexible movement trajectories. To investigate the effectiveness of our novel MPCs strategies on learning complex dynamic tasks, we recruited 40 healthy participants for a longitudinal between-subject study [3]. The task consisted of swinging a pendulum to hit incoming targets using the end-effector of the robot. The virtual environment was haptically rendered using an end-effector robotic device (Delta.3, Force Dimension, Switzerland). We found that MPC reduced the assisting forces compared with haptic guidance. Training with MPC increased the movement variability and did not hinder the pendulum swing variability during training, ultimately enhancing the learning of the task dynamics compared to other groups (control and haptic guidance).

Outcome

[1] N. Wenk et al., “Reaching in Several Realities: Motor and Cognitive Benefits of Different Visualization Technologies,” IEEE Int. Conf. Rehabil. Robot. Proc., vol. 2019, pp. 1037–1042, Jun. 2019, doi: 10.1109/ICORR.2019.8779366.

[2] N. Wenk, J. Penalver-Andres, K. A. Buetler, T. Nef, R. Muri, and L. Marchal-Crespo, “Effect of Immersive Visualization Technologies on Cognitive Load, Motivation, Usability, and Embodiment,” Virtual Real., vol. under review.

[3] Ö. Özen, K. A. Buetler, and L. Marchal-Crespo, “Promoting Motor Variability During Robotic Assistance Enhances Motor Learning of Dynamic Tasks,” Front. Neurosci., vol. 14, 2020, doi: 10.3389/fnins.2020.600059.