Impact of Virtual Limb Augmentation for Myoelectrically-Controlled Mirror Therapy

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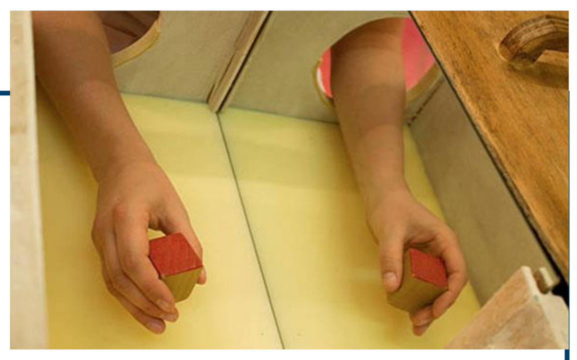
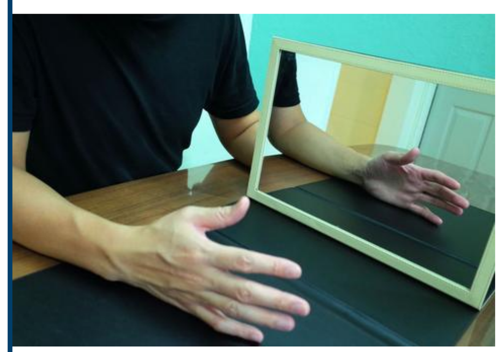
MIRROR THERAPY is a form of upper limb therapy, which consists on showing the mirrored symmetric movement of the unimparied side using a mirror placed in the medial sagittal plane. The illusion of movement corresponding to the impaired side facilitates neuroplasticity, and help patients to regain lost motor abilities. Recent studies have shown the potential and benefit of translating this effective therapy in immersive virtual reality environment, using a head mounted display and hand tracking systems.

This work investigates the feasibility of using a myoelectric control in an immersive virtual reality (VR) environment for the mirror therapy. Surface electromyography sensors were used to measure muscle activation and detect user intention to perform a grasping action in two visual feedback configurations: unimanual and bimanual. Even though in both conditions the virtual mirrored hand is controlled by healthy hand, the latter creates the illusion that two functional hands cooperate for grasping. A total of 18 healthy subjects participated in a preliminary evaluation of the environment, control method and a comparison between the two configurations.

1. MOTIVATION



Mirror Therapy induces neuroplasticity by **illusion:** impaired hand can be controlled by moving the **un**impaired hand.



Current limitations:

- Lack of attention
- Risk of distraction
- Lack of motivation
- Limited to simple hand and finger
- Distorted visual feedback

Strengths of VR:

- Augmented sensory feedback
- Improved adherance and motivation
- Adaptable complexity of tasks
- Potentially less distractive

→ VR MVF Therapy could be superior to conventional mirror therapy

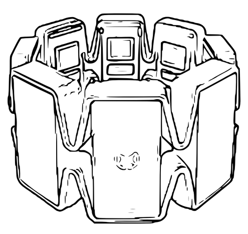
Clinical relevance— VR-based therapy and telerehabilitation can result in decreased treatment cost, increased access for patients, and increased quantifiable data for therapists. Moreover, patients may achieve better results in rehabilitation due to the increased feedback, controlled environment and specific features enabled by VR.

2. CONCEPT

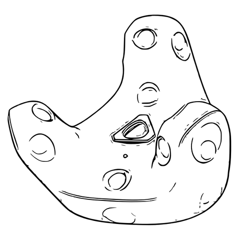
Immersive VR environment | Bimanual manipulation | Myoelectric control | Two visual feedback configurations

CONTROL MODALITY:

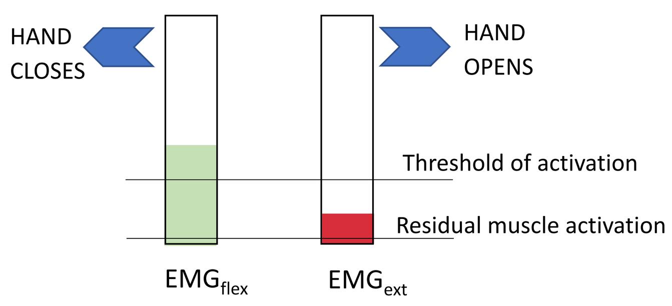
EMG data: Myo Armband
8 electrodes placed at the forearm



Kinematic data: HTC Vive Tracker
9 DoF IMU + optical sensors capture position and rotation



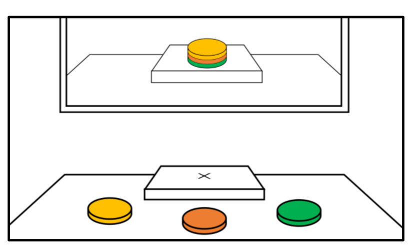
Myoelectric direct control: Two EMG sensors are selected to represent signals from the anterior (flexor) and posterior (extensor) compartment of the forearm. The movement of the virtual hand is controlled according to the following logic:



Note that once the system enters in one Virtual Hand grasping modality , the VH position is proportionally mapped to the corresponding EMG_i signal.

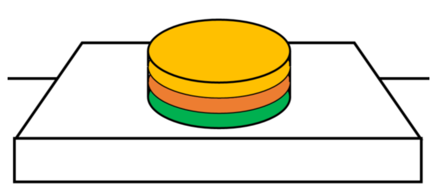
TOWER STACKING GAME

Factors of a task facilitating neuroplasticity: Complexity of exercise, repetition, variation, progression of task difficulty functional specificity, problem solving, motivation.

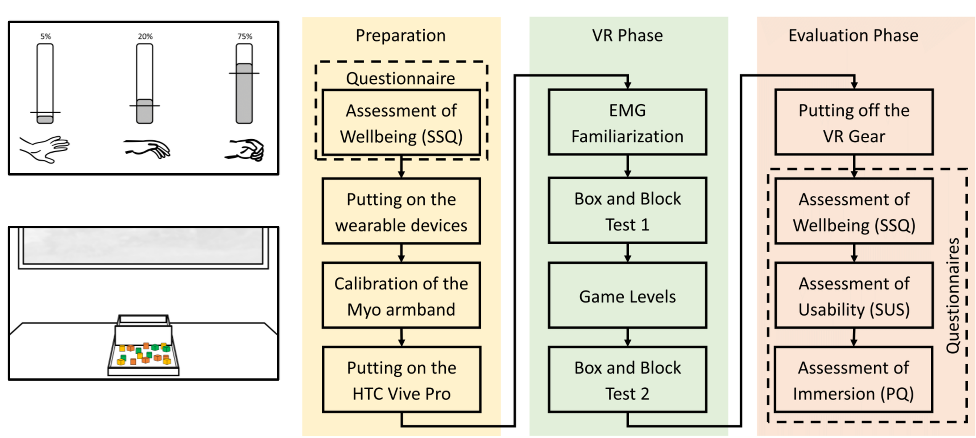


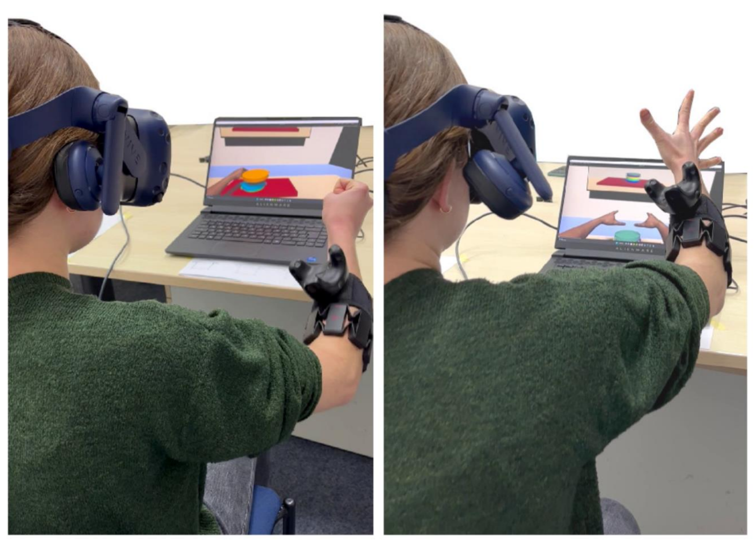
Pick and place objects

- 3 different levels of complexity
- Cognitive elements (game goal)
- Length can be set
- Performed in a seated posture
- Acustic cue for gamification



PROTOCOL and VISUAL FEEDBACK





Unimanual **Bimanual**

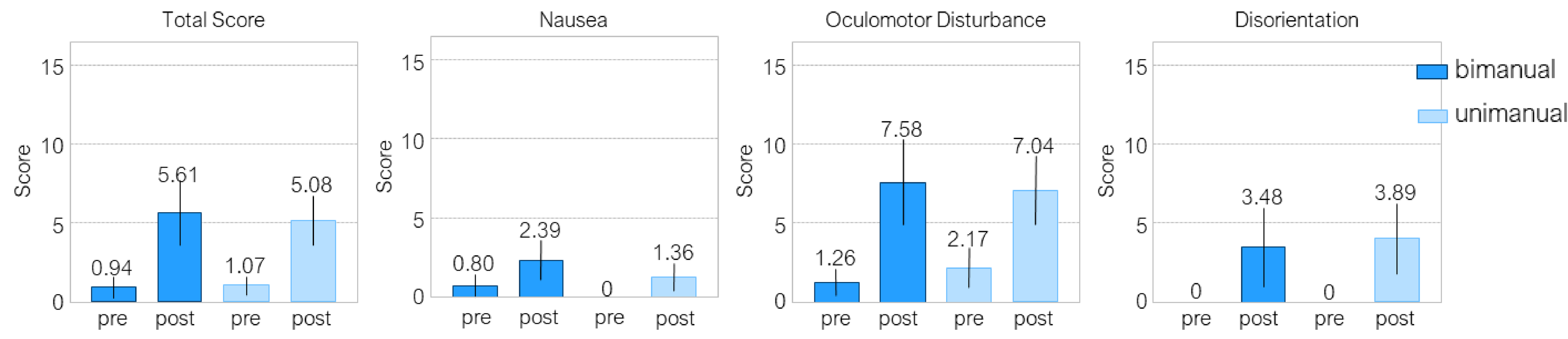
The unimanual condition permits the full focus in the mirrored hand by removing the healthy side from the scene. However, the bimanual condition includes the virtual image of the healthy side in the manipulation task. In both, only the unimpaired side is in control of the virtual movements.

3. RESULTS

Simulator Sickness Questionnaire

Total Score (**TS**), Nauesa (**N**), Oculomotor Disturbance (**O**), Disorientation (**D**)

- **SSQ1**: subjects reported **minimal** or better (SSQ < 10) symptoms **before** the intervention (n = 26 reports)

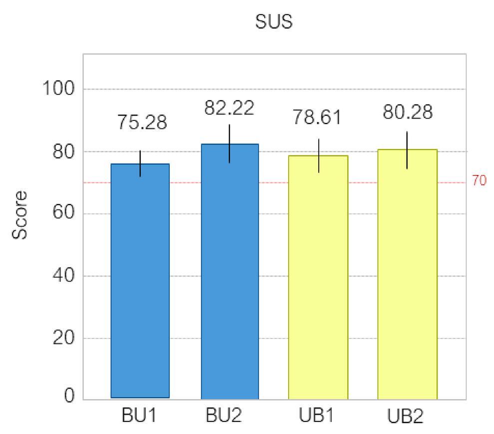


Total Score: both visual feedbacks are similar, only minimal possible negative effect to user's wellbeing.
N, O, D: Only O crosses the threshold due to visual input.

Control type	Session 1	Session 2
bimanual	BU1	UB2
unimanual	UB1	BU2

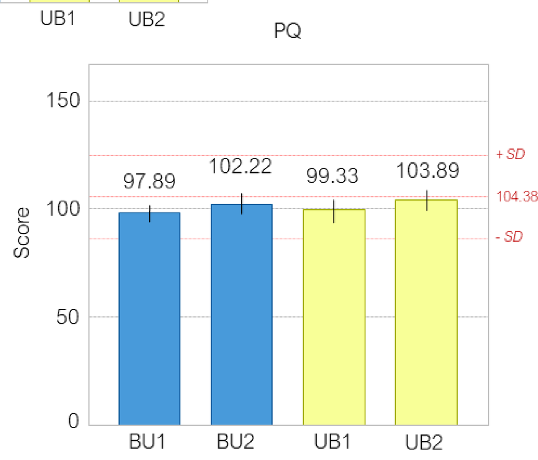
System Usability Scale

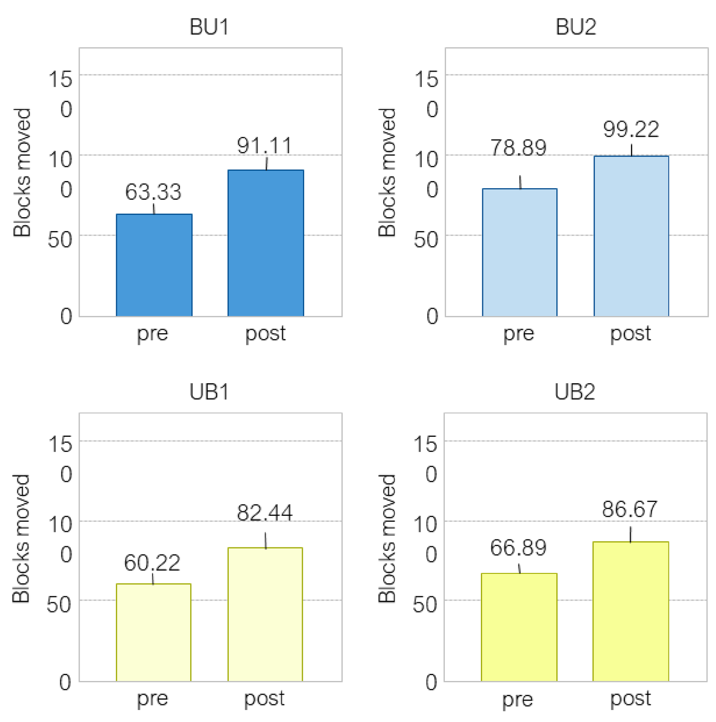
- All datasets indicate good usability (M = 79.1)
- Second session > first session (M = 81.3 vs. 77.0)
- Unimanual > bimanual control (M = 80.4 vs. 77.8)
- Differences between datases are not significant (Kruskal-Wallis): **H(3) = 1.632, p = .65**



Presence Questionnaire

- Average sense of presence is created
- Higher scores with experience





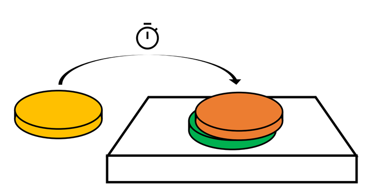
Box and Block Test

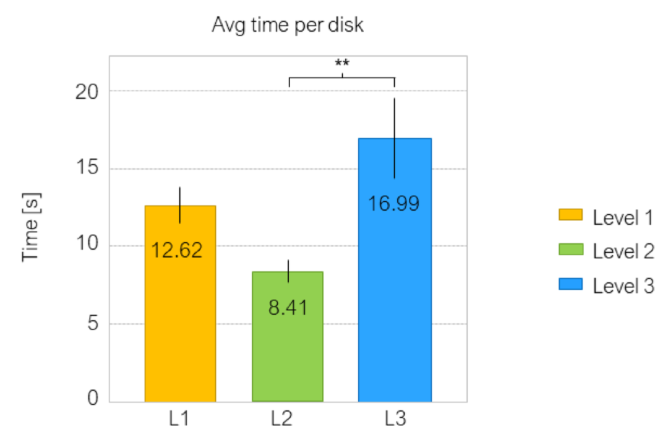
Beginning of session vs. end of session (pre vs. post)

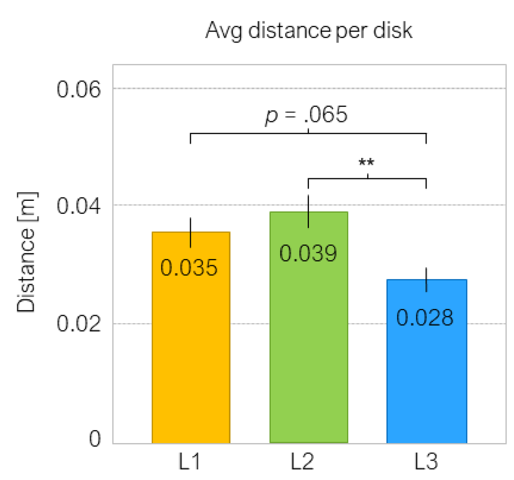
Subjects improved their ability to use the system significantly **F(1,3) = 51.689, p < .001** in a timeframe of ~10 minutes or less
No significance for control type or session

Time per disk – Level average

Improvement by experience, especially in harder levels
Level 3 is significantly higher than Level 2, therefore, reducing the disk size is not as critical as increasing the disk number

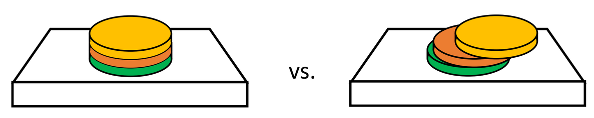






Accuracy – Level average

- No significant difference between level 1 and level 2
- Level 3 is the slowest and the most accurate
- Larger sample size could reveal significant effect between L1 and L3



CONCLUSIONS

- SSQ results indicate safety and absence of adverse events
- SUS results indicate good usability
- PQ results indicate adequate presence/immersion for a good illusion
- BBT results indicate fast learning effect
- Performance measures indicate no difference between unimanual or bimanual visual feedback

High repetition of task-oriented exercises is critical for motor recovery. VR-based physical rehabilitation can induce adherence to therapy protocol. Capabilities of augmented multi-sensory real-time feedback facilitates neuroplasticity and can persuade users to exercise harder through increased stimuli (greater motivation and immersion). Results highlight the potential of the developed system, indicating its suitability for a future experimental validation with stroke patients.