ABSTRACT BOOK

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WCISVR 2023 Abstract Book

Oral Session 1 – 16:00 to 17:30, July 23rd, 2023

Poster Session 1 – 10:15 to 11:15, July 24th, 2023

Oral Session 2 – 11:15 to 12:45, July 24th, 2023

ICDVRAT Oral Session – 15:15 to 16:00, July 24th, 2023

Oral Session 3 – 16:30 to 17:45, July 24th, 2023

Poster Session 2 – 09:45 to 10:45, July 25th, 2023

Oral Session 4 – 10:45 to 12:15, July 25th, 2023

Oral Session 5 – 13:45 to 15:15, July 25th, 2023

Oral Session 6 – 16:15 to 17:45, July 25th, 2023

ISVR
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Oral Session 1

Upper limb virtual rehabilitation

16:00 to 17:30

July 23rd, 2023

EEG Based Resting State Connectivity Changes Asssociated with Upper Limb Recovery after Home Therapy in the Chronic Phase Post-Stroke.

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***Abstract*— This preliminary investigation evaluates resting state connectivity measured via electroencephalography (EEG) as a neural biomarker of recovery post-stroke. Seven individuals with chronic stroke were included in the study. We show an association between changes in EEG based resting state directional connectivity between ipsilesional parietal and ipsilesional premotor areas and impairment based upper limb recovery subsequent to 12 weeks of home-based virtual reality training.**

Keywords—EEG, resting state connectivity, home based therapy, virtual reality, stroke

I. Introduction

Stroke is a leading cause of long-term disability in adults [1]. It is a heterogenous condition, which makes it difficult to identify individuals who will benefit the most from a given therapeutic intervention. Identifying biomarkers that provide information about neural events underlying treatment related gains could improve individualization of rehabilitation therapy [2]. Stroke not only causes focal deficits but can impact neural interactions throughout the brain and periphery [3]. Evidence suggests that reduced connectivity between key nodes of the sensorimotor system could serve as a marker of reduced efficiency in processing sensorimotor signals in the stroke-injured brain [4, 5]. Biomarkers such as functional connectivity have an improved ability to represent this complex cortical processing compared to assessments of focal brain regions [6]. EEG measures of brain activity are safe, inexpensive, and provide a representation of network interactions post-stroke. EEG based resting state connectivity (RSC) can be used to quantify patterns of neural reorganization during recovery and in response to treatment. Despite the inherent value of RSC as a biomarker of recovery post-stroke, there are few published studies using this method. To our knowledge, only two interventional studies have used EEG-based RSC as an indicator of changes in neural substrate in an effort to track recovery in the chronic phase post-stroke. Both studies used coherence to measure the strength of the connectivity. One showed increased ipsilesional premotor (iPM) with ipsilesional primary motor (iM1) RSC was associated with greater Upper Extremity Fugl-Meyer Assessment scores after 28 days of intense, home-based upper extremity rehabilitation [6]. This study also showed that decreased ipsilesional parietal (iPAR) with iM1 RSC was associated with improved scores on the UEFMA. The second study demonstrated that decreases in interhemispheric primary sensory cortex (S1) was associated

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with improved scores on the UEFMA after a 12-week upper extremity robotic intervention [7]. Our study question is unique because it 1) investigates directional connectivity instead of coherence, and 2) evaluates the association between changes in directional RSC in the beta range (12 – 30 Hz) between key sensory and motor nodes and an impairment-based measure of upper limb recovery in a group of individuals with stroke receiving 12 weeks of home-based virtual reality (VR) training focused on the distal upper extremity. Specifically, we evaluated EEG based RSC between the ipsilesional superior parietal lobule (iSPL) and both ventral PM (iPMv) and dorsal PM (iPMd) areas as a biomarker of upper limb recovery. The sensory association cortex (SPL) integrates multiple sensory inputs and has modulatory effect on the PM cortex to produce visually directed movements. This interaction is important to evaluate because VR training inherently incorporates visuomotor tasks. This preliminary investigation aims to answer the targeted question of whether a greater increase in iSPL to iPMv and iSPL to iPMd directional RSC measured via EEG is associated with greater upper limb impairment-based recovery in persons with stroke receiving 12 weeks of VR training.

II. Methods

A. Participants

Subjects were recruited through stroke support group activities and two assistive technology fairs. They were part of a home-based study using the New Jersey Institute of Technology-Home based Virtual Rehabilitation System (HoVRS) to train movement of their shoulder, elbow, wrist, and fingers. HoVRS consists of four elements: (1) an affordable and commercially available infrared camera specifically designed to capture finger movements—which are not captured by game consoles like Kinect or Wii, (2) multiple engaging games designed to train the hand and arm using commercial gaming mechanics to optimize players' motivation to perform these activities for long periods of time, (3) monitoring and archiving software that allows clinicians to design custom rehabilitation interventions, track a patient's progress, and modify a patient's rehabilitation program, in-person or remotely, and (4) a secure wireless data connector to collect detailed information on patient movement in real time. The secure communication channel allows for remote monitoring by clinicians, remote technical support, and remote patient and clinician interaction face to face while the patient uses HoVRS [8] (see fig. 1 for set up). The study team set up the apparatus in their home at the initial visit and taught them to how use it. Thereafter, participants practiced in their homes independently with online or in-person support as needed. They were instructed to practice as much as possible, but at least 20 minutes, daily for 12 weeks. Inclusion criteria: 1) persons at least six months post-stroke, 2) persons between 20 and 90 years of age, 3) persons with pre-training UEFMA scores between 15 and 62 [9], 4) persons without hemi spatial neglect or proprioceptive loss, 5) persons without receptive aphasia, and 6) persons with a score of 22 or greater on the Montreal Cognitive Assessment [10]. Exclusion criteria: 1) persons with upper extremity orthopedic pathology and 2) persons with other central nervous system pathology.

Fig 1. HoVRS set up.

B. Data Collection Method

All data were collected at baseline after consenting to the research study (PRE) and again at immediately post training (POST).

Motor recovery. Motor recovery at the impairment level was measured by a blinded physical therapist using the UEFMA. Change in UEFMA score from PRE to POST was calculated as the percentage of the maximal possible change, (UEFMA POST-UEFMA PRE) / (66-UEFMA PRE).

EEG. Resting state EEG data were collected for 5 minutes while participants relaxed and focused their gaze on an object or cursor in the center of their visual field. EEG data were acquired with an actiCHamp-Plus amplifier and 64 channel water-based R-NET electrode cap (Brain Vision LLC, Morrisville, NC, USA). Electrodes were positioned according to the 10/20 international system, with the reference channel placed at Fz. EEG data were preprocessed using custom scripts written for the EEGLAB Matlab toolbox. Data was bandpass filtered (1-50Hz) using a 2nd order Butterworth filter. Artifact Subspace Reconstruction (ASR) was used for signal correction/noise removal with parameter K = 30 [11]. The EEGLAB plugin, cleanrawdata, was used to reject and interpolate any channels deemed too noisy. All channels were re-referenced to average. 60 Hz line-noise was removed using the Prep plugin for EEGLAB. The resting data were epoched (split into evenly spaced 4-second epochs). Epochs containing artifacts were removed through visual inspection. Independent Component Analysis (ICA) was performed on the data. Components representing artifacts (muscle activity, eye blinks, channel noise) were identified and removed manually with the help of the EEGLAB plugin ICLabel. Preprocessed, epoched EEG data were imported into the Fieldtrip toolbox for

EEGLAB. Standard 10-20 electrode locations used during collection were then projected onto the template head model included with Fieldtrip, which is based on the Colin27 MRI. A lead field source model was computed using this head model and electrode set at a resolution of 4 mm. Source data were calculated at each point of the lead Field (~30,000 points) on a per-trial basis. These points were averaged together within our regions of interest based on a parcellation created from the AAL (Automated Anatomical Labeling) atlas. A Multivariate Autoregressive Model (MVAR) was created using the trial-by-trial regions of interest (ROI) source Data (Window Length = 0.5 sec, Window Step Size = 0.03 sec). The optimal model order was estimated, and a model was created in the SIFT toolbox for EEG. Directed Transfer Function (DTF) connectivity was calculated based on this model using functions provided by SIFT toolbox. DTF is a measure of directed connectivity from one region of interest to another.

C. Statistical Analysis

Normality. Normality of EEG based RSC data and UEFMA scores at PRE and POST were confirmed using the Lillifors test.

Correlations. Spearman rank correlations were performed to evaluate the association between changes in directional connectivity between iSPL to iPMv and iSPL to iPMd from PRE to POST and changes in UEFMA scores from PRE to POST.

All statistics were performed using MATLAB.

III. Results

A. Participants

Seven individuals with a mean age of 62.86 (13.81) and ranging from 6 to 264 months post-stroke were included in this preliminary study (part of the larger HoVRS study). All seven completed PRE and POST EEG and UEFMA testing.

B. Impairment based upper limb recovery.

The mean change in UEFMA score from PRE to POST was 5.57 (2.3) which is greater than the Minimally Clinically Important Difference of 4.25 in a similar population in the chronic phase post-stroke [12]. The percent of maximal change possible ranged from 16.7% to 47.1%.

C. Association between directional RSC and UEFMA.

Figures 2 and 3 show the association between change in DTF resting connectivity (beta band) in iSPL to iPMv and change in UEFMA scores from PRE to POST, and the association between change in DTF resting state connectivity (beta band) in iSPL to iPMd and change in UEFMA during the same time frame. We show a significant correlation between iSPL to iPMv RSC and change in UEFMA – $p = 0.024$, $rho = 0.857$ (fig.2) and only an association between iSPL to iPMd RSC and UEFMA change – $p = 0.0964$, $rho = 0.036$ (fig. 3).

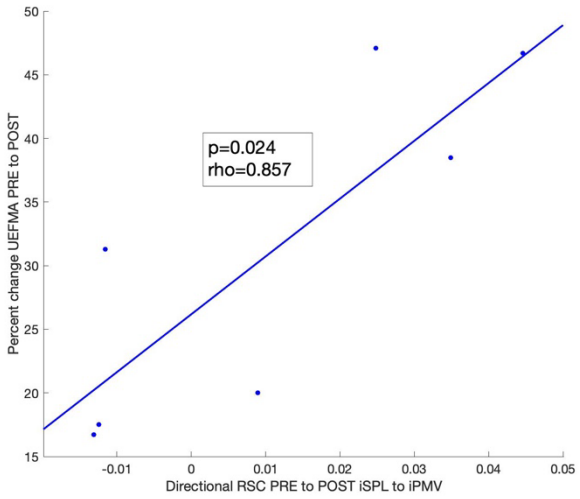

Fig. 2 Association between change in resting directional connectivity (DTF, beta band) in iSPL to iPMv and percent of maximal change in UEFMA scores from PRE to POST.

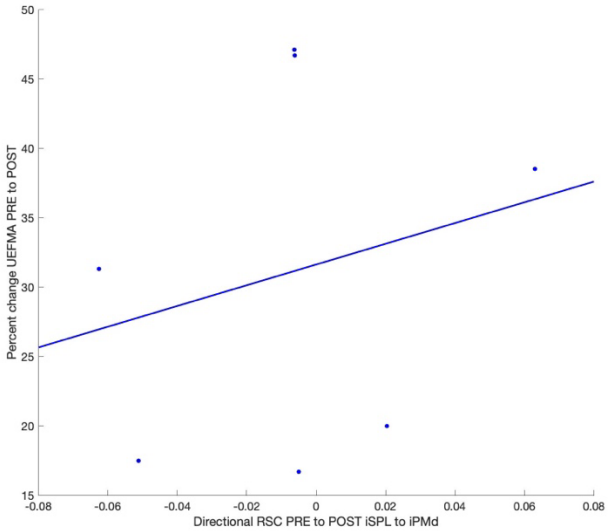

Fig. 3 Association between change in resting directional connectivity (DTF, beta band) in iSPL to iPMd and percent of maximal change in UEFMA scores from PRE to POST.

IV. Discussion

Few studies have utilized resting state EEG to evaluate functional plasticity underlying upper limb recovery post intervention and to examine possible effect of cortical activation or connectivity on response to therapy. This preliminary study evaluated the association between changes in EEG based RSC between key sensory-motor nodes and impairment based upper limb recovery in a group of individuals that were part of a larger home-based VR study (HoVRS study). Specifically, the connectivity between iSPL and iPMv and iSPL and iPMd were investigated as the HoVRS training involved visuomotor tasks of the upper limb (focused on the hand). These areas are key for producing such movements. We hypothesized that directional RSC in the beta band between the

iSPL and iPMv and iSPL and iPMd would increase parallel to increases in UEFMA scores in these individuals from PRE to POST training with the HoVRS. Preliminary data from seven individuals in general show an association between change in ipsilesional parietal – ipsilesional premotor connectivity and UEFMA change. This change in RSC between key sensorimotor areas may reflect a mechanism for recovery in our group. Looking at the data in greater detail, we show a stronger association between change in iSPL to iPMv and UEFMA change, than between iSPL and iPMd and UEFMA change. We propose that these differences may be due to the different roles played by PMv and PMd in humans. PMv is thought to be more involved in direct sensorimotor processing - PMv receives information on a motor target and sends outputs to achieve an action that directly matches the information [13]. In contrast, PMd is thought to have a more indirect role in sensorimotor processing – it is engaged in selection of movement responses based on previously learned arbitrary associations between cues and responses [14].

Although the study is preliminary, and the data are from a small sample, our overall results show sensorimotor plasticity underlying upper limb recovery. They also highlight the need for more research utilizing EEG based RSC as a neural substrate for recovery. Specifically of interest would be to compare changes in directional RSC between iSPL and iPMv and iSPL and iPMD in a group of individuals with chronic stroke who received the same dose of conventional training (non – visuomotor). As well, it would be important to reproduce our findings with a larger cohort.

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An Augmented Reality Hand Trainer for Neurological Rehabilitation

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***Abstract*— One of the major forms of disability from neurologic disorders is upper limb impairment. For stroke survivors, hand dysfunction results from hemiparesis, while for other neurological disorders such as Parkinson's disease (PD), hand dysfunction is associated with loss of finger dexterity due to rigidity, slowness, and involuntary movements. Hand therapy for either condition requires considerable feedback and guidance from a therapist or use of a robotic device, which are costly and of limited access to many older persons. We are developing an augmented reality (AR) hand trainer to facilitate finger and hand function by projecting virtual targets to the hand for goal-directed exercises, while tracking hand kinematics for feedback. The AR Hand Trainer was evaluated among control participants to establish tracking accuracy on par with a reference standard. Feasibility assessment among stroke survivors and individuals with PD demonstrated that this innovation is a feasible modality for hand rehabilitation based on usability and acceptance among stakeholders.**

Keywords—augmented reality, rehabilitation, stroke, Parkinson's disease, hand tracking, exercise, dexterity, paresis

I. Introduction

Every year, over 795,000 people in the United States, and 12.2 million people worldwide, suffer from a stroke [1, 2]. It is currently the third leading cause of death and disability, with the number of people experiencing a stroke expected to increase in the coming decades [2]. Of those that survive their stroke, many suffer both short-term and long-term impairments that directly impede upper-limb function [1]. Parkinson's disease is second only to stroke in prevalence of neurological conditions in the elderly leading to a loss of hand dexterity, function and ultimately independence, all cardinal signs of this progressive disease [3]. In both conditions, the resulting motor impairments restrict an individual's upper-limb function, hinder activities of daily living and impede independence and quality of life [4].

Traditional therapy methods to rehabilitate individuals with neurological hand dysfunction can demand long and frequent visits with a therapist, which can be inconvenient and costly for the patient [5]. While advances in robotic rehabilitation has automated some aspects of therapy and extended its reach to the home—using body-worn exoskeletons or robotic arms that guide individuals through exercise—the high cost and complexity of robotics equipment is a major drawback of present systems [5]. Adherence to home programs requiring frequent repetition of exercise is another challenge due to boredom, which can impede progress toward successful rehabilitation outcomes [6]. To overcome these challenges virtual reality (VR) and augmented reality (AR) are emerging as feasible therapeutic alternatives requiring less system set-up and one-on-one time with a clinician. In fact, the use of AR technology has already shown promising initial outcomes in restoration of function and ADL performance [7].

The goal of this project was to design and evaluate the feasibility of a therapeutic tool for hand rehabilitation using AR technology that can guide different evidence-based hand exercise modalities (modules) used in rehabilitation practice for patients with neurological disorders. For this proof-of-concept prototype, we programmed an AR headset to project holographic targets to the hand in three modalities: 1) repeated finger opposition with thumb; 2) repeated functional hand grasp; and 3) repeated synergy hand grasp patterns. Feasibility testing was carried out initially to test the accuracy of hand tracking in a control population, followed by usability testing in participants with hand impairment from a stroke or PD. Our findings validated hand tracking accuracy relative to standard motion capture, and demonstrated high levels of usability and acceptance, with minimal discomfort among patients. Clinician input was also favorable with suggestions for further development to improve therapeutic goals.

II. Methods

A. Design Architecture

Our system architecture includes algorithms for a real-time range of motion tracking of each finger, and a software package for a standalone Microsoft HoloLens 2 AR headset that augments the participant's field of view with holographic targets superimposed on their hand throughout 3 different hand exercise modalities. Real-time feedback indicating the relative position of finger targets, distance to target, task completion scores, and task completion time were also included in the software package to promote user engagement and feedback to the participant and clinician. The architecture was programmed in a modular design to support future patient-centric customization by a therapist, objective performance analytics, and compatibility with other mixed reality (MR) headsets offering a lower price point and future home exercise use.

The algorithm design of the AR Hand Trainer is based on the Mixed Reality Tool Kit (MRTK) [8] – an opensource library

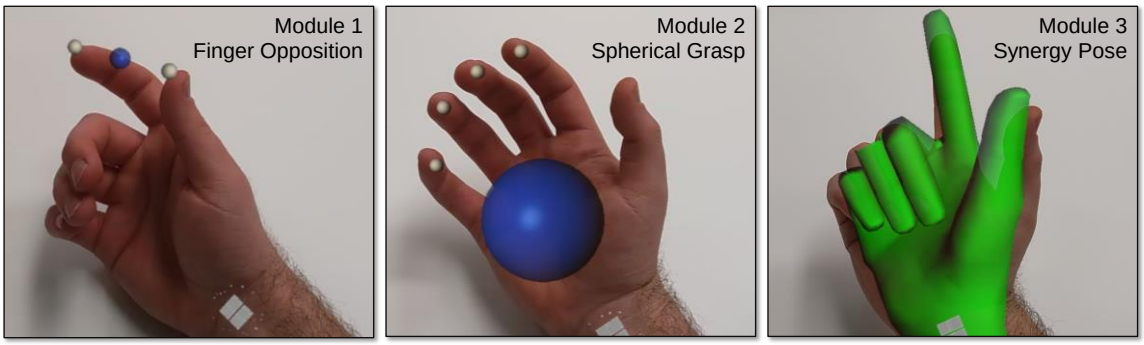

Fig. 1. AR holographic targets projected on the hand for 3 exercise modules – A) In the finger opposition module, the white spheres present the current position of the index finger and thumb, while the blue sphere indicates the target 3D location to pinch, B) In the functional grasp module, the smaller white spheres indicate the current location of each finger while the big blue sphere presents the holographic target to grasp, and C) In the fundamental synergy module, the smaller white spheres indicate the target fingers to move (hidden from current view) and the overlaid projection of the hand synergy pattern presents the targeted synergy.

provided by Microsoft that can track the 3D depth position of the hand and transmit these data to the HoloLens 2 AR headset through pre-established data communication channels [9]. Hand movement data recorded by the headset were processed through onboard hand tracking algorithms to identify 7 different landmarks on the hand: the wrist joint center, palm center, and all five fingertips.

The tracked 3D joint information was utilized by our custom-developed software package that projected virtual task-specific targets to guide the user through the exercises. We programmed 3 modules (Fig. 1) within the trainer that are categorized as neuro-facilitation, task-oriented, and functional synergy exercises, respectively as follows: 1) a Finger Opposition module, which projects a spherical target between the thumb and each subsequent finger to encourage the user to bring the two fingers together in an opposition gesture; 2) a Spherical Grasp module, which guides the user to curl their fingers around a virtual sphere projected to the center of their palm; and 3) a Synergy Pose module, which presents a virtual hand synergy end-pose superimposed on their real hand [10, 11]. Targets were programmed to change color when task is successfully completed. Additional software features such as real-time scores and a timer were included for motivation.

B. Experiment Design

Two sets of experiments were conducted to evaluate the system performance of the AR Hand Trainer. For the first set of experiments, we recruited n=10 healthy control participants [mean 27±4 y.o.; 5M, 5F] with normal hand function to validate the accuracy of hand range of motion tracking from our AR Hand Trainer system with respect to that of a gold-standard multi-camera motion capture system (MTX 160, Vicon Systems) using motion tracking markers that were instrumented on the participant's wrist, center of the palm, and the tips of each of the five finger. Each participant sequentially performed all 3 modules presented by the AR Hand Trainer, while seated with their hand resting on a table. We recorded the biomechanical data: range of motion of the fingertips, center of the palm and wrist center; as well as task performance data: the total number of targets reached, and task completion time.

A second set of experiments were conducted following the accuracy assessment to evaluate usability and acceptance of our AR Hand Trainer prototype among a population of clinical end-users. We recruited n=8 participants with impaired hand function [n=3 post-acute stroke survivors (mean 64±10 y.o.; 2M, 1F); n=5 individuals with mild to moderate PD (mean 61±7 y.o.; 4M, 1F)]. Our goal was to select individuals with sufficient motor recovery to at least partially flex/extend, oppose thumb to digits, or approximate the hand synergy pose volitionally (based on neurologist examination and Fugl-Meyer Scale [12]). Stroke participants with more than mild/moderate spasticity (Ashworth Scale>2 [13]) or PD participants with severe PD (Hoen & Yahr ≥4 [14]), or inability to follow verbal commands were excluded – Refer to Table 1.

Before the start of the experiment, participants were familiarized with the AR platform and the exercise activities by presenting a video of a pre-recorded exercise session followed by a free-practice session to try out the exercise modules using the AR headset. Two trials of each activity within a module were recorded for Modules 1-3 (with brief rest periods between trials) while capturing outcome measures including 3D fingertip locations, task completion, and time taken per exercise.

Quantitative user feedback was solicited through a questionnaire to assess perceived motion sickness immediately after using the AR technology. Based on the Simulator Sickness Questionnaire (SSQ) [15], the participant selected either 'None', 'Slight', 'Moderate', or 'Severe' to communicate how much the system currently affected them based on 7 items: *Dizziness, Nausea, Vision, Discomfort, Pain, and Fatigue.* Participants

TABLE I. PATIENT PARTICIPANT DEMOGRAPHICS

ID	Demographics						
	Dx	***Age***	***Sex***	***Duration***	***Fugl-Meyer***	***Hoen-Yahr***	***Ash worth***
1	Stroke	66	M	6 mo	5/0/4	NT	2
2	Stroke	51	F	8 mo	6/5/3	NT	1+
3	PD	58	M	4 y	14/9/3	2/5	NT
4	PD	72	F	6 y	13/10/3	2/5	NT
5	PD	54	M	4 y	13/10/3	2/5	NT
6	Stroke	77	M	2 y	12/8/3	NT	1
7	PD	69	M	4 y	14/9/3	2/5	NT
8	PD	54	M	4 y	12/9/2	2/5	NT

[a.] Parkinson's disease (PD) and Stroke survivor characteristics. Fugl-Meyer [Hand (16*)/Wrist (12*)/Coordination (4*) *Maximum

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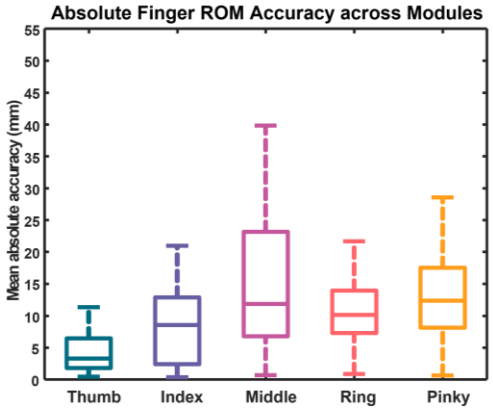

Fig. 2. Mean absolute finger ROM accuracy across all 3 exercise modules. Boxes represent range between the 25th and 75th quartiles and whiskers indictae range of between minimum and maxiumum data points.

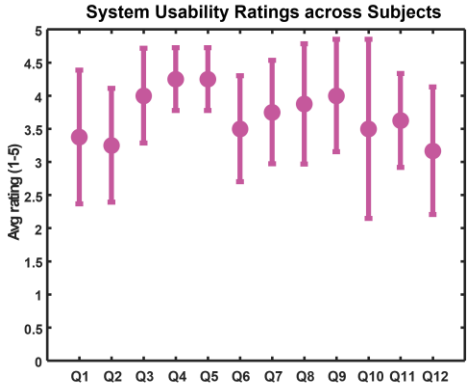

Fig. 3. System usability mean ratings with 95% confidence intervals across participants for hand trainer. Ratings are based on Likert scale (1 worst, 5 best).

then filled out a questionnaire on the system's usability by responding to statements with a Likert scale rating from 1 (worst) to 5 (best), with 3 being a neutral response. The statements were based on a modified version of the System Usability Scale (SUS) [16], to capture feedback specifically relevant to our system. Following the questionnaires, we conducted structured interviews with each participant for their subjective feedback on their engagement, likes and dislikes of the system, and its potential impact. Video recordings of the prototype in use were presented to a physical therapist and neurologist for recommendations for further development.

III. Results

A. *System Validation – Control Participants*

Testing of our system with control participants demonstrated the feasibility of achieving the accuracy and usability outcomes that meet our design goals. Compared to standard motion capture, the AR Hand Trainer achieved an 8.4 ± 6.1 mm mean absolute ROM error across all participants, digits, modules, and task repetitions (Fig. 2), well within the 12-20 mm average width of the human fingertip [17]. The system also achieved a 17.23 ± 1.57 millisecond delay between frame updates which is well within the perceptible delay by human users of AR/VR applications [18], with no significant difference across users, trials, and modules. Users did not observe any significant delay between their real hand movements and the targets' response.

The control participant's task completion statistics showcase the ease of use of the AR system. Their overall score, based on the percentage of targets successfully reached over the total targets presented, was 99.6 ± 0.72%. The participants succeeded in reaching each target in an average of 1.58 ± 0.74 seconds across all modules, exemplifying the ability of our system to communicate each exercise repetition to the user efficiently.

B. *Feasibility Amongst A Clinical Population*

We analyzed the results from the SSQ questionnaire, to assess perceived motion sickness and discomfort after using the AR technology amongst participant participants with impaired hand function. No participants reported experiencing any dizziness, nausea, or general discomfort after using the AR headset. Two participants perceived slightly blurred vision right after removing the headset, which went away within a few minutes. Only one participant (ID 1 – Table 1) found the tasks severely difficult and was slightly fatigued, and none reported pain in their hands after the exercises. The results are encouraging and indicate that the AR system was well received.

Our analysis of the modified SUS questionnaire responses showed encouraging results for the usability of the system based on Fig. 3, which summarizes the mean and 95% confidence intervals for each of the 12 questions. Participants rated positively overall the device's aid in completing the exercises (Q1), the rules being easy to follow (Q2), the clarity of the virtual images displayed (Q3), the exercises being fun (Q4), the usefulness of the targets for understanding exercise completion, (Q5), the usefulness of each module's target (Q6-Q8), the score being motivating (Q9), the exercises' engagement (Q10), the likelihood that the user would use the device at home (Q11), and the level of concentration required (Q12). The above-average mean responses displayed in Fig. 3 indicate that the Hand Trainer was well-received in its usability and potential value.

From our structured interview, we gathered key information about the participants' perceptions of the strengths and areas for improvement of our system and its future potential for at-home rehabilitation. Key themes that emerged from these interviews included impact, engagement, and usability of the AR hand trainer device as an alternative to perform the activities and practice hand movements. The clinical team also saw potential in this technology for at-home rehabilitation and gathering critical data for disease management and clinical trials or as a means of improving compliance with hand exercise therapy at home. Excerpts from the structured interviews with patients and clinicians are organized in Table II, with direct quotations in quotes and indirect summary statements in italics.

IV. Conclusion

The AR Hand Trainer demonstrated feasibility for rehabilitation of hand function among stroke survivors and individuals with PD. Although only 3 exercise modules were designed and evaluated, their selection was intended to represent the types of evidence-based hand exercise commonly used by physical and occupational therapy in practice for individuals with neurological disorders. Although the sample population of patients with neurological disorders was relatively small, they

TABLE II. STRUCTURED INTERVIEW FEEDBACK

	Patient Feedback	***Clinician Feedback***	***Recommendations***
Impact	- *Saw that the device could help people with rehabilitation.* - *Indicated that system could increase motivation for exercising.* - "If I could see to the end of the tunnel, I think the product has a lot of innate value"	- "Remarkable how the patients caught on very quickly with the technology they have never used before." - *Liked the variability of the 3 exercises and could add many more* - *Tolerated exercises and use of the headset*	Patient: *Include other everyday tasks, such as writing, typing, opening containers. Provide instructions on getting headset adjusted properly.* Clinician: "Add feedback that emphasizes grasp release". "Would be great to combine with reaching tasks." Add additional grasp patterns, and dynamic (moving) targets.
Engagement	- *Thought the exercises were easy and interactive* - "They were good exercises, and each one had its own value". - *Liked the simplicity of the Curl stage that used a virtual ball as a target*	- "This makes exercise fun and different for these patients." - *Must be careful to keep visual targeted tasks simple to avoid frustration* - *Liked the inclusion of scoring but would add more emphases on repetitions*	Patient: *Would be interested in making the exercises/stages more challenging. Would like to see it more game-like, such as adding audio.* Clinician: *Strengthen the scoring to emphasize more exercise repetitions. Include "prizes" for reaching goals*
Usability	- *Indicated that the virtual targets/trackers responded well to their movements* - "I think that the small spheres worked best"	- "The opposition targets were simple and clear but needed better targets for grasping sphere." *-Training could have better indicators of readiness, but overall tolerated very well*	Patient: *Clearer instruction for some tasks. Break up movement tasks into smaller parts. Clarity of targets shouldn't change with hand position.* Clinician: *Brighter colors for target that changes intensity as you get closer. Adjustable lighting.*

represented a relatively wide range of motor severity and yet still achieved relatively high scores of usability and acceptance when using the device. Taken together, the multiple therapeutic exercises, accurate range of motion measures, and usability among prospective clinical end-users (with minimal reports of discomfort), the system not only meets expectations for feasibility but provides a unique opportunity to deliver therapy to individuals with impaired hand function.

Future work will focus on a greater variety of exercise activities and modules, including bilateral activities and the ability to project virtual targets to real world objects for greater proprioceptive feedback and training for real-world hand capability. Additional development of a clinical interface or dashboard is needed to project the patient's AR view with superimposed clinical outcome metrics in real time, thereby allowing a therapist to monitor a patient's progress and tailor exercises based on the individual patient needs. Through these efforts we aim to equip rehabilitation practitioners with a technology that can be individually tailored to transfer functional gains beyond the clinic and into the home to empower survivors of neurological impairment to engage in activities of daily living and improve their quality of life.

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Activity intensity and electrodermal activity during virtual reality as compared to traditional intensive motor learning-based therapy for children with hemiplegia

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***Abstract*— Hand-Arm Bimanual Intensive Therapy Including Lower Extremities (HABIT-ILE) requires significant motor-engaged time of bilateral tasks. Virtual reality and active video games (VR/AVGs) may engage children in intensive practice to a greater extent than traditional activities. The purpose of this study was to compare objective indicators of activity intensity (moderate to vigorous physical activity; MVPA) and engagement/arousal (electrodermal activity; EDA) between VR/AVG and traditional gross motor activities. We hypothesized similar MVPA between VR/AVG and traditional activities, and higher EDA peaks/minute during VR/AVG activities. Six children aged 8-11 years wore an Actigraph GT9X accelerometer to measure MVPA and an Empatica E4 wristband to measure EDA during equivalent periods of VR/AVG and traditional gross motor activities on 2 non-consecutive days of a 10-day HABIT-ILE program. Across both sessions, children spent significantly more sedentary time in VR/AVG activities as compared to traditional activities. There was no difference in average MVPA or EDA peaks/minute between activities. Results suggest VR/AVG systems are applicable intensive interventions, but suggest caution with respect to how VR instructions, debugging, and system set-up time may limit activity intensity. Subsequent research with larger samples should correlate neurophysiological correlates of engagement and arousal with validated self-report measures of these constructs.**

Keywords—Virtual reality, active video games, activity intensity, electrodermal activity, pediatric rehabilitation, hemiplegia

I. Introduction

HABIT-ILE (*Hand and Bimanual Intensive Therapy Including Lower Extremities)* is an rehabilitation intervention for children with cerebral palsy (CP) that emphasizes evidence-based motor learning principles of abundant, variable, motivating and progressively challenging task practice [1]. Because of their motor learning affordances and their variable, engaging tasks and environments, virtual reality systems and active video games (VR/AVGs) may be relevant therapeutic interventions within HABIT-ILE and other intensive interventions [2], [3]. To support decisions about VR/AVG system integration in HABIT-ILE, evidence is required as to whether and how these technologies may facilitate children's participation in intensive intervention programs.

A potential rationale for VR/AVG use is that motivating virtual environments may increase children's engagement in challenging tasks, leading to more effortful activity or longer durations of practice. Studies quantifying the energy expenditure of children during VR/AVG game play report moderate intensity physiological responses and indicate the potential to for these technologies to increase general physical activity levels [4]–[6]. Indeed, a recent scoping review recommends the use of AVGs to improve the physical health of children with CP [7]. Triaxial accelerometers such as the Actigraph *GT9X* (Actigraph, LLC) can reliably quantify time spent in moderate to vigorous physical activity (MVPA) in pediatric populations [8]–[10].

While increased motivation and engagement during VR/AVG interaction is a frequent rationale for their use in rehabilitation [11], few studies have quantified these constructs [11]–[13]. Neurophysiological measures may provide objective proxies. For example, electrodermal activity (EDA) reflects the sympathetic response of the autonomic nervous system [14], [15]. EDA response has been linked with arousal (a dimension of affective response to stimuli) and engagement in gaming and immersive media contexts in children and adults [15]–[17]. The Empatica (E4) wristband measures EDA with acceptable accuracy and reliability [18], [19] and is feasible for use with pediatric populations [20], [21].

To the authors' knowledge, no study has compared objective or subjective measures of physical activity intensity or engagement between VR/AVG-based and traditional activities in HABIT-ILE or other an intensive intervention contexts. The objective of this study was to compare activity intensity (classified as sedentary, light, or moderate-vigorous MVPA) and EDA (peaks/minute) between equivalent durations of VR/AVG and traditional gross motor HABIT-ILE activities in children with hemiplegia at two non-consecutive timepoints over a 10-day intervention period. We hypothesized that MVPA would be similar between VR/AVG and traditional

activities, while EDA peaks/min would be higher during VR/AVG activities.

II. METHODS

A. Participant inclusion and exclusion criteria

Participants aged 7-12 years with a diagnosis of hemiplegia secondary to CP or neurotrauma were purposefully selected by supervising clinicians to participate in HABIT-ILE. Exclusion criteria were recent orthopedic interventions, seizure disorder, and uncorrected visual or auditory impairments.

B. Study procedures

A 10-day (65 hours) HABIT-ILE camp was offered at the Centre de Réadaptation Marie Enfant (CRME) in Montréal, QC [3]. Participants were paired in a 1:1 or 1:2 ratio with physiotherapy (PT) or occupational therapy (OT) students who were supervised by CRME clinicians. All interventions targeted individually chosen bimanual fine and/or gross motor skill goals and followed established HABIT-ILE principles. In addition to individualized gross motor activity goal directed practice (e.g., jumping rope, soccer kicking and passing, holding a tray while walking), gross motor skills were targeted through individual and group activities including volleyball, yoga, and obstacle courses.

Children received 40 minutes of individualized VR/AVG interventions per day (6.5 hours). VR/AVG interventions followed HABIT-ILE principles and were delivered by trained VR/AVG interventionists using custom (designed specifically for rehabilitation) and non-custom (created for the public) systems. Custom systems included Jintronix (www.jintronix.com), Astrosurfeur (using the MetaQuest head-mounted display), and BootleBlast (https://hollandbloorview.ca/research-education/bloorview-research-institute/research-centres-labs/pearl-lab-current-research/bootleblast-movement-tracking). Non-custom systems included Nintendo Switch RingFit and Kinect Xbox360 Adventures. VR/AVG interventions targeted functional gross motor goals through part-task practice focused on underlying subcomponents (e.g., jumping, stepping, balance, running in place) and included material adaptation as necessary (e.g., kicking a soccer ball during a virtual soccer game, or holding a tray with both hands while playing a game focused on balance and stepping abilities).

Two non-consecutive intervention days were chosen in a predetermined schedule. Sensors were worn for the duration of the intervention day, which included a short rest period for meditation at the beginning of the day, traditional gross motor and VR/AVG gross motor activities. A study coordinator assisted in donning and doffing the sensors; the Actigraph GT9X Link sensor was worn on the non-dominant hip and the E4 sensor on the non-dominant wrist. The E4 was removed during the day for short periods of water-related activities.

C. Measures

1. Activity intensity: The Actigraph GT9X Link sensor quantifies activity intensity as sedentary, light, moderate, vigorous, moderate-vigorous (MVPA) according to a proprietary algorithm (Actilife, Inc).
2. Electrodermal activity (EDA): The Empatica E4 sensor measures electrical conductance on the skin surface. We determined the number of peaks/min using an open-source toolkit (see *statistical analyses*).

D. Statistical analyses

Using daily intervention logs, the pre-planned HABIT-ILE camp schedule, and video recordings to confirm continuity of activity wear periods, we extracted segments from time-stamped sensor data for a 2-minute rest period (supine; meditation), 40 minutes of continuous gross motor activity participation (traditional activities) and 40 minutes of continuous VR/AVG participation for 2 different intervention days. Actigraph GT9X Link data for each wear session per child was processed with the proprietary software ActiLife and exported into Excel. EDA data was analyzed using pyEDA, an open-source python toolkit [22] to derive average peaks/minute during each period. Due to the small sample size, non-parametric Spearman correlations identified relationships between MVPA and EDA peaks/minute for each activity (rest, traditional, and VR/AVG). A two-way repeated measure analysis of variance (ANOVA) was used to account for potential interaction effects in our repeated measure design. Non-parametric Wilcoxon tests compared 1) within-child differences in EDA and in MVPA between traditional and VR/AVG activities and 2) within-child differences in each measure between sessions 1 and 2.

III. RESULTS

A. Participants

Six children aged 8-11 years (mean age 9.3 years, SD 1.4 years) with right-sided (n=2) or left-sided (n=4) hemiplegia resulting from CP (n=5) or neurotrauma (n=1) at Gross Motor Function Classification System (GMFCS) Level 1 (n=5) and GMFCS level II (n=1) participated in the study. Study procedures were approved by the Research Ethics Board of the CHU Sainte-Justine; children and parents provided informed assent/consent.

B. Activity intensity

Table 1 lists the percentage of time classified as sedentary or MPVA for each participant in each activity and session. **Figure 1** illustrates that on average, most of the time in each session and activity was classified as 'light' physical activity. A two-way repeated ANOVA revealed no significant interactions between session days and activity type (VR/AVG versus traditional gross motor activities). There were no significant differences between the 2 intervention days for either VR/AVG or traditional activities. Across both session days, children spent a higher percentage of sedentary time in VR/AVG as compared to traditional activities (VR/AVG=0.23, traditional=0.094; $p=0.038$, $Z=-2.073$). There were no significant differences in percentage of MVPA between VR/AVG and traditional activities.

Table 1

Session 1 Session 2	VR/AVG			Traditional activities		
Participant ID	**Sed**	**MVPA**	**Peaks/ min**	**Sed**	**MVPA**	**Peaks/ min**
CP01	0.36	0.06	19.18	0	0.46	29.55
	0	0.32	19.14	0.04	0.14	27.07
CP02	0.06	0.24	18	0.06	0.06	16.03
	0.08	0.21	19.13	0.03	0.18	22.11
CP03	0.38	0	12.57	0.05	0.05	19.03
	0.57	0	12.5	0.21	0.07	15.21
CP04	0.4	0.03	14.63	0.14	0.14	19.51
	0	0.48	21	0	0.24	17.9
CP05	0.05	0	14.44	0.14	0.06	14.56
	0.41	0	12.03	0.14	0	15.31
CP06	0.05	0.1	15.2	0.05	0.15	16.7
	0	0.45	17.39	0.26	0	13.57
Average Session 1	0.29 ±0.19	0.07 ±0.09	15.67 ±2.46	0.07 ±0.06	0.15 ±0.16	19.23 ±5.39
Average Session 2	0.18 ±0.25	0.24 ±0.21	16.87 ±3.74	0.11 ±0.11	0.11 ±0.1	18.53± 0.25
Total Average	0.23 ±0.22	0.16 ±0.18	16.27 ±3.08	0.09 ±0.08	0.13 ±0.13	18.88 ±5.03

Table 1: Percentage of time spent in each activity intensity (sedentary or MVPA) and average EDA peaks/min per participant per activity and session.

C. *Electrodermal activity (EDA)*

Table 1 illustrates the average EDA peaks/min per participant in both activities and sessions. Across all participants, the average EDA peaks/min at rest (the morning meditation) was 12.44 ± 0.94 (Session 1) and 11.25 ± 3.25 (Session 2). Across both sessions, there was a significant difference in the number of EDA peaks/min between rest and traditional activity ($p=0.002$, $Z=-3.059$) as well as between rest and VR/AVG activity ($p=0.005$, $Z=-2.824$). There were no significant differences in peaks/minute between the 2 intervention days for either VR/AVG or traditional activities. The two-way repeated ANOVA revealed no significant interactions between session day and activity type (VR/AVG vs traditional). No significant differences in EDA peaks/min were found between VR/AVG and traditional activity.

D. *Relationship between activity intensity and EDA*

Strong positive correlations were found between the average number of EDA peaks/min and the percentage of MVPA during traditional ($p=0.010$, $r=0.705$) and VR/AVG activities ($p=0.001$, $r=0.826$). Similarly, there were strong negative correlations between percentage of sedentary activity and the number of EDA peaks/min for traditional ($p=0.010$, $r=-0.751$) and VR/AVG activities ($p=0.005$, $r=-0.754$).

IV. DISCUSSION

Contrary to our hypothesis, both VR/AVG and traditional activities had a similar 'light' activity intensity classification, and participants were more sedentary in VR/AVG activities as compared to in traditional gross motor activities. Inherent to VR/AVG use with children is the time required to provide

Figure 1

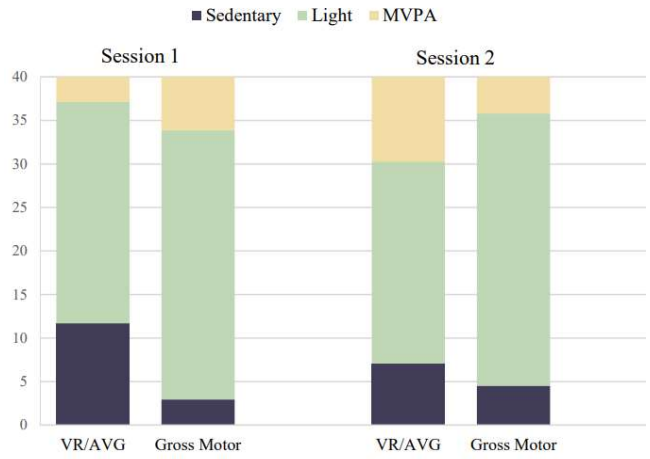

Figure 1: Average minutes spent at different activity intensities across 2 wear sessions for all participants.

instructions about VR/AVG game play, and the necessity for children to wait during VR/AVG set up and between-system transitions of differing lengths, including dealing with unplanned technology bugs. Subsequent work can use study results to emphasize engaging children in relevant movements outside of a VR/AVG context during these non-VR/AVG-engaged moments. Interestingly, in both types of activities, participants spent little time in MVPA and most of their time in 'light' intensity activity. This may be because of that fact that HABIT-ILE activities encouraged a high motor-engaged time, but this motor engagement was focused on repetitions of specific movement skills, such as kicking a ball or reaching for an object, which may have little impact on an accelerometer worn on the hip. While it was interesting to examine intensity from a physical exertion perspective across the two types of activities, the actual 'intensity' of intensive interventions such as HABIT-ILE is likely reflected in the frequency of task repetitions and the progression of task challenge as abilities improve, which are not measured by our study sensors.

We hypothesized that children would be more engaged in VR/AVG activities as compared to traditional activities, as evidenced by a difference in EDA peaks/minute; this hypothesis was not confirmed. While both activities were significantly different in term of EDA results from rest, there was no difference between the activity types. This may be because HABIT-ILE interventions were designed to be individually engaging and were offered in a fun camp context. As such, the potential 'active ingredient' of engagement was targeted in both types of activities. EDA may have reached a measurement ceiling in terms of ability to distinguish differences between different, equally fun and meaningful, activity types. EDA is a proxy neurophysiological measure for engagement; subsequent work can consider using more precise measures including electroencephalography or heart-rate variability, as well as include validated self-report measures of engagement or qualitative interviews to capture children's subjective responses and their perceived differences in engagement between different types of activities.

Several methodological limitations our restrict study interpretations, including our small sample size and the non-standardized timing of activities. HABIT-ILE interventions are personalized; children engaged in different VR/AVG and traditional activities at different times of the day. While student interventionists kept daily logs, the consistency and precision of activity content description varied among interventionists. Subsequent work with a larger sample size should include measurements over a greater number of intervention days as well as explore relationships between subjective engagement measures and neurophysiological engagement indicators.

V. CONCLUSION

Results suggest VR/AVG systems are applicable intensive interventions, but suggest caution with respect to how VR instructions, debugging, and system set-up time may limit activity intensity. Subsequent research should quantify intensity using metrics relevant to the motor learning focus of HABIT-ILE intervention interventions (e.g., frequency of repetitions and number of task challenge progressions). In personalized summer camp contexts, all activities can be engaging; to contribute to the literature base describing the rationale for VR/AVG use in the context of recognized implementation obstacles [23], researchers can correlate neurophysiological correlates of engagement and arousal with validated self-report measures to identify how children's individual characteristics and preferences interact with VR/AVG attributes to promote engagement in intensive, repetitive intervention programs.

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Changes in reach to grasp kinematics after home based Virtual Rehabilitation in chronic stroke

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Abstract— This study examines the upper extremity functionality improvement after a three month long home-based intervention using exergames. A custom designed Reach to Grasp (RTG) test was used to identify changes in movement patterns following the intervention. A subset of RTG measures was identified that predicted clinical outcomes

Keywords—Stroke rehabilitation, Virtual Rehabilitation, hand functional assessment

I. INTRODUCTION

Impaired hand and arm functionality caused by stroke is particularly difficult to recover and significantly reduces the quality of life and curtails independence[1, 2]. UE function is complex and requires coordination across multiple joints to complete different functional tasks involving gross movement, stabilization, and object manipulation [3, 4]. The widely varying presentation of impairments post-stroke contributes to the complexity of and difficulty in fully recovering UE motor function [5].

Exergame systems for hand and arm rehabilitation combine traditional therapeutic exercises with interactive gaming technology and can target specific UE movements and coordination. Gamified rehabilitation can provide motivating and engaging therapy to patients, targeting improved outcomes in rehabilitation [6].

Currently, there are no standardized methods to evaluate the effectiveness of exergame therapies [7]. Additionally, assessing the changes in hand functionality can be particularly challenging [8]. The Upper Extremity Fugl-Meyer Assessment (UEFMA) and other clinical assessments are commonly used by therapists to evaluate changes in UE function throughout the rehabilitation process [9]. However, clinical assessments provide imprecise measures of patient progress due to reduced sensitivity and floor or ceiling effects [10]. In addition, measures that focus purely on task outcomes fail to distinguish between true neural recovery of premorbid movement patterns versus learned use of efficient, but abnormal, compensatory movement patterns [11]. These outcome-based tools also fail to assess the generalization of the in-game movement learned during training to movements used in the patient's daily life [11].

Multiple authors cite kinematic analysis of three dimensional reach to grasp movements as a feasible method to assess recovery of normal motor function post-stroke [12, 13]. The Reach to Grasp (RTG) test provides detailed information about a patient's hand and arm functional abilities and can be used to evaluate motor control and coordination. The ability to pre-shape the hand and manipulate the fingers to grip objects of different shapes and sizes during the RTG test is an important aspect of manual dexterity. This skill is an essential indicator of an individual's ability to perform everyday activities in the real world [14].

This paper attempts to identify changes in the fine motor function of individuals with stroke, who underwent a 3-month UE exergame intervention for the hand and arm using the Home-base Virtual Rehabilitation System (HoVRS). RTG kinematics were collected to evaluate changes in subjects' movement patterns and were compared to changes in the UEFMA.

II. METHODS

A. Participants

Inclusion criteria include persons: a) who are 25-90 years of age, b) who sustained a unilateral right or left sided stroke, c) with a score of 22 or greater on the Montreal Cognitive Assessment, d) without hemispatial neglect evidenced by a score of 0 on item 11 of the National Institutes of Health Stroke

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scale or severe proprioceptive loss evidenced by the inability to detect a 1-inch passive movement of the fifth digit with eyes closed, e) with pre-training UEFMA scores of 15-62/66, f) without receptive aphasia, g) with intact cutaneous sensation. Exclusion criteria are a) orthopedic pathology limiting the ability to perform upper extremity movements without pain and b) other central nervous system pathology

B. *Intervention System*

HoVRS was designed and developed by our team to deliver personalized intensive upper extremity training using exergames [15]. HoVRS integrates an infrared camera for hand motion tracking with advanced algorithms that identify and correct movement patterns comprehensively. It includes three components: 1) a user station with a library of exergames, an infrared camera and an optional anti-gravity arm support, 2) a HIPAA compliant cloud data platform for remote patient monitoring and real-time data streaming, and 3) a web portal for clinicians to access patient progress reports.

C. *Training procedure*

The initial setup session was conducted in the lab (pre-training). The UEFMA and RTG tests were conducted. Clinicians prescribed three initial exergames from different categories (arm, wrist and hand) appropriate for each subject's presentation. An engineer calibrated the system based on each subject's ability and taught them how to set up and use HoVRS at home.

After initial setup, HoVRS was placed in subjects' homes for three months. Each weekday, subjects were encouraged to play at least four rehabilitation activities for a total minimum of 20 minutes. During the first month, the research team visited their home once a week to assess calibrations and game progress, answer any questions, and provide any needed technical support. In the second month of the study, 50% of these home visits were replaced with video calls. For the final month, all subject communication was done remotely. At the end of three months, the post-training outcome measurements were collected in the lab.

D. *Reach to Grasp Setup*

RTG test with the affected side was conducted at the same test points as clinical measurements. The RTG test with the unaffected arm was conducted once during pre-training data collection. The RTG tests were administered using an optical motion capture system (Prime 13 cameras, OptiTrack, USA). Fifteen active markers were placed on each subject's fingertips, metacarpophalangeal, and proximal interphalangeal joint (Figure 1). Additionally, four passive markers were placed on the dorsum of the hand, the elbow, the shoulder, and the

TABLE I. SUBJECTS DEMOGRAPHIC INFORMATION

Subj	Age	Gender	Time since CVA (months)	Affected side	UEFMA
S1	44	F	12	R	56
S2	57	M	6	L	30
S3	74	M	47	L	53
S4	76	F	9	R	48
S5	67	M	161	R	61

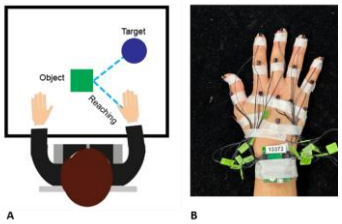

Figure 1. A. Subjects' seating position during RTG test. B. Active markers were placed on each finger joint.

sternum. Subjects were seated at a table with their hips and knees in a 90-degree position. Their semi pronated forearm and palm rested on a table, with the hand in front of and 10 cm away from the acromioclavicular joint.

Test objects were positioned at the subject's midline, approximately 15 cm from the subject's chest. Objects were transported to a target approximately 30 cm from their AC joints. Each to reach to grasp movement was repeated up to 10 times based on the subject's tolerance. The four objects consisted of 1" and 3" sized cubic objects and 2.5" and 4.5" diameter circular objects. Figure 1 shows the subjects' seating position and active maker placement during the RTG test.

E. *Metrics*

Clinical and RTG related kinematics measures were conducted at baseline, and immediately post three months of home-based training. In addition, kinematic data were collected from the unaffected side once during the pre-training session.

1) *Clinical measurements*

The UEFMA was used to evaluate motor recovery at the impairment level for the hand and arm.

2) *Kinematic measurements from RTG*

Kinematics measurements were derived during the reaching phase of the movement. Reaching onset was defined as the time at which the tangential wrist velocity exceeded 5 percent of the peak. Reaching offset was defined as the point at which the wrist changed the movement direction to initiate the transport

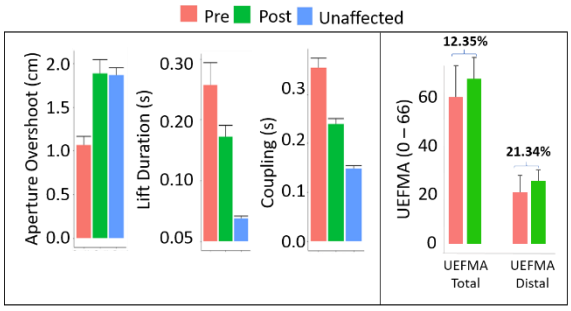

Figure 2. Mean Reach to Grasp Kinematics. The left panel shows group averages of hand aperture relative to the object size (Aperture Overshoot), the time required to lift the object after the initial reaching movement is complete (Lift Duration), and Reach Grasp Coupling (RGC). The right panel shows the group averages of overall UEFMA and distal UEFMA scores. Error bars denote standard errors.

of the grasped object. Wrist Peak Velocity (PV), Time To Peak Velocity (TTPV), and peak hand aperture relative to the size of the grasped object (Aperture Overshoot) were calculated. Furthermore, the time required to lift the object, Lift Duration, was calculated as the time between hand velocity decreasing below 5% of PV at the end of reach and hand velocity exceeding 5% of PV when lifting the object. Finally, Reach Grasp *Coupling* (RGC) as a measure of reach and grasp coordination was evaluated by subtracting time to peak hand aperture from time to wrist peak velocity [16].

3) Hand pre-shaping measurements

Hand pre-shaping was evaluated by an SVM classification algorithm using 13 finger joint angles (all 5 PIP joints, MCP of four fingers and all four finger pair abduction angles) measured during the reaching phase of the RTG movement. At each time sample during reaching, the classifier tries to decide which of the two objects of similar size but different shapes (a two inch per side cube and a two-inch diameter disc) will be grasped in the current trial.

F. Data Analysis

Changes between pre-training and post-training test scores were evaluated using a repeated measures ANOVA. The Best Subset Analysis [17] was used to find the subset of independent RTG kinematic measures that best predicts the UEFMA scores. Kinematic variables described above were z-normalized and exploratory best subsets regression analysis was applied to identify a combination with the largest R2_predicted (cross-validated) value and appropriate Cp Mallows.

III. RESULTS

Five chronic stroke subjects participated in a 3-month home-based gamified therapy and completed all clinical and kinematics assessments for both pre and post training sessions. Subjects' demographic information is shown in Table 1.

A. RTG Kinematics and clinics changes

All five subjects improved in both distal parts of the kinematic measurements. Grasp Overshoot increased from 1.34cm (SE=0.3) to 2.85cm (SE = 0.6), Lift Duration reduced from 0.27s (SE = 0.09) to 0.18s (SE = 0.08), and RGC reduced from 0.35s (SE = 0,09) to 0.24s (SE = 0.06). The total UEFMA improved by 12% after training, from 50.4 (SE = 9.5) to 56.8 (SE = 6.8). The distal section of UEFMA improved by 21%, from 11.25 (SE = 2.7) to 12.5 (SE = 2.6) (see Figure 2).

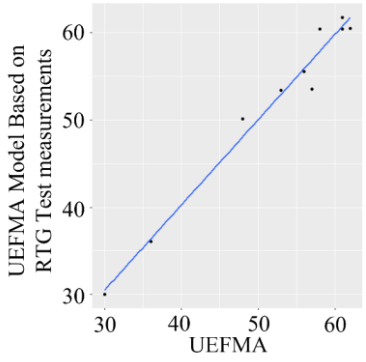

Figure 3: Correlation between actual UEFMA scores and scores predicted from best model of RTG kinematic measures. UEFMA Model = 32.15 + 2101.94*PV + 305.82*Aperture_Overshoot - 0.1126*Lift_Duration + 24.9350*Coupling, R2(adj) = 95.8, R2(pred) = 95.4.

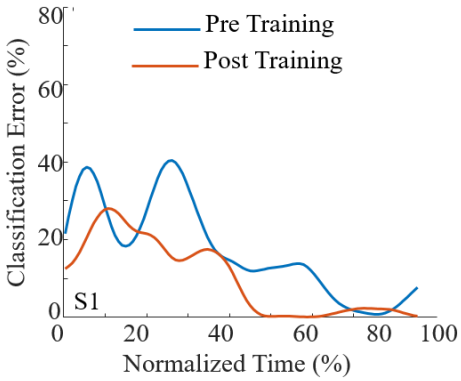

Figure 4. Finger joint angles at each time point during reaching for a 2-inch cube or a 2-inch disc were entered into an SVM-based classification procedure. Percentage of classification errors over ten movements per object are plotted versus normalized time for a single subject. Pre-training classification error peaked at 40% and reached zero after 80% of the total movement duration. Post training mean error peaked at 30% and reached zero at 48% of movement duration.

B. Best-subset Analysis

Best Subsets regression analysis identified a linear combination of RTG kinematic measures to predict the UEFMA score with the largest R2_adjusted value at 95.8 and R2_predicted value at 95.4 (Figure 3).

C. Hand pre-shaping improves post training

An example of an SVM classification error change for one subject is illustrated in Figure 4. Subject S1 demonstrated improved efficiency in hand pre-shaping at post-training, as evidenced by the classification errors reached zero earlier into the reaching movement compared to pre-training.

IV. DISCUSSION

This group of subjects demonstrated a trend toward improvement in grasp duration, a well-researched measure with strong science underpinning its association with motor recovery [3]. Our subjects also showed trends toward improvement in Aperture Overshoot and Reach Grasp Coupling. These distal measures made meaningful contributions to our regression models, suggesting that they may add unique information to the analysis of upper extremity motor recovery.

Regression models of RTG kinematic measurements demonstrated a strong relationship between kinematic and clinical measurements of motor function. The best model included variables describing proximal function (PV), distal function (Aperture Overshoot and Lift Duration), as well as a measure of coordination between proximal and distal degrees of freedom (Coupling). This is consistent with our findings in subjects with subacute stroke [18].

Post-training classification error for subject S1 reached zero at about 48% of reach movements time which is similar to the timing demonstrated by persons without stroke [19]. She demonstrated an 8-point increase in UEFMA score, suggesting that changes in hand shaping ability may have occurred due to improvements in UE motor function.

The major limitation of this study is the small sample size. Furthermore, our current testing approach uses only four objects, two discs and two rectangular blocks. This may introduce floor and ceiling effects into our analysis of hand pre-shaping and some of our distal measures. Future studies including more participants and a wider range of object shapes and sizes will allow for more robust evaluations of these measures as biomarkers of neural recovery.

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Virtual Reality based interventions and self reported upper limb use levels after stroke– A systematic review and meta-analysis.

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***Abstract*— We examined the effectiveness of virtual reality (VR) based rehabilitation interventions on levels of self-reported quality and quantity of upper limb (UL) use. We conducted a systematic review and meta-analysis. The PEDro scale helped assess study quality. Summary effect sizes helped quantify intervention effectiveness. Eighteen studies met the inclusion criteria. The quality of retrieved studies ranged from moderate to good. Moderate effect sizes were obtained at the end of the intervention. At retention assessment, effect sizes were either moderate (quality of use) or large (quantity of use). Using VR based interventions can help improve self-perceived use of the more-affected UL after stroke.**

Keywords—cerebrovascular accident, arm use, self-report, quality of movement

I. INTRODUCTION

Stroke is a leading cause of adult morbidity in the US [1]. Many individuals sustaining a stroke present with impaired upper limb (UL) functioning [2]. UL dysfunction impacts the ability to reach, grasp, and manipulate objects. Thus, it can significantly affect participation in activities of daily living (ADL) and quality of life. The ability to perform ADLs continues to improve well into the chronic phases of stroke [3]. A variety of factors including age at onset, comorbidities, initial severity, and provision of rehabilitation influence the ability to improve ADLs [4]. The timing, frequency, duration, type of rehabilitation interventions provided and environment of task practice can influence UL motor improvement [5].

Virtual Reality (VR) provides a platform to help design enriched training environments combining above mentioned factors [6]. These training environments can be designed to include environmental interaction and allow for adaptive customization of difficulty levels for task-success [7]. This environmental interaction helps increase patient motivation and improves outcomes [8]. The effects of VR-based interventions are quantified using outcomes assessing change at the different levels of the International Classification of Functioning (ICF) [9] .

The assessment used most commonly at the activity level in studies involving VR-based interventions is the Wolf Motor Function Test (WMFT) [10]. The WMFT is a laboratory-based test involving the clinician scoring ability of and time taken for task completion. No information is provided on whether the more-affected UL is incorporated into real life everyday functional ADL performance. Previous results suggest that even those with mild levels of post-stroke motor impairment self-report reduced use of the more-affected upper limb in ADL performance [11].

Use of outcomes including the Motor Activity Log (MAL) provide information on levels of self-reported UL use. The MAL is a self-report measure with questions about the amount and quality of UL use in daily life activities . Individuals are asked to rate the amount and quality of use on a 6-point scale where 0 = *never used* and 5 = *the same amount of use as before the stroke*. Two versions of the MAL are available, the MAL-14 and MAL-28 consisting of 14 or 28 questions. The final score is a mean of the total number of items scored. Both versions have sound psychometric properties [12].

The MAL is being increasingly used as an outcome in studies proving VR-based interventions [10]. However, results of studies have been mixed. While some studies have reported improvements in MAL scores [13], others have reported no benefits to using VR-based interventions [14], including a Cochrane review [15]. The review was published in 2017 with additions to the literature since that time. Although VR-based interventions promote post-stroke UL motor improvement [4], little is known about the participant perception of real-life use of the more-affected UL. This information is essential as it provides insights into real life transfer of the effects of the VR-based interventions. The study objective was to systematically analyze the effects of VR-based interventions on self-perceived amount and quality of UL use. The PICO question guiding this study was "*In individuals with post-stroke UL hemiparesis, does the use of VR-based interventions change self-perceived quantity and quality of use of the more-affected UL*?"

II. METHODS

A. Search Strategy

This systematic review followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)

guidelines. A comprehensive search of studies published in English between 2010-2023 was conducted. Databases searched were MEDLINE and Google Scholar. The search terms including: 'stroke,' 'cerebrovascular accident,' 'upper limb', 'hemiparesis', 'arm', 'Motor Activity Log', 'VR', 'daily life activities', 'exergaming', and 'rehabilitation' were searched using Boolean operators 'OR' and 'AND'. The title and abstract of each study were examined and only studies using MAL on UL recovery were selected. We searched reference lists of retrieved studies for other relevant articles.

B. Selection Criteria

We included studies that i) involved adults who had sustained a stroke; ii) compared VR-based and other interventions for UL motor improvement; iii) were designed as randomized controlled trials and iv) used one or both components of the MAL as a primary or secondary outcome. We excluded studies that i) examined the effects of VR-based interventions on children; b) involved use of VR for gait and balance rehabilitation and c) used other study designs.

C. Data abstraction and analysis

Relevant study details including author/year, participants, chronicity, intensity of treatment provided, and results were summarized from the retrieved articles using a data extraction form. The psychometrically sound PEDro scale helped assess the quality of the included studies. All studies were independently by JAM and LR, with discrepancies resolved by SSP and SKS. Study quality was rated as *excellent* (9-10), *good* (6-8), *moderate* (4-5) or *poor* (≤3) [16].

Meta-analyses (RevMan 5.3) examined the effects of VR-based interventions on the change in quality (measured using MAL Quality of Movement; MAL-QoM scale) and quantity (measured using MAL Amount of Use; MAL-AoU scale) of UL use immediately after practice and at retention. Pooled effects were quantified with standardized mean differences and effect sizes with 95% confidence intervals (CIs). I^2 values helped assess heterogeneity and we used the random-effects model to determine significance if scores were ≥ 50% [17]. We categorized effect sizes as small (0.08 - 0.18), medium (0.19-0.40) and large (≥0.41), in accordance with the Rehabilitation Treatment Specification System recommendations [18]. Significance was set at $p<0.05$.

III. RESULTS

From a total of 253 papers, 98 publications were screened for eligibility after duplicates were removed (Fig 1). After full-text review of 28 studies, 17 studies [7,13,14,19-32] fulfilled our selection criteria and were included for both qualitative and quantitative analyses.

A. Study Quality assessment

Out of the 17 included studies, two studies scored 8/10, eight studies scored 7/10, five studies scored 6/10 and two scored 5/10 (Figure 2). Thus, majority of the studies can be classified as '*good'* quality studies.

B. MAL QoM scores

All 17 included studies used the MAL QoM scores as an outcome. These studies involved a total of 504 participants, with 260 receiving VR-based interventions and 204 receiving control interventions. Immediately at the end of the intervention period, analysis revealed a **medium effect size** ($I^2 = 25\%$, fixed effects model, **effect size 0.22,** 95% CI: 0.04 -0.40; test for overall effect: Z = 2.42, p = 0.02; Figure 3).

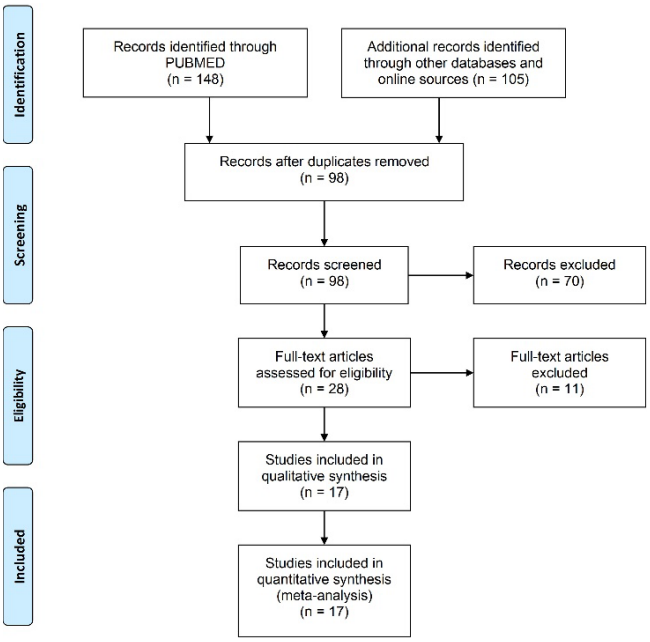

Fig. 1 *PRISMA flow diagram*

Only 13 out of the 17 studies had a retention assessment (Figure 4). Data were available from 374 participants, with 192 receiving VR-based interventions and 182 control interventions. Analysis revealed a **medium effect size** (I^2=32%, fixed effects model, **effect size 0.28,** 95% CI: 0.01 -0.54; test for overall effect: Z = 2.06, p = 0.04; Figure 4).

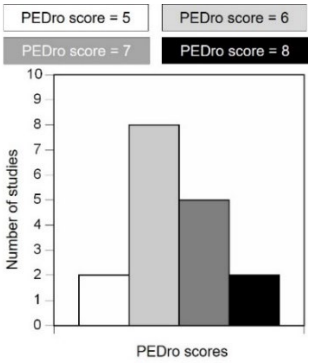

Fig. 2 *PEDro score distribution*

C. MAL AoU scores

Fourteen of the 17 included studies used the MAL AoU scores as an outcome (Figure 5). These studies involved a

total of 357 participants, with 179 receiving VR-based interventions and 178 receiving control interventions. Immediately at the end of the intervention period, analysis revealed a **medium effect size** (I^2 = 19%, fixed effects model, **effect size 0.22,** 95% CI: 0.01 -0.43; test for overall effect: Z = 2.04, p = 0.04).

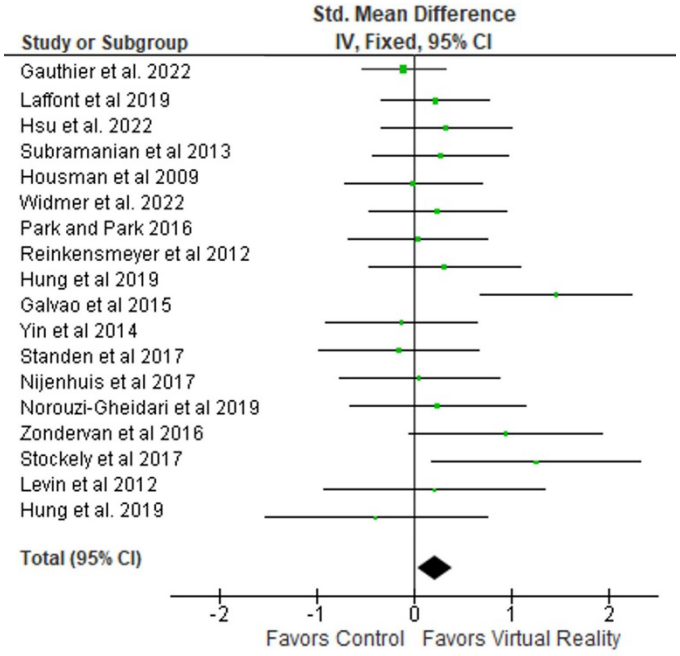

Fig. 3 *MAL QoM scores immediately after intervention provision*

Only 12 out of the 14 studies using the MAL AoU scores included a retention assessment (Figure 6). Data were available from 311 participants, with 154 controls and 157 receiving VR-based interventions. Analysis revealed a **large effect size** (I^2 = 56%, random effects model, **effect size 0.44,** 95% CI: 0.08 - 0.80; test for overall effect: Z = 2.40, p = 0.02).

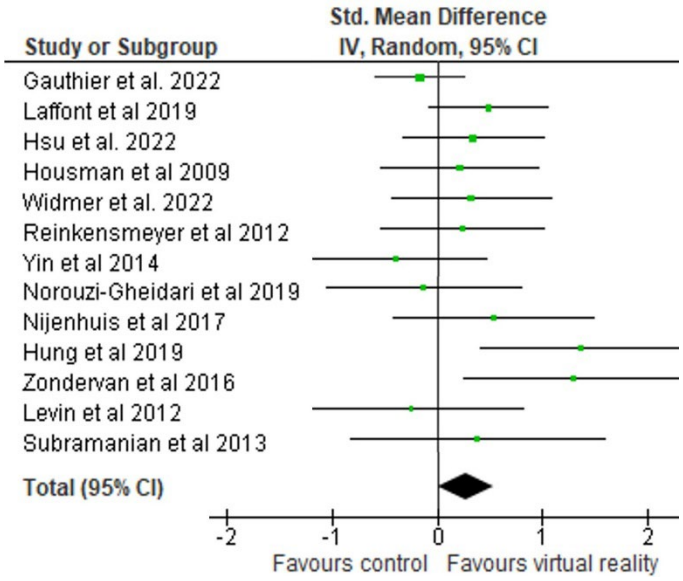

Fig. 4 *MAL QoM scores at the retention assessment*

IV. DISCUSSION

VR-based interventions are useful to improve self - perceived levels of quality and quantity of use of the more-affected side. We found a medium effect size immediately at the end of the intervention for both QoM and AoU scores. While a medium effect size was found at retention as well for the QoM score, a large effect size was obtained for AoU scores.

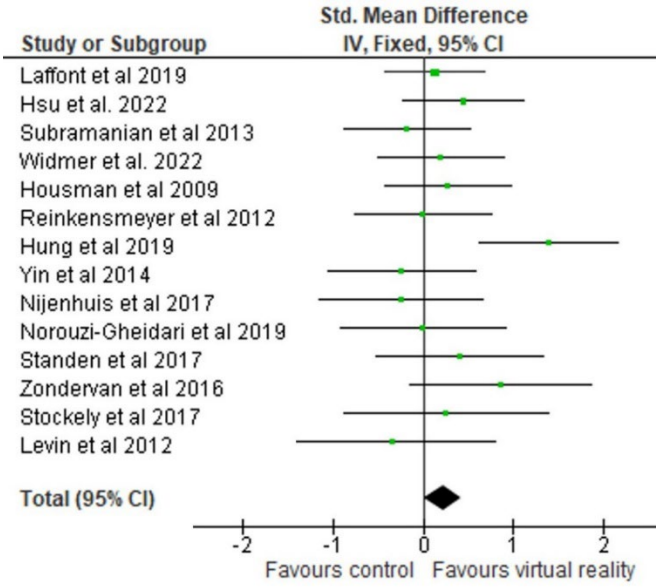

Fig. 5 *MAL AoU scores immediately after intervention provision*

A. Outcome measures used

In addition to the MAL, UL motor improvement was assessed at the various levels of the ICF in the included studies. At the impairment level, thirteen of the included studies [7, 14,19-25,28,29,31,32] used the Fugl-Meyer Assessment (FMA). The FMA focusses primarily on task completion. Information on how the task was completed, i.e., what kinds of movement patterns were used can be provided by use of kinematic measures. A couple of studies used the Reaching Performance Scale in Stroke [7,20] which is a clinical assessment based on observational kinematics. Only one study used motion analysis [7] to estimate movement pattern kinematics that quantify joint ranges of motion. This can provide a more objective assessment of movement quality. The use of either observational or motion analysis based kinematic measures should be encouraged in future studies, as it can provide a more objective measure of movement quality which can complement the subjective report of change in QoM scores.

At the activity level, the Box and Blocks test was used in nine studies [13,14,20,21,24,27,29,31,32] and WMFT was used in 6 studies [7,26,28-30,32]. In addition, the Action Research Arm Test was used in four studies [13,21,22,25]. All three measures have good psychometric properties [33] and are routinely employed in studies using VR-based interventions for UL recovery in stroke [10]. They can

function as a complementary measure of ability to perform activities on which study participants rate their amount and quality of use of the more-affected UL.

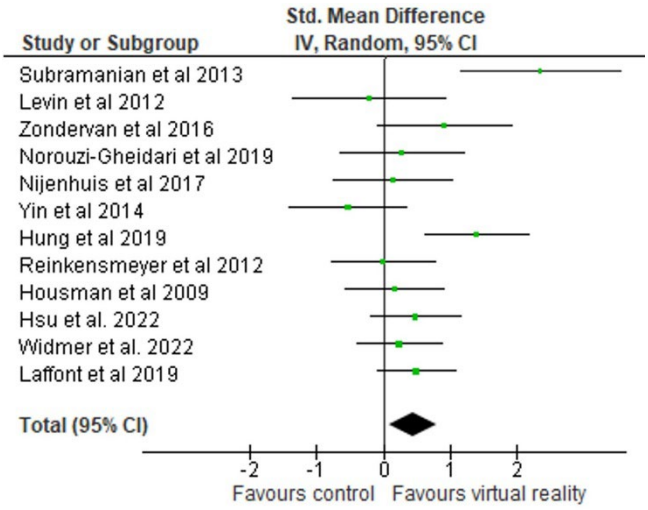

Fig. 6 *MAL AoU scores at the retention assessment*

B. Treatment duration and retention assessment

Duration on the provision of VR-based rehabilitation varied widely amongst studies. While three studies provided ≤300 minutes [14,26,30], two others provided between 400-450 minutes [20,22]. Four studies provided 540 [7,13,27] – 600 [24] minutes of therapy. While two studies provided between 720 [28] -750 [23] minutes of rehabilitation, three others provided 900 minutes of rehabilitation [29,31,32]. Three studies provided between 1080 [25] to 1440 minutes [19,21]. These treatment durations were provided across sessions, ranging in number from 4 - 36. It can be seen from the forest plots (Fig. 3-6) that provision of greater amounts of rehabilitation does not seem to be related to greater gains in MAL scores.

While amount of time spent in therapy is a commonly used metric of intensity [34], other metrics include actual numbers of active repetitions [35] and amount of effort/perceived exertion felt during the session [36]. Only two studies [7, 31] explicitly provided an estimate for the number of repetitions used/session. It remains to be estimated whether a relationship is present between the number of active repetitions/minute and amount of improvement seen in MAL scores.

Thirteen of the 17 studies included in the meta-analysis had a retention assessment. While four studies included a retention assessment one month after completion of the intervention [13,14,20,22], one study had a retention assessment after two months [26], five studies after 3 months [7,21,28,31,32], one study after four months [25] and two studies after 6 months [19,30]. Despite the wide variability, overall analysis revealed a moderate effect size for MAL QoM scores and large effect size for AoU scores. However, whether these effects last longer than 6 months is currently unknown. Future studies should attempt to include longer term follow-ups to understand how long do these effects last.

C. *Types of systems used*

Five studies used customized systems [13,22,26,29,31], while rest of the 12 studies used commercially available systems. The commercially available systems included applications such as the Wii and Kinect as well as the CAREN system and robotic systems with a VR-interface. These results are similar to previous findings [10] that commercially available systems are more commonly used. However, lack of sufficient studies on each of the systems used (for e.g., Wii, Kinect, CAREN, Jintronix, etc.) does not allow for more detailed sub-analysis on the effectiveness of a particular type of system. Thus, it remains currently unknown whether use of one type of system results in similar or better results compared to other systems.

V. LIMITATIONS

We only included randomized controlled trials. The intervention periods and follow-ups were of different lengths, and the intensity of treatment varied between studies. Third, the terms “standard care” or “usual care” or “conventional care” were used to define the control interventions. However, components of ‘standard care’ vary considerably and were not described in enough detail to allow replication by other researchers. Another major limitation is that no study reported the use of proxy-scores, i.e., scores from spouses and/or caregivers.

VI. CONCLUSION

VR-based interventions are useful in improving levels of self-perceived quantity and quality of use of the more-affected upper limb after stroke. Future studies using VR-based intervention should consider inclusion on self-reported measures to completely understand the transfer of gains into real-life functioning.

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ISVR

INTERNATIONAL SOCIETY FOR VIRTUAL REHABILITATION

Poster Session 1

10:15 to 11:15

July 24th, 2023

The Acceptability of Mobile Virtual Reality Therapy for Alcohol Misuse Treatment in Adult Drinkers

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Abstract

Alcohol misuse is a global health issue, often associated with relapse episodes during and after treatment. Easy access to treatment could prevent relapse when high-risk situations are encountered. However, this is not always possible, for example amidst pandemics, or when patients live in rural areas or require out-of-hours support. Virtual Reality Therapy delivered via a mobile device (mVRT) online or in-person, could be a flexible, cost-effective solution, but whether it would be acceptable in patients has not been explored. We therefore conducted an online survey with 259 adult drinkers to determine mVRT's treatment acceptability for alcohol misuse, relatively to VRT (delivered via a standard headset) and typical alcohol treatments available in healthcare systems. Predictors of acceptability regarding familiarity with and preference for mVRT, VR experience, treatment delivery preferences, hazardous drinking, perceived stigma, treatment uptake attitudes, gender, ethnicity and mental health were also considered. MVRT was perceived less acceptable than VRT and traditional treatments. Treatment familiarity and preference for mVRT, VR experience, stigma, treatment uptake attitudes, mental health and gender were related to mVRT's acceptability. Familiarisation procedures in delivery protocols could increase mVRT's acceptability, especially in patients who experience alcohol stigma, co-occurring mental health issues or do not use technology regularly.

Using Interactive Computer Play in Clinical Practice in Pediatric Rehabilitation

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***Abstract*—This observational study documented the motor learning strategies (MLS) that are integrated into Bootle Blast, an interactive computer play system, and those which are added or enhanced by clinician involvement. Video-recorded therapy sessions using Bootle Blast were reviewed by two raters and scored using a validated MLS rating scale. Eight MLS were effectively delivered via visual/audio prompts within Bootle Blast including: *directing attention to objects* and *relating to results*. Clinician involvement led to meaningful increases in three MLS: *asking to problem solve, physical guidance* and practice being *progressive*. Further refinements to MLS elements may help to optimize the therapeutic potential of Bootle Blast.**

Keywords—interactive computer play, clinical practice, pediatric rehabilitation, motor learning strategies, cerebral palsy

I. Introduction

The use of interactive computer play (ICP), "any kind of computer game or virtual-reality technique where the child can interact and play with virtual objects in a computer generated environment," [1] has increased in use within rehabilitation interventions. Levac et al., identified a number of "active ingredients" of ICP including opportunities for practice, task specificity and feedback, while also recognizing the importance of therapists in ICP-based interventions that tailor sessions to client needs and provide client-specific feedback. [3] In doing so, therapists aim to support motor learning, i.e., the acquisition, retention and transfer of motor skills, through the use of motor learning strategies (MLS), the selection and manipulation of motor learning variables to support neuroplasticity. [4]

While movement-tracking video games designed for entertainment purposes have been used for therapeutic purposes, they cannot be individualized to match an individual's capacity or therapy goals. [5] The Possibility Engineering and Research Lab (PEARL) has developed a mixed-reality ICP system, Bootle Blast, that uses a 3D camera-computer to provide real time feedback on skeletal movements and interactions with real life objects used during gameplay. The aims of this project were to understand what MLS are integrated into Bootle Blast and to identify clinicians' actions (i.e., their role) in motor learning facilitation during clinician-child-system interactions via documentation of the MLS they introduce during the session.

II. Methods

A. Participants

Children over the age of 5 years, already engaged in ICP-based motor therapies at Holland Bloorview Kids Rehabilitation Hospital, and their treating clinicians (physiotherapists, PTs, occupational therapists, OTs, and therapy assistants, OTA/PTAs) were eligible to participate. Children and their clinicians needed to be able to communicate in English.

B. Procedure and Data Collection

In this observational study, children who consented to study participation played one Bootle Blast mini game independently before clinicians carried out therapy sessions using Bootle Blast as per usual care. Video recordings of therapy sessions using Bootle Blast were then reviewed by two raters who rated MLS observed using the 22-item Motor Learning Strategies Rating Instrument (MLSRI-22), [4] a tool that documents the type and extent of use of 22 MLS. Seventeen of the 22 items are rated on a 5-point scale with 0=very little (the MLS was observed 0-5% of the time), 1=somewhat (observed 6-24% of the time), 2=often (observed 25-49% of the time), 3=very often (observed 50-75% of the time) and 4=mostly (observed 76-100% of the time). [4] Five items (items 4, 10, 11, 16 and 17) are rated on a 3-point scale (0, 2, 4) based on the quality of the MLS observed. [4] A minimum score of 2 has been considered an indication of definitive MLS use. [4]

III. Results

Five children, 2 boys and three girls, mean age 9.4 years (SD 0.5) with cerebral palsy (Gross Motor Classification System Levels I-III) and their treating clinicians (1 PT, 1 OT, 2 OTA/PTAs) participated. Of the 8 visual/audio MLS prompts integrated into Bootle Blast, *directing attention to objects/environment,* and *relating to results* were used to the greatest extent (median=4, IQR=1) (Table 1, top section). Mini game practice was *repetitive* and *whole* (median=4, IQR=1). Through verbal and physical means, seven MLS were added by

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clinicians, reaching the definitive extent of use for three of these: *asking to problem solve* (median=2, IQR=0), *physical guidance* (median=2, IQR=1) and *progressive* practice (median=2, IQR=2) (Table 1, mid-section). The MLS of *providing an environment where errors are a part of learning* appeared to show greater extent of use when children played Bootle Blast independently (median=4, IQR=0) than when the clinician was involved in the session (median=3, IQR=0). Seven other MLS were not observed in any of the children's sessions (Table 1, lower section).

TABLE I. MLSRI-22 ITEM SCORES FOR INDEPENDENT (BB) AND CLINICIAN GUIDED (BB + CLINICIAN) GAME PLAY

Item Number	*Motor Learning Strategy (MLS)*	*Median Score (BB)*	*IQR*	*Median Score (BB + Clinician)*	*IQR*
	MLS Integrated into Bootle Blast				
2	Direct attention to objects/environment	4	1	4	0
6	Relate to results	4	1	4	2
7	Indicate what was done well	3	1	3	1
8	Indicate what was done poorly	3	1	3	1
14	Provides environment where errors are a part of learning	4	0	3	0
15	Use external device(s) to augment feedback	4	0	4	0
18	Practice is repetitive	4	0	4	0
19	Practice is whole	4	0	4	0
	MLS Added or Enhanced by Clinicians				
1	Provide encouragement	0	0	1	0
3	Direct attention to body	0	0	1	1
4	Involve 'asking' to problem solve	0	0	2	0
5	Relate to performance	0	0	1	1
12	Uses demonstration/ modelling	0	0	1	1
13	Provides physical guidance	0	0	2	1
22	Practice is progressive	1	1	2	2
	MLS Not Provided by Bootle Blast or Clinicians				
9	Involve analogy	0	0	0	0
10	Link activity being practiced to other activities	0	0	0	
11	Encourage mental practice	0	0	0	0
16	Recommends practice outside therapy	0	0	0	0
17	Provides training or education to child/ caregiver	0	0	0	2
20	Practice is variable	0	0	0	1
21	Practice is random	0	0	0	0

IV. DISCUSSION

To our knowledge, this is the first instance of the MLSRI-22 being used to quantify MLS provided by an ICP system during ICP-based interventions. By providing additional MLS, clinicians are able to enhance the MLS that are already integrated into Bootle Blast. Concurrent research is exploring clinicians' awareness of their MLS use, the reasons behind their reinforcement and expansion of MLS use during Bootle Blast sessions, and their broader perceptions of their role during ICP sessions.

While Bootle Blast successfully integrates several MLS, further game refinements, including the addition of training tutorials, encouragement, prompts to increase body spatial awareness, individualized feedback related to performance, opportunities for problem solving and linking the activity practiced to other activities may help optimize the system's therapeutic potential. Study results will help enhance Bootle Blast game elements and caregiver training resources to expand Bootle Blast for home use.

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Practical considerations for head-mounted display use in pediatric rehabilitation: a narrative review

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Abstract— **Non-immersive (flat-screen display) virtual reality (VR) has become an accepted pediatric rehabilitation tool, but immersive VR (head-mounted displays [HMDs]) are in the early stages of adoption and evaluation in this field. Little information exists to inform clinical decision-making about HMD use in rehabilitation. We undertook a narrative review to 1) Categorize available HMDs; 2) Identify manufacturer guidelines specific to pediatric use; and 3) Synthetize contextual information regarding HMD use in pediatric rehabilitation. Of twenty-four HMDs (19 manufacturers) with an English online presence, 9 included small amounts of pediatric-specific information in their guidelines. Fourteen studies involving pediatric cognitive or physical rehabilitation populations published between 2018-2023 took place in hospital or laboratory settings. HMD use was an average of 1.8 sessions/participant for an average duration of 15.4 (SD 10.1) minutes. The most reported side effect was nausea, followed by dizziness, headache, and eye strain. More research is required to address gaps in evidence for more frequent, longer-term use in different populations and settings. With larger sample sizes, studies should explore the impact of individual (i.e., age, diagnostic) and contextual (i.e., type of HMD, interaction method) factors. Review findings will inform initial pediatric rehabilitation use recommendations that will evolve as new evidence emerges.**

Keywords—virtual reality, safety, rehabilitation, pediatrics

I. INTRODUCTION

Head-mounted displays (HMDs) provide a 3D visually immersive virtual reality (VR) experience where the user's view of the virtual environment changes in accordance with head movements. The affordances of immersive VR align with evidence-based motor learning principles essential for effective rehabilitation interventions, including provision of multisensory feedback, engaging and variable environments, ecologically valid and meaningful tasks, and abundant task repetitions [1]. HMDs can also provide opportunities to practice challenging motor skills in a safe, controlled environment.

While HMDs have a more established evidence base in pediatric medical (e.g., for pain management [2]) and educational contexts), their use in pediatric rehabilitation is in its infancy [4]. Rehabilitation differs from medical and educational contexts for its focus on movement interactions with the virtual environment (as compared to passive immersive viewing experiences) and for potentially requiring more frequent and longer durations of use. Impact on the developing visual system as well as impact of HMD weight on balance and postural control are among the possible safety issues of longer-term use [5]. In addition, the wide variety of HMD options (e.g., PC-based, gaming, or standalone) as well as VR market tendencies for rapidly developing technology and obsolescence of current models complicate clinical decisions about purchase and use.

To provide clinically relevant information about current HMD options and to identify gaps in the current evidence base requiring further research, we undertook a narrative review to 1) Categorize available HMDs; 2) Identify manufacturer guidelines regarding safety precautions for pediatric use; and 3) Synthetize contextual information about HMD use in pediatric rehabilitation.

II. METHODS

A narrative review is a type of literature review that provides a comprehensive analysis of current knowledge on a topic. We followed the Scale for the Quality Assessment of Narrative Review articles guidelines [6]. For objectives 1 and 2, we used the Google search engine to find commercially available HMDs and access manufacturers' published guidelines (available in English or French). We also searched online for VR software marked specifically for pediatric rehabilitation use. For objective 3, we searched PubMed and EMBASE databases using relevant keywords for studies published in English or French between 2018-2023 involving immersive VR (HMD) use in a primarily rehabilitation context with children and youth. Two authors independently extracted study information using an Excel spreadsheet. Numerical analysis of counts and

frequencies of study characteristics and usage information was used to synthetize results.

III. RESULTS

A. Objective 1:Categorize available HMDs

We classified headsets according to their technological requirements as PC-powered, standalone, mobile (smartphone), and gaming (console-based). Online, we found a total of 24 HMDs made by 19 manufacturers with English websites. (When multiple HMDs are manufactured by the same manufacturer, we listed the HMD as one product). Six HMDs were PC-powered: HTC VIVE (with a series of products including XR Elite, Pro, and Cosmos), Reverb G2, Valve Index, VRgineers XTAL3, Canon MREAL X1, and Vario Aero. Thirteen were standalone HMDs: Meta Quest, VIVE Focus, Pimax Artisan, Pico Neo, Lynx R1, Skyworth Pancake 1C, Lenovo Legion VR 700, YVR 1, IQIYI Qiyu, DPVR, Samsung Odyssey, and Nolo. Four were mobile: Samsung Gear VR, Google Cardboard, Homido VR, and Vive Flow. The Sony Playstation 2 VR headset was the only gaming HMD found. No HMD was marketed specifically for children or youth. One commercially available software designed for pediatric rehabilitation use (ViribusVR) which combines an Oculus (now Meta) Go HMD with a suit containing IMU sensors to detect body movements.

B. Objective 2: Describe manufacturers' guidelines

Among the 19 manufacturers, 8 product guidelines were available online (Meta, Samsung, PlayStation, HTC VIVE, Google Cardboard, Pico, DVPR, and Vario Aero), all of which included varying specificities of pediatric-specific information. Four manufacturers discouraged use for children under 13 years of age; 2 discouraged use by children under 12, and 2 (HTC, Google Cardboard) did not specify age restrictions. Six recommend adult supervision, while 8 encourage users to be alert to possible listed side-effects. All 8 recommend limiting usage sessions; 5 suggest taking breaks after 30 minutes of use. When intra-pupillary adjustment is possible (3 HMDs), all recommend adjusting it appropriately to each user. The ViribusVR website recommends session of less than 30 minutes and to begin with shorter periods to acclimatize to the VR environment (www.viribusvr.com).

C. Objective 3: Synthetize evidence in pediatric rehabilitation.

Fourteen studies involving pediatric cognitive or physical rehabilitation populations (Autism, upper limb injuries, patients in the Pediatric Intensive Care Unit) published between 2018-2023 took place in hospital or laboratory (n=6) settings. HMD type was not always specified; standalone HMDs were used in 5 studies. HMD use was an average of 1.8 sessions/participant for an average duration of 15.4 (SD 10.1) minutes. 13/14 studies reported side-effects; the most reported side effect was nausea, followed by dizziness, headache, and eye strain, as measured by interviews, observations, or standardized or study-specific questionnaires.

IV. DISCUSSION

Primary concerns related to review findings impacting clinical decision-making are the lack of information about the safety of repetitive HMD use and the lack of clarity around precautions versus contraindications of HMD use in rehabilitation populations. Manufacturer guidelines are specific to typically-developing children; therapists and researchers require more information specific to how technological attributes may interact with individual characteristics to inform precautions versus contra-indications of HMD use. Study limitations included exclusion of non-English sources and a focus on physical effects of HMD use. Subsequent work should include psychological effects of technological immersion in children, who may respond to a greater extent than adults to immersive VR content as if it were real, impacting post-VR behavior [7].

V. CONCLUSION

The HMD market is rapidly developing [7] but no HMD is specifically marketed to children. While manufacturer guidelines discourage use by children less than 12-13 years of age, research studies frequently include younger children. Therapists should be aware that HMD use may impact the visual system, cause nausea or dizziness, or may also influence strategies for maintaining balance. More information is required as the included studies did not focus on prevalent rehabilitation populations (such as children with cerebral palsy or traumatic brain injuries) with different abilities and characteristics. The relevance of immersive VR use in pediatric rehabilitation can be expected to increase as HMDs decrease in cost and advance in gesture recognition capabilities and graphical quality to recreate both ecologically valid and fantasy environments. Findings from this narrative review will inform creation of accessible online resources, including a user-friendly comparative online table synthetizing results that will require frequent updates to account for product developments and emerging research in this domain.

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AVA: AI-driven Virtual Rehabilitation Assistant

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***Abstract*—Virtual rehabilitation has gained popularity in delivering personalized programs of exercise, education, and counseling to the home of patients. Despite the potential benefits of virtual rehabilitation programs in reducing rehospitalization and death, high dropout rates pose a significant obstacle to their effectiveness. This is due to several barriers, including a lack of motivation and confidence in completing rehabilitation exercises. This paper introduces an AI-driven Virtual Assistant (AVA) to assist patients in completing their prescribed rehabilitation exercises at home. AVA uses AI algorithms to analyze patients' movements and provide them with real-time personalized feedback. The web application containing AVA can be accessed from any camera-enabled computer or mobile device without the need for additional hardware. Through a co-design approach, the movement training components of AVA for upper-limb stroke rehabilitation exercises were developed and reviewed by the research team, including a patient partner. The importance of including an avatar in virtual rehabilitation and providing real-time feedback to guide patients in performing exercises correctly was emphasized by the patient partner. AVA has the potential to enhance healthcare outreach, increase program participation and completion, and improve long-term health outcomes.**

***Index Terms*—virtual rehabilitation, avatar, artificial intelligence, stroke rehabilitation, cardiac rehabilitation**

I. Background

Rehabilitation programs are crucial for patients who have experienced cardiac events or strokes, as they can improve their quality of life and reduce rehospitalization and mortality rates [1], [2]. Regular exercise is a key component of these programs, helping patients regain mobility and strength [3]. However, despite the benefits of rehabilitation, high dropout rates have been reported, mainly due to various barriers. These include lack of motivation and confidence, financial and transportation constraints, scheduling conflicts, and limited access to rehabilitation facilities in remote areas [4], [5]. Virtual rehabilitation (VR) is a promising solution that addresses these barriers and offers equivalent health outcomes compared to traditional in-person rehabilitation [6]. However, existing VR platforms have limitations. Some require clinicians to be present during virtual sessions, which does not solve the shortage of rehabilitation professionals [7]. Others require costly hardware such as virtual reality headsets [8], wearable robots [9], or depth cameras [10], leading to inequitable access to healthcare. In this paper, we introduce the AI-driven VR Assistant (AVA) that can guide and assist patients in completing their prescribed rehabilitation exercises at home using their computer or smartphone. The web application containing AVA uses AI algorithms to analyze patients' movements and provide personalized real-time exercise feedback. By automating the rehabilitation process, AVA addresses the shortage of rehabilitation professionals and enables rehabilitation institutions and clinicians to serve more patients simultaneously. AVA does not require additional hardware, making it ubiquitous, accessible, and a significant step towards the development of equitable digital health solutions.

II. Methodology

The VR web application being developed consists of two dashboards: one for clinicians and one for patients. The clinician dashboard allows for the prescription of individualized exercise plans for patients. This includes selecting exercises from a database of cardiac and stroke rehabilitation exercises, as well as specifying the number of sets and repetitions for each exercise. To provide patients with guidance on proper exercise techniques, an animation file performing a single repetition of each exercise is created and stored in a database. To create the animation files, video recordings of clinicians completing exercises are processed using the MediaPipe deep-learning library [14]. This allows for the extraction of body-joint sequences from the videos, which are then converted to animation files that can be executed within the web application using the Three.js library [15]. The exercise animations can further be personalized for individual patients in terms of the range of motion of specific body parts as well as the speed of completing exercises. Notably, this approach does not require the use of motion capture wearables, instead relying on deep learning algorithms to capture motion directly from the videos.

Upon launching the patient dashboard of the web application, a VR session begins. The web application presents the patient with a live video of themselves captured by their computer or smartphone camera, accompanied by AVA, the animated avatar that continuously performs the prescribed exercises in prespecified numbers of sets and repetitions, see Figure 1. The patient follows AVA's lead and completes the exercises. The body joints of the patient are extracted in real-time from their video through the use of the MediaPipe library [14]. The sequences of body joints for each repetition of exercises are analyzed by spatiotemporal AI models on the cloud for exercise quality assessment [11]–[13]. In accordance

with the results of the exercise quality assessment, AVA provides guidance to the patient regarding the technique, range of motion, and speed of the exercise. Moreover, the patient is provided with textual and progress bar feedback regarding the correctness and completion of each repetition of exercises. The data analysis results pertaining to patients' performance during VR sessions are presented to clinicians in the clinician dashboard. This enables them to monitor the progress of patients and take necessary interventions such as modifying prescribed exercises, scheduling virtual meetings with patients via the web application, or calling in for an in-person assessment.

To conduct a co-design process, three upper-limb stroke rehabilitation exercises were recorded on video, specifically shoulder flexion, shoulder abduction, and elbow flexion-extension [16]. The videos were then transformed into animations using the pipeline described above. Five different characters, including a female, a male, two robots, and a gender-less character, were used for the animations. During a virtual session, the research team, which consisted of a stroke patient partner, a clinician, a health technologist, and two AI engineers, reviewed the animations in the web application.

Fig. 1. Following the animated avatar, the patient begins performing the prescribed exercises in front of the camera on their computer or mobile device. The web application extracts their body-joint data and transfers it to the cloud. The quality of exercise is measured by AI models in the cloud. Based on the measurements generated by the AI models, the patient receives textual and progress bar feedback, as well as feedback in the form of the animated avatar.

III. Results

According to the patient partner, the exercise animations were deemed helpful, engaging, and enjoyable to interact with. The avatar design was assessed through the co-design process, with emphasis on specific parameters, namely,

- Visible joint movements and muscle actions during targeted movements;
- Realistic and customizable background scenes for the avatar;
- AI-driven real-time visual feedback for error augmentation;
- Summative feedback with performance scores and progress reports;
- Avatar personalization with gender and ethnicity;
- Use of a responsive web application compatible with portable devices such as phones to increase accessibility;
- Patient familiarization with the exercises before discharge to facilitate self-management at home.

Research ethics board applications are being submitted by the research team in order to conduct focused group interviews and co-design activities in order to identify the most appropriate design choices and features for AVA.

IV. Conclusion

This paper introduced the unique features and the development of AVA, an AI-powered virtual avatar designed by our research team through a co-design process. The implementation of VR programs that incorporate avatars, such as AVA, offers a novel approach for individuals residing in the community to access rehabilitation services in their homes, thereby facilitating their recovery.

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Feasibility of computerized and immersive VR-based visuomotor integration assessment in a busy cerebral palsy clinical setting

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***Abstract*—Visuomotor integration (VMI) difficulties can impact activities of daily living in children with cerebral palsy (CP). Compared to paper-and-pencil assessments, both computerized, eye- and hand-tracking enabled, reach-to-touch interactions and immersive virtual reality (VR; viewed in a head-mounted display [HMD]) tasks may provide more ecologically valid VMI assessment methods. This study evaluated the implementation feasibility of a computerized reach-to-target touchscreen task and an immersive VR VMI assessment in 12 children with unilateral or bilateral CP in a busy clinic environment. Equipment was transported to the clinic by the researchers and set up in a small (6ft × 6ft) clinic room. In the computerized condition, data loss secondary to suboptimal screen-based eye tracker interactions limited implementation feasibility. In immersive VR, implementation was restricted by children's difficulty interacting with the virtual targets, as quantified by a high frequency of unsuccessful virtual object interaction attempts. Findings from this small, heterogeneous sample indicate that our method of computerized and immersive VR VMI assessment is not feasible outside of the laboratory. Results can inform subsequent studies exploring the use of technological-based assessments in typical clinic environments.**

Keywords: visuomotor integration, virtual reality, feasibility, children, cerebral palsy

I. Introduction

Children with cerebral palsy (CP) experience difficulties in visuomotor integration (VMI) that limit their participation in motor activities. VMI is defined as the ability to incorporate visual information with motor skills; it is crucial for everyday upper extremity activities such as reaching for or grasping objects. The Beery-Buktenica Developmental Test of Visual-Motor Integration (Beery VMI) [1] is the gold standard VMI assessment. Research studies using computerized flatscreen-based tasks that incorporate reaching to touch a target with eye- and hand-tracking can assess VMI. While providing more quantified precise information about eye and hand movement accuracy, flatscreen target display lacks ecological validity, leading to potentially different kinematic patterns during reaching as compared to reaching for real-world objects.

Commercially available immersive virtual reality (VR), viewed in a head-mounted display (HMD) with an embedded eye tracker, enables valid eye and hand movement (through controller tracking or VR glove wearing) data collection in a more ecologically valid testing environment. However, the use of an eye-tracking HMD in a busy clinical setting may be hindered by inadequate space for a cumbersome VR setup and children's lack of experience with immersive VR interactions. As such, the objective of this study was to evaluate the feasibility of VMI assessment using both a computerized touchscreen task and an immersive VR task in a busy pediatric CP clinic. Feasibility was evaluated using Bowen et al.'s [2] *implementation* construct, defined as the extent to which touchscreen-based and immersive VR assessments could be conducted in an uncontrolled, non-laboratory environment.

II. Methods

Twelve children with unilateral or bilateral CP (mean age = 10.33 ± 2.86, female = 9, Gross Motor Function Classification System levels I-IV, Manual Ability Classification System levels I-IV) participated in the study. Recruitment was undertaken by the CP clinic physician (AC). Exclusion criteria were limited to HMD contra-indications (age < 7 years; presence of an active seizure disorder). No participant had previous experience using immersive VR. The study took place in the CP Clinic at the Barbara Bush Children's Hospital, Maine Medical Center. The study team (MC and DL) transported all devices to the clinic and conducted testing over four clinic visits. The experiment space was 6ft by 6ft and included a non-adjustable desk and height-adjustable office chair. Participants' reaching arm length was measured to position the touchscreen within reaching distance and to determine touchscreen target positions to standardize viewing angles across participants. Participants completed the Beery VMI long-form (6th edition) [1] (mean standard score = 71.29 ± 14.29) and 3 VMI tasks in both a computerized touchscreen (2D) and immersive VR condition: 1) an eye-only task requiring eye movement to a target; 2) a hand-only task where participants kept their gaze fixated at the center while reaching to touch the target; and 3) an eye-hand task that required simultaneous looking and touching the target. Each task had twelve trials in which targets appeared in a random order in 2 target positions. Interaction attempts were quantified as the number of unsuccessful virtual object touches measured by kinematic

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hand tracking using a ManusVR glove and the HTC Vive Pro Eye HMD system (HTC, New Taipei, Taiwan). Average testing time, protocol completion rate, data quality (percentage of valid data in both touchscreen and VR conditions), and frequency of interaction attempts in VR were indicators of implementation feasibility. Participants were divided into two groups based on their Beery VMI score: below average VMI (Beery scores < 90, n = 4) and average/above average VMI (Beery scores >= 90, n = 8). Wilcoxon rank sum tests and Wilcoxon signed-rank tests were used to compare differences in each feasibility measure between and within Beery groups. Kendall rank correlations evaluated relationships between arm length and data quality in the touchscreen task and between the number of interaction attempts and the trial completion rate in immersive VR.

III. Results

Participants took an average of 2.1 hours (SD 27.6 minutes) to complete the study, longer than the planned 1 hour duration. The average completion rate of the entire protocol was only 67.25 % (SD 24.89%, range 29.17% - 100%); most participants did not complete all the immersive VR tasks. The mean trial completion rate in the touchscreen condition was 90.32% (SD 23.82%), while it was 88.75% (SD 27.38%) in VR. There were no differences in completion rate between Beery groups. Among completed trials, data was lost to poor eye-tracking data quality in both Beery groups. In the touchscreen condition, 73.21% (SD 26.3%) of the data were valid; the eye-hand task had the lowest percentage of valid data ($df = 2$, $p < 0.0001$). In VR, 95.44% (SD 6.33%) of data was valid; children with below-average Beery scores had lower percentage of valid data ($w = 542$, $p < 0.0001$). Across all tasks, there was more invalid data in touchscreen task as compared to in VR ($v = 747$, $p < 0.0001$). Poor data quality in the touchscreen condition was due to inability to adhere to the required minimum 0.5 m distance between the screen-mounted eye tracker and the participant; we had insufficient reach (short arm length) in six out of our twelve participants (mean = 0.51 ± 0.11m). A shorter arm length was positively correlated with lower data quality ($\tau = 0.235$, $p < 0.0001$).

Trials were removed from analysis when less than 85% of data were valid. **Figure 1** illustrates the percentage of trials retained for analysis in each task and condition. In immersive VR, children's movements were indicative of challenges in understanding how to perceive the depth position of targets in the virtual environment. Children made unsuccessful target touch attempts per trial in immersive VR in both the hand-only ($v = 60$, $p < 0.0001$) and eye-hand tasks ($v = 85$, $p = 0.038$). Children with below-average Beery scores made more unsuccessful target touch attempts ($w = 1102.5$, $p = 0.0004$). A higher frequency of unsuccessful virtual target touch attempts was correlated to lower completion rates in VR ($\tau = -0.22$, $p < 0.0001$).

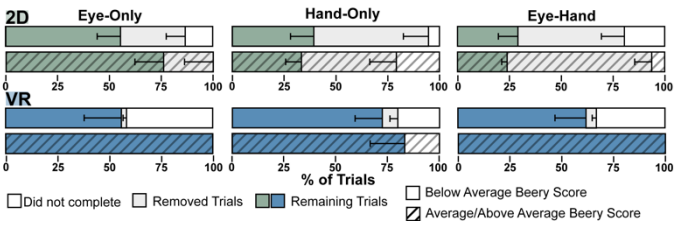

Fig. 1. Percentage of trials that retained and removed. Error bars denoted standard errors.

IV. Discussion

In this study, we endeavored to bring our laboratory-grade testing equipment to a pediatric CP clinic to facilitate recruitment accessibility and evaluate if assessment methods were feasible in this context. Because COVID shortened our our initial testing timeline, we widened our inclusion criteria, resulting in poorer data quality in the touchscreen task, principally because our participants were not able to maintain the required distance from the eye-tracker for it to work effectively. The testing environment also limited feasibility. In immersive VR, the HMD devices required a specific distance between lighthouses and the trackers, which was difficult to achieve in the small clinic room, and the lack of which impacted data quality. The time required to change the setup between the touchscreen and immersive VR conditions and resolve technological bugs made study completion time infeasible for participation during a typical clinic visit. Limited time (and lack of subjective reports of side-effects) also meant that we decided not to administer a planned VR simulator sickness questionnaire, thereby losing information relevant to implementation feasibility. Implementation of immersive VR in this population was affected by difficulties judging 3D position of virtual targets in virtual space, particularly for children with below average Beery VMI scores, due to altered visual perception of the size and distance of objects in immersive VR.

V. Conclusion

Findings from this small, heterogeneous sample do not support the feasibility of using VR for VMI assessment in this clinical setting, particularly for children who demonstrate VMI impairments. While immersive VR yielded higher data quality as compared to a touchscreen computerized task, implementation feasibility was limited by challenges with visuospatial target depth placement in the immersive VR environment. However, the study provides insights to inform subsequent work exploring how children with CP, particularly those with VMI impairments, interact with immersive virtual environments. Findings illustrate the importance of providing children with time to get acquainted with immersive VR and of further studying the mechanisms of interaction with non-haptic reach-to-touch tasks in this population.

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Body Coordination during Walking and Turning on an Omnidirectional Treadmill with Virtual Reality: Research Protocol

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***Abstract*—This study aims to investigate the impact of a self-paced omnidirectional treadmill with virtual reality on movement coordination and gait temporal-distance factors. Twenty healthy young adults (aged 18 to 29 years) will be assessed while walking and turning on an omnidirectional treadmill with and without virtual reality (VR) vs. overground without VR. Full-body kinematics and temporal distance factors will be recorded using the Xsens motion tracking system. Amplitudes and onset times of axial body segment reorientation in the horizontal plane and heading, as well as step length, cadence and step width will be compared across conditions. Results will provide insights into the impact of VR-based omnidirectional treadmill set-up on steering strategies, informing an eventual use in rehabilitation.**

Keywords — Locomotion, Movement Coordination, Omnidirectional Treadmill, Steering, Virtual Reality

I. BACKGROUD

The ability to change direction while walking (steering) is an important feature of independent community ambulation [1]. Locomotor steering was shown to be characterized by a stereotyped sequence of body segment reorientation in the new travel direction, starting with the eyes and head, followed by the trunk and the pelvis [2]. Horizontal eye and head movements were also shown to anticipate changes in the walking trajectory or heading [3], which could reflect a sensorimotor orienting mechanism allowing to steer towards the new travel direction [4].

The ability to steer can be altered by older age [5] and by neurological conditions such as stroke [6] or Parkinson's Disease [5]. This can in return compromise independent community walking [7] and lead to falls [8]. Enhancing the ability to perform locomotor adaptations such as steering while walking is thus an important component of locomotor rehabilitation.

Recent advancements in technology, such as self-paced omnidirectional treadmills (OMTs) with virtual reality (VR), have the potential to complement rehabilitation interventions for people with mobility disorders [9]. By allowing the performance of directional changes while walking, OMTs present a net advantage over unidirectional conventional treadmills, and they can be used to train complex locomotor tasks such as steering and circumventing obstacles. The addition of VR environments further allows to train individuals within safe, controlled and personalized conditions, while immersed in ecological scenarios simulating challenges representative of daily life locomotion. Lastly, OMTs allow to train complex locomotor tasks within a confined space, making it advantageous for clinical settings presenting space limitations or environmental barriers.

Despite the potential benefits of using OMTs combined with VR, it is still unclear how such set-up affects movement coordination in locomotor tasks such as steering. Understanding the influence of OMTs with VR on movement coordination is essential to determine their suitability for the evaluation and training of locomotion and to identify potential areas for improvement. Therefore, this study aims to address the following research question. "Among healthy young adults, to what extent does the use of an omnidirectional treadmill with virtual reality (OMTVR+) alter body segment coordination and gait temporal distance factors when turning while walking, in comparison to when executing the same task on the treadmill (OMTVR-) and overground (OGVR-) without VR?"

II. METHODOLOGY

A. Subjects

Prospective participants in this study are healthy young adults (aged 18 to 29 years) living in the Greater Montreal area. Twenty individuals free of any orthopedical, rheumatological or neurological conditions interfering with locomotion, with normal or corrected-to-normal visual acuity (EDTRS = LogMAR 0 or better (≥20/20)) [10] and intact cognition (Montreal Cognitive Assessment Score ≥ 26/30) [11] will be eligible to participate in this study. Participants will provide informed written consent prior to entering in the study. They will further receive a modest compensation to cover travel and parking expenses.

B. Procedures

The study involves a repeated measures design. Participants will be assessed over one session taking place at the Virtual Reality and Mobility Laboratory of the Jewish Rehabilitation Hospital, a research site of the Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR).

This study is funded by the Canadian Institutes of Health Research.

Fig. 1. Virtual environment representing the research laboratory. In this example, the green arrow on the TV display is indicating to turn right at the intersection formed by blue carpet runners.

Participants will be assessed while walking in three different conditions: (1) OMTVR+, (2) OMTVR- and (3) OGVR-. For the OMTVR+ condition, participant will be visualizing, in a head mounted display (HTC Vive Pro Eye, 110° of field of view), a virtual environment replicating the appearance and dimensions of the physical laboratory environment (**Figure 1**). For conditions involving the OT, participants will walk on the Infinadeck, a motorized treadmill providing a 360-degree moving surface [12].

In both the physical and virtual environments, 1-m wide carpet runners placed perpendicularly in a + shape configuration will delimitate the walkway, forming a 90° intersection located at 2.50 m of forward walking. As participant will walk on the walkway and reach 1m prior to the intersection, a large TV located in the far space will display an arrow signal indicating whether participants should turn 90° to the right (arrow pointing right), 90° to the left (arrow pointing left), or to continue walking straight ahead (arrow pointing up). Participants will perform 5 trials per direction, yielding a total of 45 trials for all three walking conditions. The order of the walking conditions and that of the walking directions will be randomized. Participants will habituate to walk on the treadmill without and then with VR prior to data collection, until they feel comfortable and reach a walking speed equivalent to their comfortable overground walking speed on the 10m Walk Test.

Full body kinematics will be recorded using an Xsens motion tracking system comprised of seventeen IMU sensors [13]. The main outcome of this study will be the amplitudes and onset times of segment reorientation in the horizontal plane for the head, thorax, pelvis, feet and heading. The secondary outcomes will include step length, step width and cadence. These outcomes will be compared across directions (straight, right, and left) and walking conditions (OMTVR+, OMTVR-, OGVR-) using generalized estimating equations.

III. Results

We expect to observe similar angular displacement amplitudes of body segments across walking conditions. However, the sequence of body segment and heading reorientation is expected to be more in phase (less dissociated) in the OMT conditions (OMTVR+ and OMTVR-) compared to the OGVR- condition. Moreover, similar but smaller differences in onset times of segment reorientation may be observed between the OMTVR+ and the OMTVR- condition, due to the presence of VR [14]. Furthermore, shorter step length and higher cadence, as previously reported when walking in a straight line on an OMT with or without VR [15] may further be observed in OMT conditions vs. overground. Altogether, those changes in axial body coordination and temporal-distance factors may reflect the use of a cautious steering strategy when walking on the OMT.

IV. Conclusion

This study represents the first investigation of its kind to examine the effects of an OMTVR+ set-up on locomotor steering strategies. Findings will inform on the suitability of such set-up for the purpose of evaluation and training of mobility disorders.

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Establishing Normative Ranges for Students Using NeuroFlex® - a Virtual Reality Based Software

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***Abstract*— This paper discusses the use of NeuroFlex® software, which is a Virtual Reality (VR) approach used to assess oculomotor function and record data from both head and eye responses. This provides valuable brain health-related metrics during the baseline assessment process that can then be used during assessment following a head injury in various settings. A total of 378 male students, ages 10-18 were baselined using NeuroFlex®, and normative ranges for each of the 61 NeuroFlex® metrics were calculated and established. This VR-based tool is essential in assessing overall brain health, and calculating age-specific normative ranges is important for identifying individual weaknesses and developmental issues. Recognizing and identifying outliers (especially those with lower performance) is key to supporting the development and brain health of individuals within a group. The software is useful in detecting outliers within a cohort that can then be used to establish tailored rehabilitation plans after head injuries as to optimize outcomes. This document demonstrates the usefulness of NeuroFlex® in establishing age-specific normative ranges that can be used to assess oculomotor function and ensuring the safe participation of youth in sports and in school settings.**

Keywords—oculomotor function, baseline, normative range, outlier

I. INTRODUCTION

Approximately 173,000 sport-related traumatic brain injuries were reported in the US between 2001 and 2009 for individuals 19 years old or younger, with two-thirds of this number consisting of youth 14 years old or younger [1]. Most of these head injuries (85%) presented with mild symptoms, that are often difficult to diagnose and, as a result, can be difficult to treat [2]. The lack of standard objective assessment and diagnostic tools makes concussion assessment and management challenging. Current assessments involve subjective analysis methods, and quantitative metrics on brain function are limited to tools that are inaccessible and time-consuming. To address these challenges, new tools that can assess a multitude of brain functions in a fast, accurate, and objective way are necessary, and establishing youth normative ranges is important for identifying group outliers, individual weaknesses, and/or developmental issues. The NeuroFlex® software, which uses a VR approach to provide a task and records data from both head and eye responses, was developed in this perspective. Here, we demonstrate that this tool can provide brain health-related metrics during both baseline assessment and following a head injury in a school setting. Normative ranges from baselining of a cohort participant's metrics can be used to assess oculomotor function and therefore brain health.

II. METHODS

A. Participants

A total of 378 male students, ages 10-18 were baselined using NeuroFlex®. Some students did not perform all protocols, with a minimum of 340 students analyzed for each metric. If a student had multiple baseline tests, the average value was used. Participants were healthy and without head traumas. Eligible students and parents provided written consent.

B. Instrumentation - *NeuroFlex® Protocols*

The NeuroFlex® software was used to assess subjects' eye and head movements. Eight protocols were performed using a portable VR headset and data analysis software:

1-2. Smooth pursuit (head free and head fixed)
3. 2D Saccades
4-5. Active Visual VOR (horizontal and vertical)
6. Optokinetic Nystagmus (OKN)
7. Antisaccades
8. Spontaneous Nystagmus

Visual stimuli were used to elicit eye-head coordination. The protocols took 8-10 minutes per subject and were administered by qualified personnel. Results were analyzed securely online and displayed in a dashboard. The technology is non-invasive and uses two infrared cameras to track eye position and a 3D accelerometer to track head/neck motion.

C. Analysis

Python 3.9 and relevant libraries (numpy, scipy, pandas, pingouin) were used for analyses of the 61 metrics. Descriptive statistics (mean, standard deviation, median, and skewness) were calculated. Skewness was used to determine the level of symmetry of the underlying distribution and to determine a proper analysis method. The following conditions were used to determine the most advantageous normative range calculation method:

1) For Metrics with Normal Distribution:

$$95\%\ CI = \bar{x} \pm \sigma * 2 \quad (1)$$

2) For Metrics with Skewed Distribution:

$$\text{Lower Quartile Range} = Q1 - 1.5 * IQR \quad (2)$$

$$\text{Upper Quartile Range} = Q3 + 1.5 * IQR \quad (3)$$

Where $\bar{x}$ is the sample mean, σ is the standard deviation, Q1 is the lower quartile (25%), Q3 is the upper quartile (75%), and IQR is the Interquartile Range.

III. RESULTS

Normative ranges were computed for each of the 61 NeuroFlex® metrics reported. Table 1 below reports the

analysis for the 2D Saccade protocol. The remainder of the analysis for the other 7 protocols, can be made available upon request.

TABLE I. DESCRIPTIVE STATISTICS , NORMATIVE RANGES, AND ANALYSIS METHOD USED FOR THE SACCADES PROTOCOL

	Skewness	Mean	SD	Median	Min Range	Max Range	Method Used	Number of Students
Mean Vergence (deg)	-3.9	-0.3	2.3	-0.1	-2.7	2.5	IQR	378
Vergence SD (deg)	4.1	1.5	1.3	1.1	0	2.3	IQR	378
Acquisition Error (deg)	5.4	3.2	2.3	2.6	0	5.8	IQR	378
Mean Latency (ms)	3.0	239.6	40.7	231.2	0	313	IQR	378

Students with mean vergence values below -2.7 degrees or above 2.5 degrees should be flagged as outliers. By assessing Figure 1 visually, it is evident that there are participants (as represented by the blue dots in both figures) that lie outside of the calculated student normative ranges.

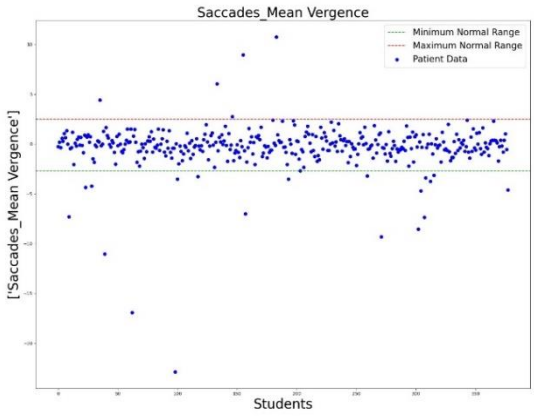

Fig. 1. Individual students' Saccades – Mean Vergence values compared to the minimum normal range (green) and the maximum normal range (red).

IV. DISCUSSION

Oculomotor function can be used to assess overall brain health, along with age specific normative ranges that can be used to identify weaknesses or developmental issues. Oculomotor function is not only a reflection of brain health but also critical in ensuring an individual's capacity to safely navigate their environment such as while participating in sports. Neurological maturity is an important factor to consider when establishing age-specific normative ranges because most of the nervous system continues to develop up until adulthood. This means that the areas of the brain activated during eye-head coordination are not fully mature during adolescence. Moreover, symptoms of abnormal oculomotor function will present differently across individuals, ranging from purely physical, cognitive, behavioral, and emotional, or as a combination of any/all these symptoms. Abnormal oculomotor function can be caused by various factors like a concussion, ear canal infection, tumors, drug use, etc. Baseline testing measures the brain's oculomotor function in a healthy state, enabling healthcare providers to determine the subject's normal state. This is vital in assessing brain health after injuries like concussions. Baselining allows for the comparison of a post-injury evaluation to the individual's baseline and assists in creating tailored rehabilitation plans to restore initial measures. Baseline assessments also help compare individuals to cohort-specific normative ranges, detecting outliers and catching any issues early on. There are 4 types of weak oculomotor metrics to consider when looking for outliers:

1. Weak results at baseline (outlier)
2. Deviations from population norms after a head impact
3. Deviations from personal baseline after a head impact
4. Deviations from personal baseline without impact

THE IMPORTANCE OF RECOGNIZING 'OUTLIERS'

An *outlier* is a test result outside the healthy population norm of a similar age group. Within a healthy population, some individuals may perform below/above the expected range, as shown in Figure 1. Recognizing the outliers in a group is key to supporting the development and health of individuals within the group. Figure 1 demonstrates that following baseline testing, some individuals lie outside of the normative ranges. Although all the baselined students were considered healthy, there are some students outside of the normative ranges. Outliers may be less capable of viewing the world accurately and are at greater risk of concussions and musculoskeletal injuries. In an academic context, academic performance may be compromised if the weakness affects focus in the classroom. Identifying these weaknesses allows clinicians, teachers, and parents to address the issue and provide the appropriate resources/care. This will prevent worsening of symptoms, and the potential for long term effect to impact their quality of life, and academic performance.

V. CONCLUSION

Results showed that using the proposed analysis methods, outliers can be identified within a cohort even when baselining subjects who had all been deemed to be healthy, highlighting the importance of establishing cohort-specific normative ranges. We demonstrated the importance and need for research aimed at establishing brain health normative ranges for youth in order to prevent and better manage head injuries. We showed that NeuroFlex® can be used as a fast and objective VR tool to assist clinicians with managing brain health.

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Split-belt treadmill training to rehabilitate freezing of gait and balance in Parkinson's Disease

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***Abstract*— Split-belt treadmill (SB-TM) training has been proposed to improve gait symmetry and overall gait performance of patients with Parkinson's disease (PD). To assess the rehabilitation potential of this intervention, we have designed a prospective, double-blind, parallel-group randomized control trial with 3-month follow up to test the efficacy of SB-TM training compared to conventional treadmill training to improve gait parameters and reduce falls in PD.**

Keywords— Parkinson's disease; Gait; Adaptation; Split-Belt treadmill

I. Introduction

Parkinson's disease (PD) related gait and balance disorders are challenging to treat because they cannot be optimized with pharmacological intervention alone. This treatment gap is important to address because gait asymmetry and incoordination are associated with increased falls in this population, which can be functionally debilitating and lead to increased morbidity and mortality.[1-3]Freezing of gait (FOG) has also been associated with reduced quality of life independent of its association with impaired mobility.[4,5] Gait disorders therefore represent an unmet need in the treatment of PD.

Physiotherapy with treadmill training is a means to address the limitations of pharmacotherapy in this population. Treadmill training increases stride length, lowers cadence and improves foot clearance; long-term treadmill training results in clinically improved gait velocity and postural stability.[4] The advent of SB-TM training can further optimize the gait instability that arises from asymmetric pathology in this population.[6] The SB-TM has 2 belts, which can either move in unison (tied) or at different speeds (split), and it has been effective in restoring symmetrical gait in the stroke population, with gait adaptation effects retained for up to 3 months.[7,8] The motor symptoms in PD develop asymmetrically, with the burden of symptoms often lateralizing to one side, so the SB-TM offers a unique opportunity to modulate spatial and temporal gait parameters to study gait adaptation in the PD population.

This method of rehabilitation can therefore be used to treat a range of gait abnormalities and previous research has demonstrated the ability to restore symmetrical gait and reduced falls for up to 3 months in the stroke population.[9] A preliminary study from our lab in individuals with PD and FOG demonstrated that velocity reduction by 25% on the least affected side resulted in a more symmetric and coordinated gait after 10 minutes of SB-TM training.[10]

II. Materials and Methods

A. Study Design

The proposed study is a prospective, parallel-group randomized control trial with 3-month follow up to test the efficacy of SB-TM training to improve gait parameters and reduce falls in PD patients. The study cohort will include patients with PD (n=28), divided into the intervention group for 18 sessions of SB-TM training and the control group for 18 sessions of tied-treadmill (TM) training (where belts move at the same speed) over 6 weeks. The velocity of the belt will be adjusted to the overground speed of the subject and will be reduced on the least affected side by 25% in the SB-TM group. We will employ virtual reality technology to mimic natural gait as closely as possible in a simulated setting (Figure 1). This is achieved with the Grail system (Motek, Netherlands), which accommodates the SB-TM and 10-camera motion tracking (Vicon, UK). The virtual scene is synchronized with the SB-TM and data is captured at 100Hz via D-Flow (v.3.34, Motek).

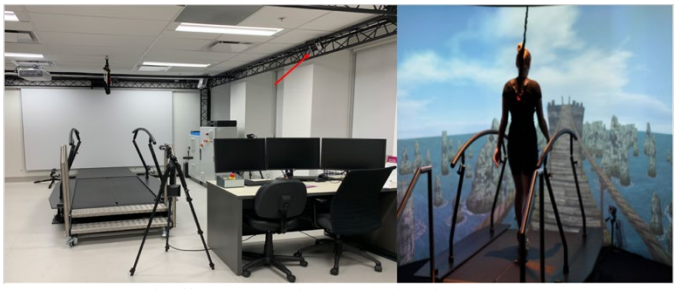

Figure 1: Treadmill training with the virtual reality system. **Left:** The gait lab, featuring the SB-TM (Grail systems®, by Motek, Netherlands) and virtual reality screen **Right:** Simulation of a subject walking on the SBTM, while attached to a harness to prevent falls.

The primary outcome measure will be the incidence of falls for 3 months after completing treadmill training. Fall rate will be analyzed by calculating relative risk using negative binomial regression models that adjust for any potential confounders.[18, 19] To demonstrate superiority of the SB-TM training over conventional TM training we will set an a priori threshold of an additional 30% reduction in fall rate. Secondary objectives include comparison of treadmill gait parameters with over-ground walking, quality of life questionnaires and assessment

of motor scores in PD. This project has been approved by our institution's ethics board.

B. Outcome measures

Figure 2 summarizes the study design and procedures. At the time of recruitment, patients will be consented and will complete a series of questionnaires including: 1) Balance and postural stability, measured by the Activities-specific Balance Confidence (ABC) scale 2) Freezing of gait, measured by the New Freezing of Gait Questionnaire (NFOGQ) 3) Health-related quality of life (PDQ-39). The Unified PD rating scale will also be administered in its entirety. During the 3 months leading up to the training period, patients will document their falls using a standardized falls calendar. The training will be preceded by an assessment of over-ground gait parameters using the Zeno walkway® gait mat (*Protokinetics, USA*), followed by 6 weeks of training depending on the group they are randomized to. Following their last training session, gait will be re-assessed using a gait mat. Patients will continue to document falls during this training period as well as in the 3 months prior to the final follow-up. Questionnaires and the UPDRS will be repeated at the final visit.

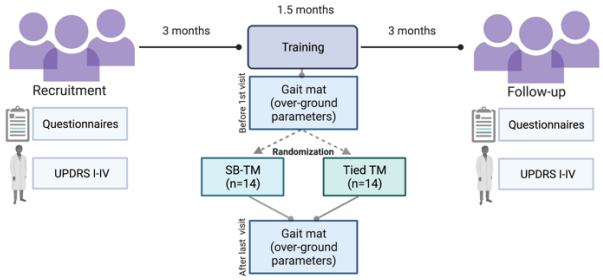

Figure 2: Overview of study design and procedures.

C. Statistics

This will be conducted on an intention-to-treat principle using all participants who complete randomization. Demographic characteristics and baseline data will be summarized by descriptive statistics (i.e., means, standard deviations and 95% confidence intervals for continuous variables, median and inter-quartile ranges for non-normal continuous ordinal data and percentages for categorical data), and will be evaluated for normalcy and homogeneity. Fall rate will be analyzed by calculating relative risk using negative binomial regression models that adjust for any potential confounders. The secondary outcome measures will be analyzed using repeated measures analysis of variance (ANOVA) to assess differences between the intervention and the active control groups, and across the endpoints of the assessments. All analyses will be adjusted for multiple comparisons. Based on a recent treadmill trial,[11] to demonstrate superiority of the SB-TM training over conventional TM training we set an a priori threshold of an additional 30% reduction in fall rate.

D. Hypotheses

1) SB-TM is superior to TM training in improving response time and ability to adapt to gait asymmetry, and therefore improves FOG in patients with PD. **2)** The after-effect from SB-TM training is reproducible to over-ground walking **3)** Younger PD patients with shorter disease duration and no cognitive impairment are more likely to adapt to gait manipulations from the SB-TM, and demonstrate prolonged after-effects **4)** SBTM improves the quality of life in PD with FOG

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A study on satisfaction of VR-based social reintegration program experience for persons with disabilities

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***Abstract*—This study investigated the satisfaction of individuals with disabilities (PWDs) participating in VR-based social reintegration programs for rehabilitation. The study included 29 participants, primarily stroke survivors (26 participants), along with one traumatic brain injury and two cerebral palsy cases. The VR program offered three types of experiences: floor-type VR, wall-type VR, and immersive VR using a head-mounted display, allowing participants to virtually engage in daily activities such as fishing, cooking, farming, and sports. The satisfaction survey questionnaire assessed participants' experiences across five components: environment, instructor, program time, overall satisfaction, and re-participation intention, using a 5-point Likert scale. The average satisfaction scores were 4.8, 4.9, 4.7, 4.8, and 4.7 for environment, instructors, time, satisfaction, and re-participation intention, respectively. These promising results can guide future VR content development, as the technology shows potential for motivation and rehabilitation effects in PWDs.**

Keywords—Disability, Social Reintegration, Rehabilitation, Virtual Reality

I. BACKGROUD

Virtual Reality (VR) is a technology beginning to occupy an important position in the area of rehabilitation treatment, especially for persons with disabilities (PWDs) who wish to return to their home and society. However, study on the VR technology used in rehabilitation programs for PWDs' social reintegration is lacking. This study aimed to investigate their experiences of satisfaction with VR-based social reintegration programs, so that it may provide the supporting data for the needs of VR programs in rehabilitation treatments for PWDs.

II. MEHODOLOGY

A. Participants

This study was conducted over a three-month from September to December 2022 at the National Rehabilitation Center, Ministry of Health and Welfare, South Korea. Twenty-nine participants (26 stroke, 1 traumatic brain injury, 2 cerebral palsy) were included. All participants were understood of the purpose and procedures of the study and signed an informed consent.

B. Environment

The VR program room was a 150-meter square area (10m X 15m) in the National Rehabilitation Center.

C. VR system

This VR system contain hardware, software, and assistive devices.

1) *Hardware:* PC (intel, windows 10), monitor (27-inch, HD, 1920X1080), projector (MC-CX301E, Maxell, Japan), motion recognition cameras, HMD, controller, and screen.

2) *Software*: To operate the VR system, rehabilitation and training software (Rehabware, Techvillege, South Korea). The VR program consisted of three VR types (floor-type VR, wall-type VR, and immersive VR using a head-mount display (HMD) for virtually conducting such daily activities as fishing, making food, growing crops, and playing sports).

3) *Accessaries*: Various props for using VR simulation (e.g. reflective basket, bean bags, etc)

D. Procedures of VR-based social reintegrated program

Participants attended the VR program once a week for 30 minutes per session. For at least one month. During the VR program, participants used 3 types of VR program for about 10 to 15 minutes each, depending on their personal preferences (Fig. 1).

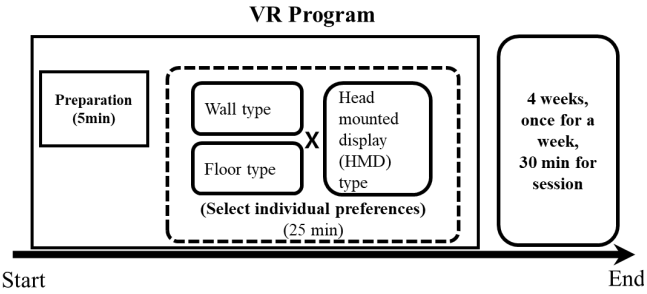

Fig 1. Virtual reality program

E. Satisfaction

The satisfaction survey questionnaire included items about the participants' experiences of VR program considering the five components; environment, instructor, program time, overall satisfaction with the program, and re-participation intention.

A 5-point Likert scale was used for each question (5-very dissatisfied, 4-somewhat dissatisfied, 3-neither satisfied nor dissatisfied, 2-somewhat satisfied, 1-very satisfied). Moreover, we asked of the motivation for participation (Table I).

TABLE I. PROGRAM MOTIVATION AND SATISFACTION QUESTIONNAIRE

Motivation						
What motivated you to participate in the program?						
① I thought it would help me improve my skills						
② I thought it would help me with my life and socialization after discharge from the hospital						
③ To relieve my boredom with hospitalization						
④ Recommended by my social worker						
⑤ Others						
Satisfaction						
	Categories	Very Satis-fied	Satis-fied	Mode rately	Dissa-tisfied	Very dissa-tisfied
1	Environment (Location, facilities, cleanliness, etc)					
2	Instructors (Professionalism, delivery, etc)					
3	Program time					
4	Overall satisfaction					
	Categories	Stron gly agree	Agree	Neutr al	Disag ree	Stron gly disagr ee
5	Re-participation					

Floor-type VR Wall-type VR Immersive VR(HMD)

Fig. 2. Tree-types of VR program.

F. Analysis

Descriptive statistics (mean, standard deviation) were used to evaluate general characteristics (sex, disability type, ages) of participants and satisfaction on a Likert scale for each of the five items. All statistical analysis was conducted SPSS 22.0 (IBM, California, USA).

III. RESULTS

A. General characteristics of participants

The details of the participants' age, gender, and disability type are shown in Table II.

TABLE II. GENERAL CHARACTERISTICS OF PARTICIPANTS

	Participants (n=29), Number (%)
Sex	
Male	23 (79%)
Female	6 (21%)
Ages	
10s	1 (3%)
20s	0 (0%)
30s	6 (21%)
40s	1 (3%)
50s	8 (28%)
60s	4 (14%)
70s	8 (28%)
80s	1 (3%)
Disability type	
Stroke	26 (90%)
Cerebral palsy	2 (7%)
Traumatic brain injury	1 (3%)

B. Satisfaction

The averages of the satisfaction survey were 4.8, 4.9, 4.7, 4.8, and 4.7 for environment, instructors, time, satisfaction, and re-participation intention, respectively.

As motivation for participating in the program, 20 (69%) individuals thought it would help improve rehabilitation treatment, followed by seven (24%) individuals who participated the program simply because of the boredom of hospitalization. Additionally, two (7%) individuals seemed to find it helpful for their personal and social life after hospital discharge and returning to society. Therefore, VR-based programs can be useful as rehabilitation programs for social reintegration.

Fig 3. Results of VR program satisfaction

IV. CONCLUSION

The satisfaction survey results on the VR-based social reintegration program showed that regardless of the environment, instructor, program time, overall satisfaction, and re-participation intention were all high. The results can be used for future VR content development because its motivative and rehabilitative effects seem to be promising. Moreover, the introduction of various types of VR programs and high-quality VR programs was suggested. Further studies are needed to develop VR programs for PWDs.

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User-centered Development and Validation of Virtual Reality Tasks to Enhance Driving Skills of Older Adults Using Motorized Mobility Scooters.

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Abstract—*Approximately 108,00 Canadians employ a motorized mobility scooter (MMS) for their mobility needs. MMS facilitate community participation and an independent lifestyle. Training is needed for users to benefit from a MMS, while avoiding accidents and injuries. However, very few MMS users receive formal training. One potential method to teach these strategies is through a virtual reality (VR) simulator. Our team has previous experience in the development and validation of low-cost simulators for manual and power wheelchairs, which we now wish to apply to MMS tasks. Objective 1: evaluating the experience of participants involved in the user-centered development of VR tasks. A team consisting of a MMS user, an occupational therapist, a VR specialist and researchers co-developed a first VR task for MMS training, through an iterative process. Experience with respect to roles, expectations and outcomes were gathered from individual interviews. Objective 2: validation of the developed VR tasks. MMS users and clinicians tested the task and were then interviewed about their experience on the system's usability. This study will allow the development and improvement of VR tasks based on the needs of MMS users. We hope to then elaborate a new MMS training program, combining both VR and real tasks.*

Keywords— motorized mobility scooter, virtual reality, virtual reality, simulator, usability (*key words****)***

I. Introduction

Older adults with mobility impairments can benefit from assistive devices such as motorized mobility scooters (MMS). In Canada, an estimated 108,000 mobility scooter users have been reported [1]. A review by Mortenson et al. [2] has concluded that MMS can potentially facilitate an independent lifestyle for their owners, help them maintain a degree of participation in the community and improve their quality of life. Driving a MMS, however, is not without risk, as it can lead to injury to self, to others or damage to the environment [3]. Proper training is likely needed, for users to benefit as much as possible from a MMS while avoiding accidents and injuries. There is, however, a lack of formal training programs for older MMS users [2]. In recent work [4], we interviewed 25 expert MMS users, aged 50 to 90, and 25 clinicians to determine which activities are difficult for new users who are learning to drive. Participants described challenges related to activities, such as handling slopes and street-crossing; personal factors, such as anxiety and impulsivity; and environmental context, such as narrow sidewalks, inadequate surfaces, and weather conditions. They also highlighted the need for training. One potential approach to safely train older MMS users in learning appropriate driving strategies is through virtual reality (VR). Indeed, our team has acquired extensive expertise in the development and evaluation of VR simulators for power and manual wheelchairs [5]. Our simulator is low-cost and portable, as it runs on an ordinary computer. Participants train using different scenarios that have been developed based on a need analysis (e.g., entering an elevator, street crossing, grocery shopping in a supermarket, etc.) [5]. Training in the simulator (power wheelchair version) was effective in improving wheelchair skills [5]. We now wish to extend this approach to MMS skills training. The general aim of this project was to design the VR tasks for the MMS simulator, through a user-centered development (UCD) process. Specifically, our objectives for this study were to: **1)** evaluate the experience of participants in the UCD of VR tasks for the MMS simulator; and **2)** validate the content and acceptance of these tasks.

II. METHOD

For the first objective (Evaluation of UCD process) and to facilitate acceptance, perceived usefulness and ease of use of the technology by end-users, we used a UCD approach defined as an iterative process involving the user throughout design and development [6]. Our development team consisted of one older MMS user, one occupational therapist (OT), one VR developer, 1 postdoctoral fellow and two researchers. Team meetings were held to iteratively create detailed use-case scenarios for a first task. Results from our previously completed interviews of older MMS users and clinicians, as well as earlier work on mobility objectives of older adults, provided material for these team meetings. Once the use-case scenario was completed, the task was created by the VR developer. This was followed by a second iterative process, where the team members tested the tasks, provided feedback to the VR developer who will then made the necessary adjustments. Initial interviews of all team members were conducted before the start of the UCD process, to obtain feedback on a priori expectations regarding objectives, roles, contributions and outcomes. Meeting notes and email exchanges between team members were also collected. A content analysis was performed on the data. For the second objective (Validation of VR tasks), we recruited 12 MMS users (age>55) and 8 clinicians (at least 2 years of experience with MMS services). A sample size >18 provides a 85% probability of identifying issues affecting 10% of users [7]. After a familiarization period, they tried all tasks; their comments during practice were recorded, using a "think aloud" approach. Participants then assessed the usability of the MMS simulator. As outcome, we employed the questionnaire *UTAUT* [8]. Participants were also asked to provide explanations for their answers. We calculated the means for each item as well as the overall mean. We also identified themes in the participants' comments and answers to the open-ended questions through a content analysis.

III. RESULTS

The initial expectations of the team members were to integrate existing knowledge about the topic, to develop and test the VR scenario, and to have open and useful team meetings that would make a real difference. The requirements the team viewed as essential for developing the VR scenario were that it should: provide consistent learning, focus on skills requiring practice, and provide graded complexity. A grocery store scene was prioritized and developed with tasks categorized into four levels: 1) appropriation; 2) narrow aisle and static obstacles; 3) narrow alley and dynamic obstacles; and 4) picking up an object from a height. The MMS user, the OT and a researcher tested the simulator which led to 57 comments divided into different themes: environment of the supermarket, objects, characters, manipulation of the MMS, tasks, gradation of difficulty, technical problems and suggestions for improvement. These tests also revealed that the *UTAUT* had several questions that were not applicable. This led to the selection of another tool for usability testing, the *USEQ* [9]. For the validation of the supermarket scenario, all participants were able to use the simulator successfully despite having different technological expertise. Some participants completed the entire task within one hour. All participants expressed enjoyment and were able to operate the simulator with either the keyboard or a video game controller regardless of their disabilities. All participants experienced some collisions, which highlighted that the distance ratio between the MMS and the objects needs to be improved. An average of 23 was obtained with the USEQ (fairly good satisfaction) for OTs and 23.9 for MMS users. Among OTs, the simulator was seen as a potential complement to the evaluation for obtaining a MMS and as an interesting training modality for people with cognitive and perceptual difficulties. The presence of a steering wheel similar to that of a MMS would have been appreciated and relevant for learning the skills of driving. With respect to perceived usefulness (Q6 - USEQ), an average of 3.3 out of 5 was obtained among MMS users. Some would have liked to have had the simulator during their rehabilitation, others did not see the value of training to drive a MMS.

IV. CONCLUSION

The virtual reality MMS simulator has the potential to be useful in rehabilitation with certain modifications (e.g., steering wheel) and certain users, but the criteria for identifying these potential users have yet to be determined. Offered in a cross-platform version (e.g. Windows, Mac, web browser), it could be an additional tool for professionals who recommend the use of a MMS to increase the training rate and consequently contribute to reduce the risks of accidents.

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Age effects on Performance and brain Engagement during simulation of an internet-based shopping task

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***Abstract*— The aim of the present study was to compare young and older adults' performance (behavioral and brain engagement) of a simulation of an internet-based shopping task in two levels of difficulty. The older adults' performance was significantly worse on behavioral outcomes only (e.g., accuracy) pointing to possible deficits in executive functions required to perform this functional activity.**

Keywords—shopping task, simulation, executive functions, age

I. INTRODUCTION

To achieve optimal daily functioning in the digital age, one is required to use the computer and Internet for daily activities such as shopping. To carry out an internet-based shopping task independently, a variety of cognitive abilities are needed such as executive functions and attention. Those abilities are known to deteriorate during the aging process [1, 2]. One of the brain areas that is linked to the control of attention and executive functions is the prefrontal cortex [3]. Previous studies show that as the level of a cognitive task difficulty increases, older adults tend to perform less accurately compared to young adults [4] and demonstrate higher prefrontal activity, [5] usually indicating compromised brain efficiency. To better capture executive functions deficits, a functional task that requires a combination of cognitive process, such as a shopping task, should be used [6]. A simulation of an internet-based shopping task can offer an ecologically valid assessment of executive functions while maintaining standardization of the task and providing accurate outcome measures. Moreover, extracting electrophysiological markers for attention as a measurement of engagement, using a simple Electroencephalography (EEG) headset can expand our understanding of task performance [7] particularly for complex functional cognitive tasks, essential for independent daily functioning, such as online shopping. Therefore, the aim of the current work is to compare patterns of performance and engagement between young and older adults while performing a simulation of an online shopping task.

II. METHODS

A. Participants

Twenty young (30.1±3.7 years) and 20 older adults (69.3± 3.0 years) with no underlying neurological conditions were recruited. All participants were independent in instrumental activities of daily living (IADL's), including shopping and computer use according to a self-report questionnaire.

B. Tools

The 6-Item Tablet Test (6ITT) (Fig. 1) was based on the 4-Item Tablet Test (4ITT) developed by Sigal Portnoy, Debbie Rand, Sivan Keidar from Tel Aviv University and Rachel Kizony from University of Haifa & Tel Aviv University. The task simulates an internet-based shopping task based on the virtual reality task described in [6]. The user was asked to purchase six items from different categories while keeping a certain budget. In the easier task the user could pop-up the shopping list whereas in the more difficult task the user had to remember the shipping list thus adding cognitive load to the task. Behavioral outcome measures included total time to complete the task, time till purchase of the first item, number of correct items purchased, number of mistakes and staying on budget.

The Cognitive Effort Index (CEI) (Brainmarc, Israel) is a measure of attentive engagement during task performance which uses a single channel EEG system (NeuroSky MindWave) [7] (Fig.1). The single electrode was placed on the prefrontal area and the reference electrode was placed on the earlobe [8]. The CEI is calculated based on Delta waves and ranges between 0-1 divided to three levels: 0-0.33=low; 0.3-0.66- effective and 0.67-1= high (CEI User Manual. Shahaf, 2020). In the current study the CEI mean value and percent of time where CEI was out of the effective range were used. Lower level of CEI may indicate an attention deficit [9] or too easy or too difficult task [7].

Montreal Cognitive Assessment (MoCA) [10] was used to screen for cognitive abilities with a score range between 0-30.

Trail Making Test A and B (TMT A and B) [11] were used to measure visual search (TMT A) and executive functions (TMT B). Time to complete each was used.

III. Results

Significant differences were found between the groups in task performance of the more difficult task in several behavioral measures: the older adults bought less correct items (Z=-2.68 p=0.001) and made more mistakes (Z=-2.1 p=0.03). Time until buying the first item was found to be longer among the older adults (Z=-3.54 p=0.00) (Table 1). Within the groups, significant differences were found between the task's levels of difficulty only among the young group and only in behavioral measures: the total time to complete the task at the high level of difficulty was longer (Z=-2.07 p=0.05) and likewise the time until buying the first item (Z=-3.64 p = 0.01). In the attention marker, no significant differences were found neither between the groups nor between the difficulty levels of the task. In further analysis, significant correlations were found between performance in TMT B and MoCA and behavioral measures of the shopping task, among both groups but mainly in the older group (r_s = 0.47-0.73, p<0.05) indicating that better cognition and executive functions are associated with better performance of the shopping task.

IV. Conclusions

The current study contributes to the existing knowledge of age-dependent changes in executive abilities while using a simulation of an internet-based shopping task. The shopping task at the high level of difficulty was sensitive enough to demonstrate age-related behavioral differences among healthy individuals, and should be further examined as a therapeutic and/or assessment tool in clinical populations. Understanding the brain mechanisms that accompany the performance of patients in meaningful functional tasks may contribute and guide the planning of effective intervention programs as well as reflect the implications of cognitive deficits to the patient and his family. In accordance with the current study's results, future studies should examine these mechanisms with other systems and longer daily tasks. In addition, we are currently examining the feasibility of using this task as a remote assessment to be used in telerehabilitation services.

TABLE I. PERFORMANCE ON THE DIFFICULT SIX ITEMS TABLET TASK

	Older Median (Intequartile range)	Younger Median (Interquartile range)
Correct Items	5.0 (2.0)	6.0 (1.0)
Errors	1.0 (1.0)	0 (0.75)
Time to 1st item- s	8.5 (3.75	5.0 (3.0)
	Mean (standard deviation)	Mean (standard deviation)
CEI (mean)	0.32 (0.08)	0.29 (0.08)
CEI (% in range)	47.26 (30.65)	45.08 (32.26)

Fig. 1. Six Items Tablet Task (right) and EEG headset NeuroSky MindWave (left)

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LogVS: Developing an affordable and user-friendly virtual reality platform to study, assess and train different aspects of locomotor navigation

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***Abstract*— Virtual reality (VR) shows promise for research in the area of locomotor navigation. However, VR platforms often lack a social environmental context involving pedestrian interactions and goal-oriented locomotor adaptations over ground. The present work describes the early development of an affordable, mobile VR platform involving over ground walking within a park with pedestrians, to study, assess and train different aspects of locomotor navigation. Focus groups with clinicians assessed the perceived clinical needs regarding the assessment and treatment of locomotor navigational skills and acceptability of such a platform. This revealed that there is a significant clinical need for standardized tools for locomotor navigation for neurological rehabilitation. However, clinicians pointed that the platform could benefit from added complexity to the scenarios. Finally, the criterion validity and test-retest reliability of the data on position and orientation extracted from the standalone head mounted display provide a promising direction for future research and development of a VR platform for locomotor navigation in social environmental contexts.**

Keywords— Mobility, Gait, Executive Functioning, Social Cognition, Rehabilitation

I. Introduction

The degree of one's independence in daily activities is largely influenced by their cognitive (attention, planning) and physical (locomotor, balance) abilities, which are crucial for maneuvering through the complex environments of daily life. However, the challenges associated with creating rich, ecological environments while ensuring user safety and standardization of measures limits controlled study and assessment of, as well as interventions for, community walking abilities. Virtual reality (VR) has the potential to overcome these limitations while also being highly motivating and engaging [1] as well as personalized to the client needs.

Yet, the use of VR in rehabilitation remains low due to several barriers such as cost, time and space [2]. Moreover, rehabilitation professionals tend not to use VR tools made available to them if they do not meet the clients' needs and expectations in terms of content, customization, and control over situations [3]. Currently, VR is mostly limited to laboratory settings and often inadequately represents real-world cognitive and physical demands, with restricted over ground walking areas or use of treadmill walking [4]. Being able to walk over ground with and without walking aids over larger areas would open new possibilities for VR research and clinical applications. However, locomotion assessment and training also require getting accurate position and orientation to assure the quality of the data collected.

The main aim of the present work was to describe the early development of a VR platform to offer over ground locomotor navigation within a large space with a social context. Another aim was to probe perceived clinical needs and acceptability of the VR platform as identified by rehabilitation professionals. Finally, the criterion validity and test-retest reliability of the standalone head mounted display (HMD) used for the platform were measured.

II. Development of the prototype of the VR platform

The new VR platform focused on over ground navigation within a social environmental context over a larger area and was named the Large Over Ground Virtual Suite (LogVS). A focus of LogVS is to provide affordable, mobile technology with a user-friendly and flexible interface. Thus, in the first stage of development, the low cost, popular, standalone, wireless Meta Quest 2 (Menlo Park, USA) HMD was chosen. The LogVS virtual environment (VE) involves a park with surrounding road environment programmed with the UnReal Gaming Engine (Epic Games, USA). The platform can be used in any large space such as a gymnasium or a drill hall of a military base.

To simulate pedestrian behaviour, virtual pedestrians (VP) were programmed (MetaHuman), to either remain stationary within the environment (Static condition) or walk towards the user (Dynamic condition). During the latter, the VP can walk at a constant velocity along a straight line, change direction at a

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controlled angle and position, or physically interact with the participant by reacting to their movements and blocking their path for a predetermined period before crossing. These socially contextualized conditions provide multiple levels of complexity in trajectory planning, which progressively taxes executive functioning [5].

Finally, a user interface has been developed for computer, tablet or smartphone to control environmental conditions and data collection from the HMD. On-line communication between the interface and the HMD is achieved using an autonomous Wi-Fi link. Data of the orientation angle, and linear position of the user and virtual pedestrian can be exported from the HMD for further analysis.

III. Perceived clinical needs and clinician acceptability

Two moderated focus groups (60 min each) comprising the same 6 clinicians working with neurological clients (physiotherapists, occupational therapists, neuropsychologists), were conducted virtually. The focus groups aimed at determining current clinical needs and gathering clinician feedback regarding the potential of LogVS to address these needs. A qualitative content analysis was completed by 2 independent evaluators (AC and JB).

Clinicians indicated that they target components of locomotor navigation in their assessments and interventions, but they rarely evaluate or train directly locomotor navigation due to its complexity. However, they expressed the need for easy access to diverse, ecological, and secure environments that can be modified according to the patients' abilities to assess and train locomotor navigational skills. They highlighted that the current version of LogVS would be most beneficial for patients with hemineglect or patients with cognitive issues related to attention, dual-tasking, distraction, and planning, as well as for those with balance deficits. To optimize the platform's usefulness, they recommended the addition of visual distractors (such as people, animals, and balloons), dual-tasking, more obstacles to avoid, surface changes, and social interactions (emotional expression of virtual pedestrians, conversations with virtual pedestrians, and queues). Moreover, the clinicians suggested that the VR walking space could be even larger and include pre-designed scenarios. They also recommended adding an option for participants to see their own body and walking aids in the virtual environment. Overall, the findings suggest that LogVS holds significant potential as a tool for cognitive and motor rehabilitation, and further developments in line with the clinicians' recommendations could increase its applicability and acceptability in clinic, although some suggestions may make the platform more complex (e.g., adding an avatar of the person).

IV. Criterion validity and relaibility of the HMD

In contrast with many previous models, the Oculus Quest 2 (OQ2; now called Meta Quest 2) is a standalone HDM. The OQ2 uses Inside-Out technology with four camera, an Inertial Measurement Unit and algorithms to calculate its position and rotation [6]. This provides a cheaper and an easier option compared to traditional VR headsets which require computers and external tracking devices. To date, the psychometric properties of OQ2 data has only been tested in static conditions and short distances [7]. Here, a static condition was recorded (10 trials) while the HMD was placed in a 3D-printed plastic support fixed on a stationary tripod, as previously reported [7]. In addition, dynamic conditions involved walking at a comfortable speed along four different trajectories of approximately 15 m (10 trials). The extracted OQ2 data were compared to data from a Vicon (Oxford, UK) motion capture system (90 Hz) as a gold standard using 4 non-collinear, retro-reflective markers attached to the front of the OQ2.

The criterion validity data during the static condition showed interesting results with mean errors of around 1cm and 1° along all axes. However, during the dynamic conditions, the quality of the localization measurements dropped, and we observed mean errors around 4 cm and 4° (Sd $\simeq$ 3cm and 3°). Nevertheless, the OQ2 test-retest reliability was measured with less than 2 cm maximum error.

V. Conclusion

In conclusion, the LogVS platform offers a novel way to study, assess and train locomotor navigation in large areas over ground with affordable, mobile equipment and a user-friendly interface. Development and testing continue with the goal of making LogVS open source.

Acknowledgements

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ISVR

INTERNATIONAL SOCIETY FOR VIRTUAL REHABILITATION

Oral Session 2

Personalization of virtual rehabilitation

11:15 to 12:45

July 24th, 2023

Towards personalized Immersive VR neurorehabilitation: A human-centered design

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***Abstract*—Head-mounted displays can be used to offer personalized immersive virtual reality training for patients who suffered an Acquired Brain Injury (ABI) by tailoring the complexity of visual and auditory stimuli to the patient's cognitive capabilities. However, it is still an open question how these virtual environments should be designed. We utilized a human-centered design approach to help define the characteristics of suitable training environments for patients who suffered from a stroke. We conducted observations, interviews with eleven experts (e.g., occupational- and physical therapists), and an online questionnaire with 24 neurorehabilitation experts to examine how therapists modify the training environment in order to optimize patients' recovery in conventional neurorehabilitation. Participants reported that modulating the number of elements (e.g., objects, people) or distractions (e.g., background noise) in the training environment enables therapists to provide their patients with suitable conditions to execute functional tasks. Results from this study provide valuable insights into modulating the training environment in immersive virtual reality.**

Keywords—stroke, neurorehabilitation, interviews, observations

I. INTRODUCTION

Stroke affects a large number of people each year (approximately 12.2 million) and can result in death or debilitating motor and/or cognitive impairments [1]. Neurorehabilitation is crucial for people who have suffered an Acquired Brain Injury (ABI) to regain functional independence. In rehabilitation centers, patients are involved in therapy sessions, supported by different professionals (e.g., occupational therapists, speech therapists, physical therapists, nurses, neuropsychologists, and rehabilitation physicians), and train activities of everyday living, such as walking and dressing, personal hygiene, and cooking. Such activities are trained in groups or individually within the rehabilitation center in areas such as gyms, corridors, and stairs, or in outdoor spaces like buses and supermarkets. Although training environments should stimulate patients by promoting social, cognitive, and physical activity, exposure to many stimuli during training might negatively influence the re-learning of functional tasks, especially among patients with cognitive impairments [2].

To allow therapists to minimize the risks of overwhelming patients' cognitive input, Immersive Virtual Reality could potentially be used as a tool that can be tailored to the individual's specific needs and abilities [3]. Immersive Virtual Reality using Head-Mounted Displays can have added value for use in conventional therapy [4]. Compared to conventional VR using computer screens, this technology can be tailored to the patient's needs and rehabilitation goals; for example, adjusting the characteristics of the virtual environment might allow patients to practice in cognitively engaging environments that do not exceed their cognitive capabilities.

This paper reports the results of three research activities, based on human-centered design [5], aimed at defining the characteristics of suitable training environments for patients suffering from a stroke as a first step toward the development of immersive virtual training environments. Specifically, we conducted *observations* [6][7] and *semi-structured interviews* [8] with stroke experts, such as physical- and occupational therapists, to understand the rehabilitation journey of individuals who suffered a stroke and the factors influencing the training of patients during conventional neurorehabilitation. We then conducted an *online questionnaire* to verify our observations, thereby identifying the strategies therapists adopt to create suitable training environments.

II. METHODOLOGY

The study was approved by the Human Research Ethics Committee of the Delft University of Technology.

A. Observations

The first author spent approximately 192 hours at *Rijndam Rehabilitation Centre* (Rotterdam, The Netherlands) observing therapist-patient interactions, the training environments, and the steps characterizing the inpatient rehabilitation experience to understand how the treatment is tailored to each individual's specific needs and goals. The observation period began with the researcher introducing himself and the goal of the activity to the different teams at the rehabilitation center.

We used two observation techniques, *Fly-on-the-wall* and *Shadowing*, and recorded our findings using field notes. Fly-on-the-wall is a technique used to collect data and gain insight into people, environments, interactions, and objects without interfering with the participants [6]. In this case, observations were made while sitting in silence inside training rooms, seeing and listening to therapists and patients. Shadowing involves researchers following a member of an organization closely for an extended period. This allows in-depth observation of the user's behavior and experiences [7], e.g., during meetings, training sessions, etc.

B. Semi-structured interviews

After the observations, we conducted *semi-structured interviews* with eleven rehabilitation experts from Rijndam, i.e., three physical therapists, two occupational therapists, one speech therapist, one rehabilitation physician, one nurse, one

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neuropsychologist, one psychologist, and one researcher. The participants included seven females and four males, with an average of 8.18 years (SD = 6.26) of professional experience in the field of their expertise. Participants received a document containing detailed information about the study, including Informed Consent, which they signed before the interview started. They were given a week to ask questions or withdraw their participation. Two interviews were conducted online, and nine were in person. Interviews were conducted individually and had an average duration of 49 minutes. Audio from the interviews was recorded using a recording device. The interviews were held in English and began with a small introduction of the activity and the experimenter, followed by open-ended questions on six topics, including roles and responsibilities, treatment design, training, and patients' challenges.

The interview data were transcribed and processed using thematic analysis [9] using Atlas.ti 22. The thematic analysis focused on the question of what strategies therapists adopt to create a suitable training environment for patients.

C. Online questionnaire

To verify our observations, we asked rehabilitation experts to participate in an *online questionnaire*. The questionnaire consisted of 22 statements derived from the previous research activities. Each statement represents a strategy that therapists seem to adopt to create suitable training environments for patients with different cognitive capabilities. Eleven Dutch rehabilitation institutes were contacted via email and invited to share a link to the questionnaire with their employees. The questionnaire was offered in Dutch. Respondents were asked to express their degree of agreement on the statements using a Likert scale, from 1 (strongly agree) to 5 (strongly disagree). Finally, they were given space to leave comments in the open-ended question section.

Twenty-four respondents (18 from Rijndam and 6 from other Dutch institutions) fully completed the questionnaire: seven occupational therapists, six physical therapists, four speech therapists, two nurses, one rehabilitation physician, one neuropsychologist, one social worker, one researcher, and one dietitian. There were twenty-one females and three males, with an average of 14.04 years (SD = 10.01) of professional experience in their field.

III. Results

A. Observations

Field notes from the *Fly-on-the-wall* and *Shadowing* activities together with learning from the related literature research resulted in a *journey map*, which is a graphic representation of an individual's process to accomplish a goal [10]. The map illustrates the recovery process of an inpatient stroke survivor in a rehabilitation center (Fig. 1). The different phases of the journey map describe the environment and the interactions among therapists, family members, and patients that allow for accomplishing specific goals (e.g., collecting patient data) and the provision of tailored treatment (e.g., adapting the physical environment to the patient's capabilities). Once a phase is completed, patients move to the next phase. We identified five treatment phases (Fig. 1). During the *screening* phase, patient data (e.g., demographics, social, and clinical data) is collected in preparation for further clinical visits. The *planning* phase involves collaboration among rehabilitation experts, patients, and families to define short- and long-term goals related to daily activities. The *training* phase focuses on individual or group sessions where patients train their paretic limbs and cognitive functions under therapists' guidance. Activities, such as preparing a meal or dressing, are deconstructed into small tasks allowing patients to reconstruct a lost ability. During this phase, the environment, tasks, activities, and therapist's attitudes are adapted based on the input of the rehabilitation team. Assessment and training tools (e.g., questionnaires, robotic devices, and virtual reality) are used to track and improve therapy outcomes. Moreover, therapists emotionally support patients ensuring they maintain high motivation. The *reflecting* phase involves therapists sitting with patients to reflect on their performances and set new goals. This allows patients to become aware of their motor-cognitive capabilities and accept their restrictions. The final phase is *discharging*, which marks the end of inpatient care and the beginning of outpatient rehabilitation. The identified treatment phases were found to be aligned with the literature, which presented four phases: assessment, goal setting, interventions, and evaluation [11].

Overall, observations allowed us to understand better the role of therapists and the training environment in helping patients recover from their function loss. A multidisciplinary team works synergically to promote and maximize recovery. They deliver treatments tailored to the individual's needs and prevent patients from getting overwhelmed by information that exceeds their cognitive resources during training.

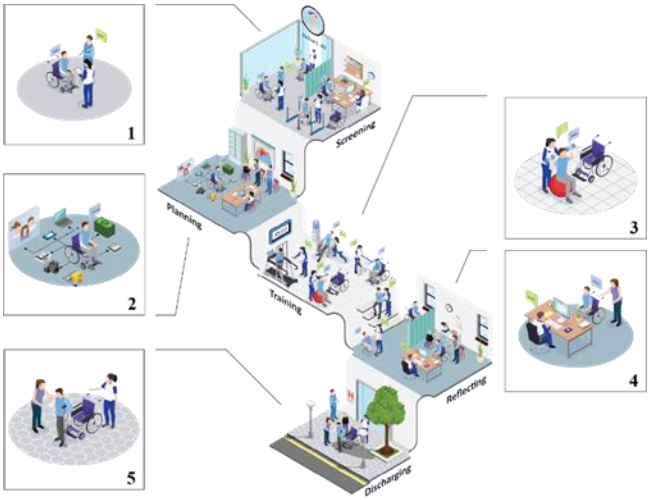

Fig. 1. The inpatient journey map, including the five treatment phases: (1) Screening, (2) Planning, (3) Training, (4) Reflecting, and (5) Discharging.

B. Semi-structured interviews

The thematic analysis identified six themes (and forty sub-themes) describing the quality of the training environments. The definitions of the themes were iterated by the authors in order to define them in a more precise fashion. The theme *Specific* refers to the patient's characteristics (e.g., clinical needs and goals, social circumstances, personality) that therapists should consider when preparing the training environment. *Authentic*

refers to real-life conditions. Training environments should not be decontextualized, inappropriate, and misleading since they could demotivate patients. *Versatile* relates to the different stimuli that should be manipulated in the training environment to facilitate functional task execution (e.g., secondary tasks, sounds, group or individual sessions, distance of people and objects from the patient, etc.). *Pedagogical* involves education and awareness, e.g., training environments should allow patients to make mistakes and reflect and learn from them. *Safe* refers to training in an environment where patients can make mistakes without the risk of injury or experiencing unnecessary stress. *Supportive* relates to motivation and the physical and verbal support given by therapists to patients. These themes led to the definition of *twenty-two statements* reporting the strategies therapists seem to adopt in conventional neurorehabilitation to create suitable training environments, which were subsequently incorporated into an online questionnaire.

C. Online questionnaire

Table I shows the mean ratings for the 22 questionnaire items, together with their corresponding themes. Overall, the therapists agreed strongly that the training environment should be adapted to the cognitive abilities and social environment of the patient (Items 1 & 4). For instance, training environments should consider whether patients lack a support system once discharged or have limited resources to adapt their homes to their conditions. Additionally, choosing between error-free learning or learning from mistakes (Item 5) and modulating the realism or richness/distractions of the task (e.g., Items 2, 12 & 14) were generally agreed-upon approaches. Motivational techniques (Item 16) and co-deciding with the patient and family were also regarded as relevant (Items 3 & 19). Relatively low ratings, but still on the 'agree' side, were provided for more specific pedagogical techniques, including the use of mirrors (Item 6) and video (Item 7), and the constraining of movements (Items 15 & 22).

TABLE I. THERAPISTS' AGREEMENT WITH STATEMENTS REGARDING THE MODULATION OF THE TRAINING ENVIRONMENT, FROM 1 (STRONGLY AGREE) TO 5 (STRONGLY DISAGREE).

No	*Theme*	*Statements*	*M (SD)*
4	Supp.	During therapy, therapists should **adjust the levels of interaction** with their patients, depending on their cognitive capacities, to improve motor learning.	1.13 (0.34)
1	Spec.	In the preparation of the training environment, therapists **should take into account the physiological and psychological capacities** of the individual patient, **with understanding for their social circumstances**.	1.17 (0.48)
5	Pedag.	During therapy, therapists should **choose between learning through mistakes and errorless learning strategies** to improve motor learning, depending on the cognitive capacities of the patient.	1.38 (0.82)
14	Auth.	During therapy, therapists should **adapt the realism of a task** to the cognitive capacities of the patient to improve motor learning.	1.42 (0.65)
2	Vers.	During therapy, therapists must **adjust the environment** to the progress and recovery goals of the patient.	1.46 (0.59)
11	Vers.	During therapy, therapists should, depending on patients' cognitive capacities, **choose whether to place patients in large and crowded rooms** (group sessions) **or small and isolated rooms** (1-on-1 sessions) to improve motor learning.	1.46 (0.59)
18	Supp.	During therapy, therapists should **choose from verbal, gesture, or written instructions**, adapted to the cognitive capacities of the patient to improve motor learning.	1.50 (0.78)
16	Supp.	During therapy, therapists should **give patients motivating feedback**, depending on their cognitive capacities, to improve motor learning.	1.50 (1.02)
12	Vers.	During therapy, therapists should **adjust the exposure to background noise or unintended sounds** according to the cognitive capacities of the patient, to improve motor learning.	1.67 (0.76)
20	Vers.	During therapy, therapists should choose to **give patients secondary tasks**, depending on their cognitive capacities, to improve motor learning.	1.75 (0.79)
8	Auth.	During therapy, therapists should **introduce familiar elements or mimic familiar conditions** to train patients' motor functions, depending on their cognitive capacities.	1.79 (0.59)
3	Safe	During therapy, **therapists and patients should decide together** whether they want to change the training environment, depending on their cognitive capacities to improve motor learning.	1.88 (0.90)
19	Supp.	During therapy, therapists should **involve the patient's family members**, depending on the cognitive capacities of the patient, to improve motor learning.	1.88 (1.03)
10	Auth.	During therapy, therapists should **provide patients with work-specific tools** - depending on their cognitive capacities to improve motor learning.	1.96 (0.81)
13	Vers.	During therapy, therapists should **modulate the direction of light and intensity**, depending on the cognitive capacities of the patient, to improve motor learning.	2.13 (0.85)
9	Auth.	During therapy, therapists should choose to **expose patients to conditions typical of a city or village** - depending on where they live - to improve motor learning, depending on their cognitive capacities.	2.17 (0.82)
17	Safe	During therapy, therapists should **influence patients' stress levels**, depending on their cognitive abilities, to improve motor learning.	2.17 (0.92)
21	Supp.	During therapy, therapists should **let patients communicate with other people**, depending on their cognitive capacities to improve motor learning.	2.17 (1.01)
22	Pedag.	During therapy, therapists should choose to **restrict the movements of the patient's less affected arm** to train the more affected arm, depending on their cognitive capacities to improve motor learning.	2.33 (0.87)
6	Pedag.	During therapy, therapists should **adapt the use of mirrors**, allowing patients to watch their movements to improve motor learning, depending on the cognitive capacities of the patient.	2.33 (1.05)
15	Spec.	During therapy, therapists should **choose between unilateral or bimanual exercises**, depending on the cognitive capacities of the patient to improve motor learning.	2.50 (1.14)
7	Pedag.	During therapy, therapists should **use video recordings of previous training sessions** with patients, depending on their cognitive capacities, to improve motor learning.	2.67 (0.96)

[a.] The authors added the boldface text for clarity, but it was not part of the original questionnaire. Also, for brevity, the authors removed some text (e.g., explanations of the level of realism) in Items 2, 4, 6, 8, 10, 12, 13, 14, 17, and 20.

IV. Conclusion

We utilized a human-centered design approach [5] to define the characteristics of suitable training environments for patients suffering from a stroke, as the basis for creating virtual training environments that would suit users with different cognitive capabilities. According to the so-called Double Diamond Model, the human-centered design process is divided into four phases: Discover, Define, Develop, and Deliver [12]. This paper engaged in the first two phases. To discover and define the characteristics of suitable training environments in neurorehabilitation, we conducted observations and semi-structured interviews. We then conducted an online questionnaire to verify our observations.

In this study, we visualized the inpatient journey from the start, through the training process, until discharge. We observed that, during training, therapists make use of larger and rich environments or move their patients to smaller, less crowded conditions with less sensory input depending on the patient's cognitive capabilities. Visual and auditory stimuli, and physical and verbal interactions are some of the elements or distractors that therapists manipulate in the training environment. While the National Clinical Guideline for Stroke (2016) provides recommendations on how to reduce the cognitive demands of people with impaired attention after a stroke, the types of elements or distractors practitioners can modulate are not detailed [13]. This study provides an overview of different types of modulation, elements, and distractors to adopt in conventional rehabilitation. Yet, our study only included 24 healthcare professionals. Insights from more therapists working in different rehabilitation centers and countries could allow us to determine if they have similar insights and which steps are uniform and which ones are unique. For instance, the type of patient bedrooms and furniture seems to influence the ability to provide care [14]. Therefore, therapists from other rehabilitation centers could use different strategies.

In light of our results, it is possible to base the design of virtual immersive training environments on what therapists do in conventional rehabilitation. For example, severely cognitively impaired patients could be exposed to fewer auditory and visual stimuli, while less severely impaired patients could practice in virtual training rooms that gradually change to noisier and crowded spaces (Fig. 2). Engaging in the last two phases of the Double Diamond Model, namely Develop and Deliver, will allow us to explore potential solutions and reach effective virtual training environments. We plan to further involve stakeholders in *co-creation sessions* to generate new ideas for training in immersive virtual worlds, and to test a prototype. Furthermore, it would be relevant to survey patients with different experience levels of cognitive capabilities who underwent the recovery process from beginning to end, and, with the support of rehabilitation experts, investigate the problems experienced and moments that were experienced as (un)comfortable. This could elucidate the factors affecting motivation during training, revealing further directions to create solutions that match patients' specific needs.

The question of how virtual training environments for rehabilitation should be personalized to each patient is an open discussion. However, patients might benefit from the re-learning of functional tasks targeting only the specific challenges they will face once at their homes. Therefore, future possibilities could include finding cost-effective ways to personalize virtual training environments to allow patients to practice their paretic limbs in virtual environments mimicking selected challenges.

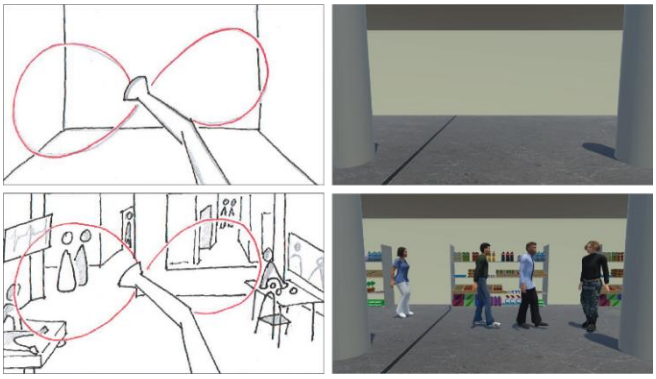

Fig. 2. Sketches and renderings of an empty and crowded virtual training environment.

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Impact of affective and environmental factors on children's motor skill transfer from virtual to physical environments

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***Abstract*—Motion-controlled virtual reality (VR) systems are potential motor learning interventions in pediatric rehabilitation. However, more evidence for transfer of learning from VR to the real world is needed. Using a novel postural reaching task, this study evaluated the impact of affective (i.e., motivation, engagement, and cognitive workload) and environmental (i.e., non-immersive VR [2D], immersive VR [3D], or a physical environment [PE]) factors on acquisition, retention, and transfer to an unpracticed real-world task. Twenty-eight typically developing children aged 8-13 years acquired the skill in 1 of 3 environments (2D, 3D, or PE) and completed affect questionnaires. They returned for retention trials in the same acquisition condition; transfer trials in the opposite condition (i.e., PE to 2D/3D VR, and 2D/3D VR to PE); and transfer trials in an unpracticed real-world postural reaching task. Mixed effect models evaluated the impact of affective and environmental factors on performance in each session. In 3D VR, children reported higher motivation, engagement, and lower cognitive workload and demonstrated higher performance at the end of acquisition. However, there were no between-condition performance differences in retention, transfer, or real-world transfer. Subsequent research should further explore the impact of differing perception-action affordances in 2D and 3D VR on skill transfer.**

Keywords: virtual reality, motor learning, motor skill transfer, motivation, engagement, children

I. Introduction

Motion-controlled virtual reality (VR) games are used in pediatric motor rehabilitation to improve upper limb function [1], motor coordination [2], and postural control [3]. Performance gains have been demonstrated after task practice in both non-immersive [4] and immersive head-mounted display (HMD) VR [5] in pediatric populations. The potential advantages of VR for rehabilitation include enhanced individualized parameter control and precise data collection, enabling standardized treatment protocols, motivating task-oriented repetitive training [6], and possible home-based practice [1]. However, evidence of motor skill transfer from skills acquired in virtual environments to real-world tasks in children is still inconclusive [4].

Affective factors such as an individual's level of motivation, engagement, and cognitive workload may impact motor learning [7]. Enhanced motivation and engagement can directly support motor learning by improving dopaminergic mechanisms and may indirectly support rehabilitation goals by increasing practice dosage [8][9]. A higher level of engagement can also increase information processing [10], reducing cognitive workload and improving learning [11]. Enriched audiovisual features in non-immersive VR have been shown to enhance motivation and engagement and improve motor skill acquisition and retention in healthy young adults [12]. Compared to non-immersive VR, immersive VR may provide a higher-level immersion (i.e., an illusion of reality) and presence (i.e., a psychological feeling of "being there") that could further enhance motivation and engagement [13].

The specificity of the practice hypothesis states that practice conditions should resemble real-world conditions [14]. Non-immersive VR lacks depth cues and may involve indirect interactions via hand-held controllers that lead to a different perception-action affordance as compared to real-world interactions [15]. Immersive VR may offer more intuitive gesture and object interactions [16], but perception-action affordances in immersive VR differ from the real-world [17]. Visual information displayed in immersive VR may activate different processing areas in the brain and require a higher load on visual networks for visual cognition [18][19]. Immersive VR interaction also lacks the haptic feedback essential for perception-action relationships, impacting visuomotor coordination [20]. A greater understanding of the interplay of both affective and technological/environmental characteristics during motor skill acquisition may provide insights into the mechanisms associated with motor learning in virtual environments.

The purpose of this study was to evaluate the affective and environmental factors that may impact VR motor skill learning, transfer, and transfer to a real-world context. Our objectives were to:

1. Compare novel motor skill acquisition and retention in a motorically-equivalent immersive VR, non-immersive VR, and physical (non-VR) environment.
2. Describe between-condition differences in self-reported motivation, engagement, and cognitive workload.
3. Evaluate the impact of affective and environmental factors on between-condition transfer and transfer to a similar but unpracticed real-world task.

This work was supported by the Charles H. Hood Foundation Child Health Grant Research Program.

II. Methods

A. Study Design

Comparative, repeated-measures design.

B. Setting

Rehabilitation Games and Virtual Reality (ReGame-VR) Laboratory at Northeastern University. The study was approved by the Northeastern University Institutional Review Board.

C. Participants

Typically developing children aged 8-13 years were recruited to participate in the study. Exclusion criteria were cognitive impairments that would interfere with task comprehension and physical or neurological conditions that prevented participation in minimal exercise.

D. Task

A novel postural reach-to-target task was used across a non-immersive VR (2D), an immersive VR (3D), a physical environment (PE), and a real-world condition. **Figure 1** illustrates the experimental setup. When a virtual target appeared (in 2D and 3D) or lit up on the board (in PE), children standing on a force plate needed 'unlock' the target by shifting weight medially, laterally, anteriorly, or posteriorly to a specific center of pressure position located between 100 and 110% of their predetermined limits of stability. The target would turn green when the correct center of pressure position was found, children then need to hold on to that position while reaching to touch the target as quickly as possible. Each target required a different amount of center of pressure displacement and would disappear when either successfully unlock and touched or after ten seconds if unsuccessful. A trial consisted of a random sequence of five targets appearing in one of six predetermined locations (1 trial = 5 targets). In the real-world condition, children needed to shift their weight and grasp one of the objects from the wardrobe based on the instruction displayed on the monitor and place it in the correct target area.

An HTC Vive Pro (HTC, New Taipei, Taiwan) HMD was used in the 3D condition, where hand interaction was enabled via a Manus VR glove (Manus Meta, Geldrop, Netherlands). A Stability and Balance Learning Environment (STABLE; Motek Medical, Netherlands) was used for the 2D condition. Hand position was tracked by motion capture cameras (Vicon Motion Systems Ltd., Centennial, CO) with a reflective marker attached to a hand-held "wand". The PE condition was controlled by an Arduino Mega and a customized Matlab script. Pressure sensors (Adafruit, New York, NY) were placed in the target area of the wardrobe in the real-world setup to assess the accuracy of object placement. The center of pressure was tracked using the STABLE integrated force plate in 2D; the same Wii Fit board (Nintendo Co. Ltd., Kyoto, Japan) was used for tracking the center of pressure for 3D, PE, and real-world conditions.

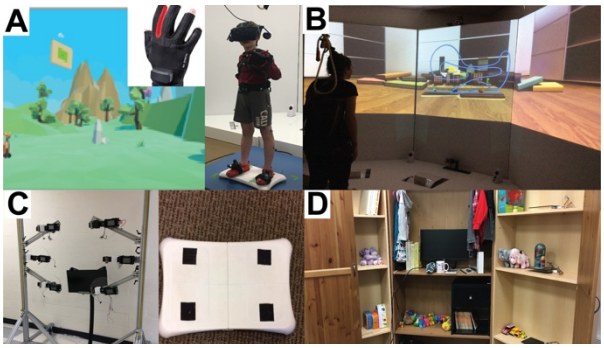

Fig 1. *A-D:* Experimental setup in 2D, 3D, PE, and the real-world.

E. Experimental procedure

Children undertook a short postural control baseline test (including static stance, base of support, and limits of stability) on the STABLE to familiarize themselves with weight-shifting on a force plate. Children then were randomly assigned to one of the acquisition conditions (40 practice trials, each with 5 targets). After the acquisition session, children completed the Intrinsic Motivation Inventory [21], User Engagement Scale [22], and the NASA Task Load Index [23]. Children returned 2-7 days after acquisition for a session that included retention in the same condition (10 trials); transfer to the opposite environment (10 trials; children in both VR conditions performed in the PE, while children who acquired the task in the PE were randomized to either the 2D or 3D condition), and 6 trials of a real-world transfer task involving reaching to pick up and place objects in an instrumented wardrobe.

F. Statistical analyses

Analyses were conducted using R (v. 4.0.2). For each trial, the average raw performance score was converted to a z-score. A z-score of zero represents mean performance. Self-reported motivation, engagement, and cognitive workload were compared among acquisition conditions and among sessions using ANOVA followed by Tukey-adjusted post hoc tests. Changes in performance scores across trials in each session and in different acquisition-transfer conditions were assessed using mixed effects models. A set of models were generated based on explanatory variables (i.e., trial, condition, and self-reported data) and interaction between these effects. A reduced set of variables was selected to prevent overfitting and determine the most important effects based on Akaike's Information Criterion (AIC). Pair-wise differences between conditions were examined using Tukey-adjusted post-hoc comparisons of estimated marginal means.

III. Results

A. Participant demographics

Twenty-eight children participated in the study (mean age = 9.93 ± 1.49 years, female = 11).

B. *Objective 1: Compare novel motor skill acquisition and retention in a motorically-equivalent immersive VR, non-immersive VR, and physical (non-VR) environment.*

Table 1 provides the mean and standard deviation of z-scores in each acquisition-transfer condition during each session. **Figure 2** illustrates the overall performance of all

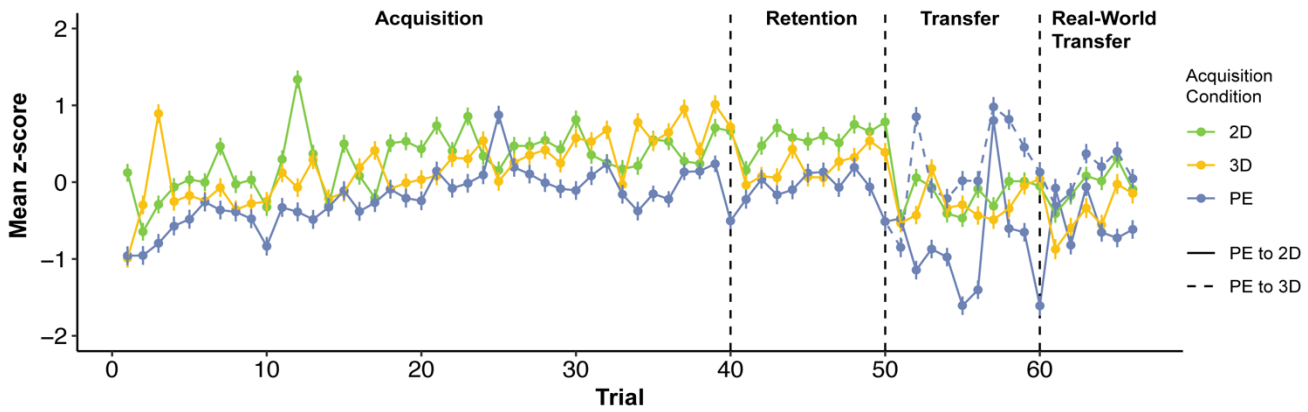

Fig 2. Mean z-core by acquisition-transfer condition across all sessions. Error bars used the standard deviation of the trial-to-trial differences.

children across all sessions. All children improved performance during the acquisition session (t = 3.502, p = 0.0005), while children in the 3D condition demonstrated the largest improvement during acquisition (t = 2.028, p = 0.043 estimate (3D) = 0.012). Children in the PE condition had the lowest scores throughout the acquisition session (t = -1.942, p = 0.060). Similar trends were also found in the retention session. All children improved their performance (t = -1.446, p = 0.036). Children in the PE condition had the lowest score but did not achieve significance (t = 1.950, p = 0.052) and had the slowest improvement (t = -2.554, p = 0.011, estimate (PE) = -0.074).

TABLE I. MEAN AND SD OF Z-SCORES IN EACH SESSION.

Acquisition		**Retention**		**Transfer**		**Real-world**
Condition	***z-score***	***Condition***	***z-score***	***Condition***	***z-score***	***z-score***
3D (n = 11)	0.145 (1.085)	3D (n = 11)	0.241 (0.660)	PE (n = 11)	-0.187 (0.841)	-0.441 (0.771)
2D (n = 8)	0.174 (1.034)	2D (n = 8)	0.503 (0.600)	PE (n = 8)	-0.301 (0.860)	-0.039 (0.773)
PE (n = 9)	-0.313 (0.960)	PE (n = 9)	-0.062 (1.022)	2D (n = 2)	-0.814 (1.185)	-0.493 (0.384)
				3D (n = 7)	0.212 (1.377)	0.095 (0.612)

C. Objective 2: Describe between-condition differences in self-reported motivation, engagement, and cognitive workload.

Figure 3 illustrates each self-report measure for each acquisition condition. Children in the 3D condition reported the highest motivation (F(2, 20) = 0.041, p = 0.049), highest engagement (F(2, 21) = 0.445, p = 0.064), and lowest cognitive workload (F(2, 22) = 0.214, p = 0.081) but did not achieve significance during the acquisition session, while children in the PE condition reported the lowest motivation and engagement.

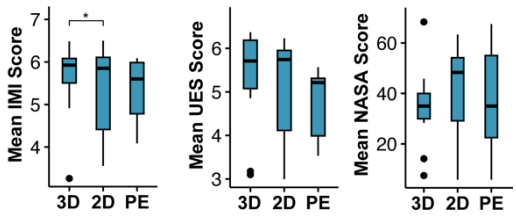

Fig 3. Self-reported motivation, engagement, and cognitive workload scores by acquisition condition.

During the acquisition session, higher motivation was associated with higher task performance (t = -2.179, p = 0.041). Higher engagement was associated with higher task performance but did not achieve significance (t = -1.953, p = 0.063). There was no relationship between cognitive workload scores and task performance during the acquisition session. No relationships between affect measures post-acquisition and task performance in the retention session.

D. Objective 3: Evaluate the impact of affective and environmental factors on between-condition transfer and transfer to a similar but unpracticed real-world task.

Children in each condition improved their performance within the cross-condition transfer session (t = 2.171, p = 0.027) and most of the children improved their performance during the real-world transfer as well (t = 2.509, p = 0.014). However, children who transferred from PE to 2D had the lowest cross-condition transfer performance (t = 2.157, p = 0.003), and the poorest real-world transfer performance (t = -2.260, p = 0.026). There were no significant relationships between affective factors and task performance during close transfer (opposite condition) or transfer to the real world.

IV. DISCUSSION

Aligned with previous studies, motor skill acquisition was enhanced in VR, especially in 3D VR as compared to in a physical environment [5][24][25]. Similar to previous findings [8], children self-reported higher motivation in VR conditions due to the richness of audiovisual features in VR. The more elevated motivation in immersive VR may be due to the higher level of immersion and presence created by the HMD and hand tracking, which allows children to perform the reaching movement with the same kinematic and accuracy requirement as in the real world but in an immersive and enriched environment. Development of a Presence scale for children is required to confirm this interpretation.

Children who practiced in VR conditions had a better performance during acquisition and retention but did not show an advantage of practice on transfer to the same task in a PE. This may be due to the perception-action differences between VR and non-VR environments; children might rely

solely on vision due to the lack of tactile information in VR conditions [17]. The perception-action differences might also impact transfer to the opposite direction. Children who transferred from PE to 2D had the lowest performance among all children during the transfer session. This might be due to the inconsistency in perception-action coupling between PE and 2D, given the lack of haptic information in VR. Such disrupted perception-action link continued to have an impact during transfer to the real world, where children transferred from PE to 2D had the lowest performance and were not able to improve their performance during the session as children in other acquisition-transfer groups.

V. Conclusion

Typically developing children improved their performance of a novel postural reaching task in both VR and PE conditions, with acquisition performance gains greatest in immersive VR. Children were more motivated during acquisition in VR. Environmental and affective factors did not impact transfer performance in the real world. These preliminary results from a small sample support subsequent studies with rehabilitation populations to evaluate how immersive VR could support motor skill (re)learning in rehabilitation contexts. Further research should explore the impact of perception-action differences in VR on motor learning and transfer toward different types of therapeutic goals.

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A movement tracking videogame with a family-centered approach to upper limb rehabilitation for children with cerebral palsy

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***Abstract*— This study aimed to assess the *feasibility of implementation* and *probable efficacy* of an 8-week, home intervention program with Bootle Blast, a motion-based videogame designed for upper limb rehabilitation, in Costa Rican children with cerebral palsy. Videorecorded (Perceived Quality Rating Scale [PQRS]) and self-reported measures (Canadian Occupational Performance Measure [COPM]) evaluating motor performance on self-identified, upper limb activities were collected using a multiple-baseline, Single-Subject Case Experimental Design for the PQRS, and pre-post measures for the COPM. Children established a weekly playtime goal and played at home for 8-consecutive weeks. Videogame logs recorded time played per week. Technical barriers were documented during weekly videocalls with a monitoring therapist. Treatment effect size and percentage of non-overlapping data were used for PQRS analysis. COPM change was interpreted based on minimally clinical importance difference. Descriptive statistics summarized videogame logs and technical barriers. Fifteen children participated and 13 completed the intervention. Children's mean total play time was 377±181 minutes. Six technical barriers in total were reported. Probable efficacy was established. Of the participants, 85% improved in > 1 PQRS activity and 100% improved on the COPM. Bootle Blast is a feasible option to facilitate access to home therapy for children with cerebral palsy.**

Keywords*— *home-based therapy, interactive computer play, Latin America, accessibility barriers, virtual assessments.

I. Introduction

Worldwide, children with Cerebral Palsy (CP) living in low-income families, rural areas and developing countries often face barriers in accessing motor therapy services. For example, in Costa Rica, 43% of children with disabilities do not have access to basic health services[1]. Motion-based videogame interventions that engage children in practicing upper limb (UL) therapy at home, can help bridge this accessibility gap.

Bootle Blast (BB) is a series of 13 mini-games targeting motor skills development played through movements of the ULs, tracked via a colour, depth sensor and an integrated computer device (Orbbec Persee). Some of the mini-games are "mixed reality" wherein real-life objects are manipulated (e.g., toy musical instruments) to play. BB does not require internet connection and can be easily connected to a standard TV screen or monitor. BB's set up involves a calibration game in which the range of movement of each ULs is determined (identifying the specific UL to engage in unilateral play activities), therapy goals are identified, and the targeted play time is linked to in game rewards. BB applies best practices in video game design, theories of motivation and motor learning, to optimize engagement and clinical effectiveness [2].

Pilot work with BB in Canada has provided a first understanding of how BB can be integrated into home use and what supports are needed [3]. However, while North American and European literature supports the use of movement-tracking video games for home rehabilitation in pediatric populations[4], how to properly implement these technologies in children with disabilities in developing countries still needs to be explored.

This paper reports a sub-set of results of an overarching multi-phased mixed methods project (NCT05403567) aiming to address the feasibility[5] of implementing an 8-week BB home intervention in a semi-controlled, real-world environment among Costa Rican families with children with CP. Specifically, the objectives reported on here are to: 1) evaluate *implementation*, and 2) establish *probable efficacy testing* of an 8-week BB home intervention in Costa Rican children with CP.

II. Methods

A. Study Design

This study was designed and partially conducted during the Coronavirus pandemic. The intervention was designed, and

clinical research assessments selected to support remote administration. Ethical approval was granted by the University of Costa Rica and the Bloorview Research Institute ethics boards. A randomized, multiple-baseline, Single-Subject Case Experimental Design (SCED) [6] was used with the Perceived Quality Rating Scale (PQRS) [7] as the repeated measure in addition to pre-post measurement of the Canadian Occupational Performance Measure (COPM) [8]A baseline phase (phase A, 3-5 weeks) was followed by the BB intervention (phase B, 8 weeks). Repeated weekly video measurements of the PQRS were recorded throughout the baseline and intervention phases via videocalls (Zoom) with a monitoring therapist or in some cases, by parents independently recording a video of the child and sending it to the therapist (Table 1). Notes from the monitoring therapist (DC) regarding the dyad's experiences with BB, were recorded weekly during the intervention.

B. Participants and Sampling

Main inclusion criteria to participate were as follows:

- Diagnosis of CP, 7 to 17 years of age.
- Difficulty to manipulate objects and/or perform activities of daily living with at least one hand/arm in alignment with the Manual Classification System levels I-III [9] as reported by the parent and assessed via telephone by a clinician-researcher.
- One of the parents was willing to participate.
- Able to communicate verbally in Spanish or English.
- Having a TV screen or monitor at home.
- Ability to cooperate, understand, and follow simple instructions for game play as reported by parent.
- Having an accessibility barrier to UL rehabilitation services (e.g., not able to pay for therapy, services not available in their area), as reported by the parent.
- The family expectations and the child therapy goals were in line with the scope of the BB intervention.
- Child-parent dyad stablished a play time goal of at least 45 minutes a week [3].

Children were excluded if they had history of uncontrolled epilepsy, visual or hearing impairments that limited the ability to play BB, had received constraint induced movement therapy in the past six months, or botulinum toxin injections, or active therapy of the UL within three months of the study enrollment.

A volunteer convenience sample was used. Recruitment was carried out across Costa Rica using snowball sampling (i.e., word-of-mouth), parent and therapist networks, and social media postings recruitment strategies. After stablishing contact with the research team, prospective participants were screened.

TABLE I. EXAMPLE OF ADMINISTRATION OF CLINICAL RESEARCH ASSESSMENTS WITH A 3 WEEK BASELINE

Assessment	Weeks at which was administered				
	Baseline			*Intervention*	*Post*
	1	2	3	4-11	12
PQRS	X	X	X	X	X
COPM			X		X

C. Data Collection

Prior to the baseline clinical assessment, a BB welcome package was delivered to the participants' homes. This package included: 1) the Orbbec Persee with BB previously installed, 2) a box with toy musical instruments and color blocks (Mega Blocks) to play the mixed-reality games, and 3) a user manual with explanations and troubleshooting tips.

1) Baseline (phase A) and post assessments

The PQRS and the COPM addressed *probable efficacy*. A Costa Rican physiotherapist (DC) administered all assessments. The COPM evaluates the performance and the satisfaction with performance of self-identified therapy goals. Participants identified two UL goals of daily life activities that they wish to improve on. The parent rated (via RedCAP [10]) the child's level of performance and satisfaction with performance over a 10-point scale (1 is poor, 10 is excellent) for each goal.

The PQRS is an observational, video-based tool that looks at performance on client-selected activities. It uses a 10-point scale (1="can't do the skill at all", 10= "does the skill very well"), and judgement of quality includes timeliness of completion, accuracy and overall quality of performance. In this study, the PQRS consisted of recordings of the children completing their COPM goals during a videocall (same day each week) directed by a monitoring therapist. In weeks when a videocall was not possible, the parent took a video of the child performing the PQRS activities and sent it to the monitoring therapist via WhatsApp. Parents needed to send the videos within a +/- 2-days window from their usual videocall day. The first baseline assessment was always delivered via Zoom, wherein the monitoring therapist confirmed with the family that their chosen activities could be videorecorded and guided them on how to do it independently if needed.

2) Onboarding session

On the last baseline videocall, the monitoring therapist gave instructions on how to calibrate, use and play the BB at home. Lastly, the monitoring therapist observed the child playing for a few minutes and addressed any other necessary technical details (e.g., best position for the camera to capture the child).

3) Home intervention (phase B)

Children played BB at home for 8 continuous weeks. The monitoring therapist had a weekly videocall (approximately 15 minutes) with the dyad to check-in, conduct the PQRS assessment, answer questions, troubleshoot any technical problems, and identify possible factors influencing play motivation. The content from each of these interactions, technical assistance requests, and therapists' views on the challenges/value of BB faced by the parent and child were documented. Once a participant reached week 8, the game programmatically locked to prevent further play until the post-intervention assessments were complete. These were scheduled within one week of the completion of the intervention.

Computer logs and the monitoring therapists' field notes from weekly calls addressed *implementation*. Computer logs measured adherence to the BB intervention. These logs recorded details for each play session, including active (i.e.,

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minutes spent engaging in therapeutic movements) and passive play time (e.g., time spent navigating menus). The monitoring therapist's field notes outlined the participants' experiences with BB during each week and documented technical issues.

D. Data Analysis

The feasibility success criteria were developed with reference to previous studies of similar UL, home-based interventions in children with CP[3], [11]. To evaluate *implementation* of the BB home intervention, indicators were:

- ≥ 80% of children will achieve their weekly play time goal in at least 6 weeks, and complete the intervention.
- Number and type of reported technical barriers.
- ≤ 20% of participants experienced technical barriers preventing them from playing for more than 4 days.

To address objective 1, descriptive statistics of computer logs and presence of technical barriers were reported. Logs data were revised, and outliers were removed when it was clear the logged playtime had been altered by a technical issue (e.g., a 6 hr play session). Logs identified the percentage children that met their weekly play time goal, and on how many weeks this goal was achieved. The monitoring therapist's notes were analyzed using content analysis and reported alongside the computer logs data.

Indicators to establish *probable efficacy* were: at least 75% of the children showed a) a positive change in one of the PQRS activities, with a small to moderate effect size, and b) a positive, minimally clinical importance difference (MCID) in the perceived performance in one of the COPM goals [8]

To address objective 2, the PQRS was scored by a therapist blinded to the timepoint at which the test was administered. PQRS improvement was established as the difference between the highest score in the baseline phase and the highest score in the intervention phase. Wilcoxon-signed rank test identified PQRS improvement descriptive statistics and effect size (r_B). Individual treatment effect sizes (SMDs) were given by: (mean of phase B – mean of phase A) / SD of phase A [6]. Slope changes where visually identified using the split-mid method and the by looking at individual SMDs. An online calculator identified the percentage of non-overlapping data (PND)[12]. Pre-post differences on the COPM scores were established using a paired sample t-test (SMD and 95% CIs) and interpreted based on a 2-point MCID. Statistical analyses were conducted using JASP 0.17.1 software.

III. Results

A. Participants

Fifteen children (8-16 years old) participated in the study with one parent (two fathers, 13 mothers). Five children were female, the left UL was affected in nine participants, 10 children had spastic hemiplegia, one had spastic quadriplegia, and four spastic triplegia affecting both legs and one UL. Two children (P13, P04) withdrew after completing baseline assessments. Reasons for abandoning the study are unknown for P13. For P04, a family situation delaying the start of phase B resulted in the dyad loosing interest in continuing in the study.

B. Implementation

Feasibility of implementation indicators were partially met:

- Only 23% of children achieved their weekly play time goal in at least 6 weeks (*not met*).
- 87% of children completed the intervention (*met*).
- 15% of participants had technical barriers preventing them from playing for more than 4 days (*met*).

Weekly playtime goals set by families varied from 45-100 minutes (63±17) on 3-4 days/week. Children played on average 16±6 days across the 8-weeks, with seven participants achieving ≥75% of their total intervention playtime goal (weekly goal * 8).

Six children reported technical issues in at least one intervention week. For three children technical problems were solved remotely within 48 hrs. For one child, the issue was resolved remotely after eight days. One participant needed a home visit from a research team member. This family had mistakenly left the game running overnight, causing the memory to reach capacity. Of note, computer logs and videos of the child playing BB (collected to address different study objectives) were designed to upload to the cloud each time the system was turned on, but this family did not have access to internet which led to the memory capacity issue. The researcher manually extracted the files and taught the dyad how to correctly turn off the videogame. Letting BB running for a long period of time was the main reason technical barriers arouse, as some participants would only turn off their TVs instead of exiting the game and turning off the system. Other issues reported included: mini games not unlocking after achieving the required level, and the system not identifying one of the mixed reality items (i.e. the sound of a musical instrument) correctly.

C. Probable Efficacy

All outcome measures targets to establish probable efficacy were met. For the *PQRS*, 85% of participants who completed the intervention improved in at least one activity with a moderate to large treatment effect size seen in 9/13 participants. For the *COPM*, 100% of children improved in both performance and satisfaction, in at least one goal, with 85% improving by at least 2 points.

1) PQRS

The median PQRS improvement was of 1.00±2.26 pts ($r_B=1$; $p=0.01$) for activity 1 (first goal in the COPM), and of 0.50±1.07 pts ($r_B=1$; $p=0.008$,) for activity 2 (second goal in the COPM). When the PQRS activity with the best improvement was considered, the median increase was of 1.00±2.17 pts ($r_B=1$; $p=0.004$). Figure 1 summarizes the effect size, the slope trend and the PND across all participants.

2) COPM

Post intervention performance and satisfaction scores showed MCIDs increases with large effect for both goals (Table 3). Most common goals included improving the ability to put on and button up a shirt (n=7), typing in the computer (n=3), tying shoelaces (n=5) and cutting with knife and fork (n=3). Goal 1 increased by 3.3 pts in performance ($p = < 0.001$, SMD -1.36, 95%CI = -∞, -0.7) and by 2.85 pts in satisfaction (r_B=-0.77, 95%CI = -∞, -0.5; $p = < 0.008$). Goal 2 improved by 2.15

pts in performance (SMD -0.84, 95%CI = -∞, -0.3; p= 0.005,) and by 2.62 pts in satisfaction (SMD -1.18, 95%CI = -∞, -0.6; p= < 0.001). Of note, the order of the goals was not necessarily associated with the importance of the goal to the family.

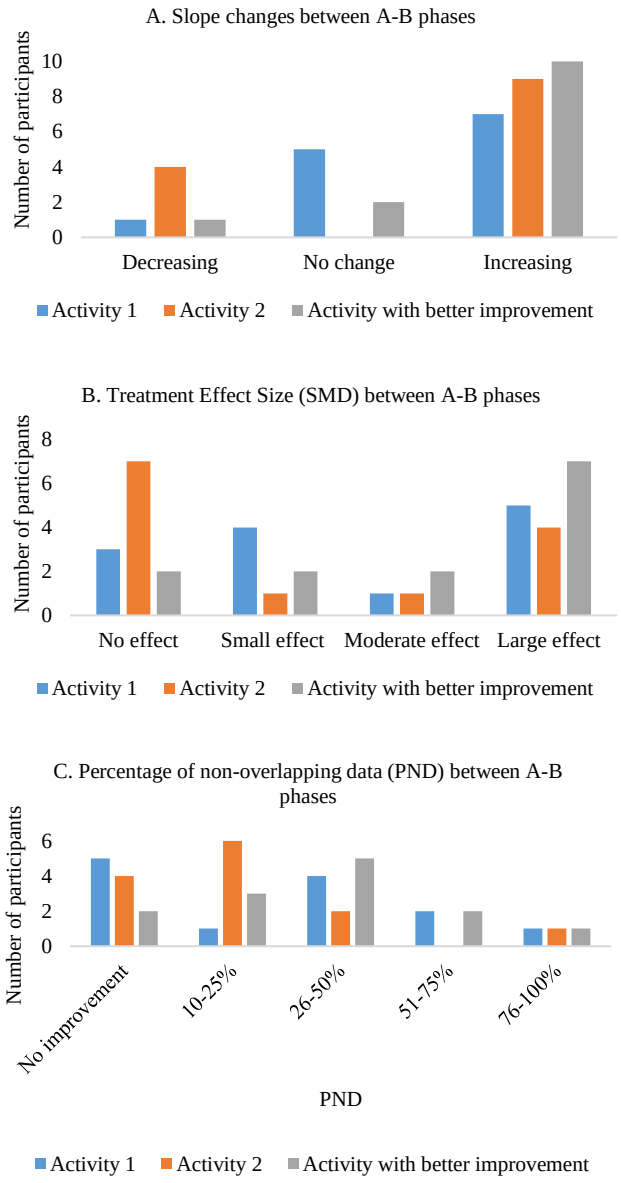

Fig. 1. Visual analyses summary. Number of participants (n=13) showing changes between baseline (A) and intervention (B) phases in PQRS activities. A.*Increasing* was used when the intervention slope was greater than the baseline. B. No effect <0.19 pts, small ⩾ 0.20 pts, moderate ⩾ 0.50 pts, large ⩾ 0.80 pts C. 26-50% of non overlapping data indicates a small separation, 51-75% indicates a moderate separation, and >76% indicates a large separation between A-B phases.

TABLE II. COPM PRE-POST SCORES (N=13)

	Pre		Post	
Goal 1	***Mean***	***Std. Deviation***	***Mean***	***Std. Deviation***
Performance	4.54	1.85	7.85	1.63
Satisfaction	5.77	2.59	8.62	1.94
Goal 2				
Performance	5.62	2.40	7.77	1.36
Satisfaction	5.62	2.60	8.23	1.42

IV. CONCLUSIONS

BB has the potential to support improvements in overall performance of daily life activities of the UL, when implemented in a real-world environment in Costa Rican children with CP. Setting initial play time targets ≤ 60 minutes/week is key for successful implementation, as this goal was feasible for most families. Positive changes in measurement scores, even when playtime was limited, suggests UL motor improvement may not necessarily depend on the amount of time spent playing, but may be influenced by other variables such as the specific mini-games played, the degree of room for improvement at baseline, and the type of goal chosen as a measure. Motion-based videogaming home interventions, like BB, can facilitate access to therapy for children with CP, especially for those living in low-income families, rural areas, and remote communities, and as a complement to traditional clinician-led home interventions.

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Quantifying individual and contextual factors that contribute to *just-right* challenge in an immersive virtual reality pediatric rehabilitation task: a protocol

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***Abstract*—One advantage of immersive virtual reality (VR) as a pediatric rehabilitation tool is its potential to engage and motivate children in sustained efforts towards skill improvement. To promote motor learning, therapists strive for a *just-right* task challenge level that is just difficult enough to motivate the child in persistent efforts for success. VR enables finely-graded individualized task difficulty parameters in a motivating environment, making it ideally suited for *just-right* challenge. While dynamic difficulty adjustment models currently personalize task difficulty based on performance results, they lack input variables relevant to the affective component (motivation, engagement, or flow) of effortful persistence. If we can measure and quantify these factors, they could be added to artificial intelligence (AI) models that use this information in real-time to individualize virtual task parameters to sustain *just-right* challenge. In pursuit of this long-term goal, the objectives of this paper are to propose a method to identify *just-right* challenge from individual and contextual factors, identify neurophysiological and subjective measurement options, and outline a research methodology to validate the method. If successful, we plan to collect data to train an AI model to identify, intervene and sustain *just-right* challenge for children undergoing immersive VR rehabilitation interventions.**

***Index Terms*—*Just-right* challenge, virtual reality, immersion, flow, motivation, children**

I. Introduction

A primary goal of pediatric rehabilitation is to promote functional motor skill learning by providing interventions at a *just-right* task challenge level. *Just-right* task challenge is neither too easy nor too hard, but just difficult enough to motivate the child in persistent efforts to successfully complete the task [1], [2]. However, therapists may have difficulty motivating children to engage in persistent efforts required to improve skill beyond current ability levels, especially in populations requiring long-term rehabilitation interventions. Virtual reality (VR) systems can be attractive options in this regard because they can provide meaningful tasks in engaging environments, potentially reducing effort perception or motivating children to sustain effort. Custom-designed VR games and systems can enable precise individualization of relevant task difficulty parameters to match children's heterogeneous and changing abilities, and offer multisensory feedback. The visual and auditory immersion inherent to immersive VR displayed in head-mounted displays (HMD; providing a 3-dimensional [3D] immersive VR experience where the visual display changes in a natural way with head movements) may be particularly engaging [3]. Children wearing HMDs can use naturalistic body movements to interact with virtual objects through unencumbered gesture tracking, by holding controllers, or via body-worn sensors. HMDs are already used safely by children in health care applications (e.g., for pain management) and in educational contexts. Studies evaluating the rehabilitative benefits of immersive VR using HMDs with children are underway [4]; a recent bibliometric analysis [5] confirms the need for more evidence in pediatric populations.

Recognizing the many barriers to sustainable VR integration in rehabilitation contexts [6], the impetus is on researchers to provide strong clinical rationale for its use. Much has been written about the potential of VR affordances to target neuroplastic processes underlying motor learning [7]. Related compelling rationale may lie in demonstrating that custom VR systems, with the help of low-cost physiological sensors and artificial intelligence (AI) models, can be a therapeutic tool to help therapists achieve personalized *just-right* task challenge for children at different ability levels, and that this challenge level can be modulated over time in response to changes in skill. *Just-right* challenge is a critical component of pediatric rehabilitation tasks because evidence suggests that scaffolding optimally challenging and ultimately successful, skill acquisition experiences may promote mastery motivation [2] in children and youth with disabilities.

The "challenge" of determining *just-right* task challenge is that it depends on children's individual traits and states. A

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task difficulty level that is just outside of a child's abilities may be *just-right* for a child who is motivated to succeed and likes to be challenged, but not at all right for a child frustrated and discouraged by failure. Therapists are finely tuned to how children are reacting to the task and accustomed to adjusting their interventions accordingly. Children's affective and emotional state during learning is a critical variable in the *just-right* challenge equation. VR systems that could objectively and reliably detect children's affective state (through information from physiological sensors) and adjust task difficulty (or another relevant task parameter, such as the amount of visual or auditory stimuli in the virtual environment) accordingly would reduce the burden of clinical decision-making on therapists and enhance the relevance of VR in an unsupervised telerehabilitation context [7]. Objective state estimation would also advance Dynamic Difficulty Adjustment models [8] that make decisions based on performance variables. Indeed, the potential of VR to enhance user motivation and engagement is a key cited rationale for its use in rehabilitation [9].

The objective of this paper is to propose a novel method that includes both affective and performance variables for determining whether an immersive VR rehabilitation task is at a *just-right* challenge level. We outline the affective variables of interest to immersive VR and, when available, suggest potential feasible, low-cost measurement options and subjective questionnaires. We present hypothesized *just-right* measurement thresholds for relevant variables. Finally, we propose a protocol to validate the method using custom-made immersive VR tasks, based on motor learning tasks principles, evaluated with a heterogeneous sample of typically developing children and children with cerebral palsy (CP).

II. Which variables may influence just-right challenge in an immersive VR rehabilitation task?

A. The nature of the task (meaningful and motivating)

Rehabilitation tasks are meaningful when they relate, either directly (through whole-task practice) or indirectly (through part-task practice of relevant skills necessary for the task), to children's individual therapy goals [1]. Immersive VR task practice is system-dependent, in that tasks could be meaningful if they are directly relevant to children's goals (e.g., kicking a virtual soccer ball) or they could be meaningful because they take place in a "fantasy" environment of the child's choosing, in which a task necessitates movement skills relevant to the child's real-world goal. Meaningful tasks enhance the likelihood that children are intrinsically motivated to persist and succeed, reducing the need for therapists to provide extrinsic motivational rewards to sustain effort. Task meaningfulness could be identified by using the Canadian Occupational Performance Measure to set individual goals. Meaningful tasks are generally motivating; motivation is an individual state related to the rehabilitation task or process that drives effort towards goal-directed behavior [10]. Standardized questionnaires are available; the Pediatric Motivation Scale is one example.

B. Task performance (success/error ratio)

There is no well-defined success threshold for *just-right* challenge; we hypothesize a 60-70% success ratio, over multiple attempts. The specific ratio is child-dependent and likely depends on other factors, such as age. Performance indicators (success and error metrics) relevant to the task are tracked during task interaction by the VR system.

C. Affective state

Baseline trait variables such as self-efficacy, attention, and resilience are relevant to how children respond to challenging tasks, but are beyond the scope of this paper. The child's in-the-moment affective state contributes to their interaction with, and reaction to, rehabilitation tasks, interacting with performance results to influence whether they are experiencing a specific task difficulty level as *just-right*. Affective variables relevant to immersive task interaction, and their measurement options, are described below.

1) Flow: Flow is defined by [11] as a state of concentration so focused, in conjunction with enjoyment related to the activity, that it amounts to absolute absorption in any activity. Flow can be experienced in any type of activity or environment; the immersive affordances of VR, including a heightened sense of presence, may encourage a flow state [12]. A flow state is facilitated when task challenge matches user ability [13]. Flow can be viewed as an affective state relevant to *just-right* task challenge if we consider it as a contributor to sustaining effort in a task. Indeed, [1] link *just-right* challenge to a flow state, stating that mastering challenging tasks is akin to a peak flow experience.

To our knowledge, the Flow State Scale (FSS) [14] is the only questionnaire specific to quantifying an individual's flow experience during a physical activity. It has not been validated with children. The Physical Activity Enjoyment Scale (PACES) [15] measures task enjoyment; it has an "absorption" sub-scale, which can be seen as a proxy component of flow. Studies that have attempted to measure flow state through psychophysiological proxies, such as engagement, arousal, cognitive workload, and attention. These proxies are measured mostly through electroencephalography (EEG), as well as combinations of heartrate variability (HRV) and electrodermal activity (EDA) [16].

2) Engagement: Engagement is a multidimensional state of affective, cognitive and behavioral investment in a task that drives children's energy and effort [17]. Immersive VR can engage children through the meaningfulness or novelty of the virtual environment or task, or through task interaction elements such as feedback or results. The User Engagement Scale is commonly used to measure task engagement, but has not been validated in pediatric populations. Neurophysiologically, engagement can be measured using EEG in an established index based on the ratio of beta to alpha plus theta activity ($\beta/(\alpha+\theta)$).

3) Arousal: Arousal is one component of the intensity of an emotional reaction. EDA reflects the sympathetic response of the autonomic nervous system. EDA response (peaks per

minute) has been linked with arousal (a dimension of affective response to stimuli) in gaming and immersive media contexts in children and adults. A normalized value of EDA, with a baseline calculated on a neutral state (low arousal), can be used to measure changes in arousal during a task. In addition, HRV, specifically the ratio of low-frequency HRV (LF-HRV) to high frequency HRV (HF-HRV) can be a neurophysiological arousal proxy.

4) Cognitive workload: Cognitive workload relates to perceived mental effort; a subjective questionnaire for measurement is the NASA Task Load Index. Neurophysiologically, it can be measured using EEG oscillatory signatures. As task difficulty increases, the amount of theta (4-7 Hz) activity should increase while the amount of alpha (8-12 Hz) activity should decrease.

5) Attention to the task: Eye-tracking sensors embedded in HMDs can be a proxy measure for focused attention as quantified by the proportion of eye gaze total fixation duration to virtual task targets as compared to the rest of the virtual environment. A lower blink rate is also indicative of a higher focused attention.

III. A PROPOSED METHOD TO DETERMINE IF A TASK IS AT A JUST-RIGHT CHALLENGE LEVEL IN IMMERSIVE VR

Based on the proposed affective and performance variables described above, how can we determine, reliably and precisely, whether a specific difficulty level is *just-right* for a specific child and task? We assume that the child and therapist have collaborated to select a meaningful task. We note the difficulty in quantifying a flow state; determining the relationship between flow and *just-right* task challenge is a secondary question that we will pursue through this research program.

Figure 1 illustrates how each variable must be within the predefined *just-right* task challenge threshold. Table I presents the known (or logically hypothesized) thresholds indicative of *just-right* challenge. There will always be unmeasured noise stemming from factors we have not considered; for this reason we account for unmeasured variability that could impact the results. As part of the validation method, the neurophysiological variables we present for our identification of a *just-right* challenge will be compared to the children's descriptions of their subjective experiences.

TABLE I
VARIABLES MEASURED TO DETECT JUST-RIGHT CHALLENGE.

Variable	*Just-right*	Too easy	Too hard
Success rate	60-70%	>70%	<60%
Engagement	high $\beta/(\alpha+\theta)$	low $\beta/(\alpha+\theta)$	low $\beta/(\alpha+\theta)$
Arousal	moderate EDA moderate HRV	low EDA low HRV	high EDA high HRV
Cognitive workload	high θ moderate α	low θ high α	moderate θ high α
Attention	long fixation low saccadic eye movement lower blink	short fixation high saccadic eye movement regular blink	short fixation high saccadic eye movement regular blink

A. Proposed data collection protocol

We will use 2 custom-made games, based on motor learning tasks principles, developed for immersive VR HMDs with embedded eye-tracking (Pico Neo 3 and HTC VIVE ProEye) with typically developing children and children with CP at different ability levels who meet our baseline inclusion criteria for successful comprehension of instructions and participation in the tasks. Tasks will be undertaken in a seated position using the less-affected upper extremity. One task involves bouncing a virtual ball on a virtual racket, with a goal of consecutive bounces to a target line. Task difficulty parameters consist of gravity manipulation on ball speed and height and width of the virtual target. The second task involves reaching to touch a series of targets at different positions and advancing towards them at different speeds following a rhythmic beat. Task difficulty parameters are the number and positions of targets. Children will wear sensors to capture neurophysiological data. We will first identify whether our sensors measuring the input variables described above can detect changes at different difficulty levels of the above tasks, whether our proposed thresholds are valid, and whether neurophysiological findings align with children's self-reported state. All sensor data will be time synchronized with task. After a rest period (for baseline physiological variables) and an initial introduction to the immersive VR environment, a period of practice to determine baseline competence and select the starting difficulty level accordingly, children will practice the task at defined periods of progressive difficulty levels, responding to custom Likert-scale questions about affective state after each level and to standardized questionnaires at the end of the session.

Data analyses will identify changes in variables of interest at each difficulty level, taking into consideration baseline abilities as well as age, sex, VR experience, and impairment level (Gross Motor Function Classification System; Manual Ability Classification System). We will explore relationships between neurophysiological data at each difficulty level, children's task performance, and responses to Likert-scale single questions and subjective questionnaires.

IV. CONCLUSION

Emphasizing *just-right* task challenge during rehabilitation interventions is anchored in evidence-based motor learning principles underlying neurorehabilitation [2]. Currently, therapists use objective performance indicators and subjective judgements of a child's affective state when making task difficulty decisions targeting *just-right* challenge. Immersive VR, an emerging intervention modality in pediatric rehabilitation, may be a valuable testbed for investigating which objective neurophysiological estimation of affective state indicators is the most useful in identifying *just-right* challenge, in terms of validity, sensibility, and easiness of use. Eventually, using this information in real-time to individualize in accordance with in-the-moment state. Significant measurement challenges are to be expected; we welcome feedback and suggestions related to our proposed method. We plan on collecting data with more children who progress at their own pace through

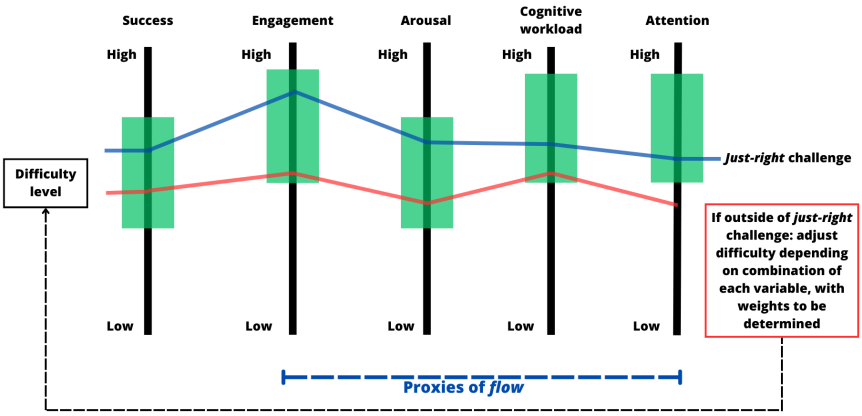

Fig. 1. Estimation of *just-right* task challenge based on relevant input variables (vertical lines) hypothesised thresholds (green blocks).

task difficulty levels and use this training data to build an AI model to identify when a child is in a *just-right* challenge level. Subsequent larger-scale work with larger sample sizes will involve collaborations with AI scientists to refine the model and make decisions about appropriate changes to task difficulty or virtual task parameters in real time to achieve and maintain *just-right* task challenge. Overall, our goal is to contribute to the body of knowledge about factors influencing children's user experiences in immersive VR to contribute to a future of precision rehabilitation [18] where interactive technologies, physiological sensors and AI models can provide personalized interventions in clinic and home-based contexts.

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ISVR

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Immersive Virtual Reality vs non-Immersive Applications for Managing Chronic Cancer Pain, a Randomized Control Trial

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***Abstract*— While cancer survivorship is growing worldwide, chronic cancer pain remains a challenge. Virtual Reality (VR) is promising for delivering non-pharmacological pain therapy. This trial evaluated the efficacy of using VR-based therapy as adjunctive pain therapy for chronic cancer pain. Participants engaged in home-based pain therapy through 4 applications involving cognitive distraction and mindfulness meditation for 30min/day, 6 sequential days per application, for 4 weeks, either in VR or a laptop control. Daily pain scores were collected via visual analog scale (VAS) for before, during, and after exposure; weekly questionnaires evaluated immersion and presence. Across Canada, 110 participants were recruited; 100 were included in the analysis. Participants in both groups experienced pain benefits (VAS decrease ≥ 10/100mm) over at least 1 week (43/50 VR; 37/50 control). However, linear mixed effects analysis showed no statistical difference between groups. Immersion, but not presence, differences were observed in 2 applications. Cybersickness was greater in VR for 2 applications. Therefore, 2D-display based delivery of adjunctive pain therapy for chronic cancer pain may be similarly effective as VR. Recommendations for applications will depend on individual taste and preferences for cognitive engagement vs mindfulness meditation.**

Keywords*— *virtual reality, cancer, chronic pain, cognitive engagement, mindfulness, meditation, immersion, presence

I. Introduction

Cancer survivorship is growing rapidly worldwide with over half expected to live beyond ten years due to advances in treatments [1], yet chronic cancer pain remains ongoing challenge. Non-pharmacological interventions (NPIs) such as distraction therapy and mindfulness meditation have proved useful in reducing cancer pain with few adverse effects [1]. Virtual reality (VR) as an NPI for pain management is a promising new approach with successes reported in the treatment of acute pain [2]. VR technology can distract from pain by immersing users in computer-generated 3D environments with sensory stimulation, which can be calming or engaging. Combining mindfulness meditation within a VR intervention may help support acceptance and adherence to the practice while having a synergistic effect on pain reduction through immersive VR distraction. However, research exploring its use for chronic and cancer pain is limited, with few randomized controlled trials (RCT) [3]. This RCT was designed to explore the daily home use of VR for chronic pain in cancer survivors. This study aimed to determine the efficacy of VR-based therapy as an adjunctive NPI for managing chronic cancer pain in comparison to traditional non-immersive technology and identify any cybersickness effects from VR exposure.

II. Methods

The study was a parallel two-arm (VR vs non-VR control) participant blinded prospective RCT with 1:1 allocation (clinicaltrials.gov, NCT #02995434). Community-dwelling adults with cancer related chronic pain were recruited across Canada between 2017 and 2022. We included those who were: 1) Aged > 16 years, with a past or current diagnosis of cancer 2) Experiencing chronic cancer pain, 3) Able to communicate in English, 4) Normal stereoscopic vision, 5) sufficient mobility for VR activities. Those with significant cognitive issues, a history of seizures, claustrophobia, or susceptible to motion-sickness were excluded. The trial was approved by the University of British Columbia Clinical Research Ethics Board (Approval #: H16-01510).

The adjunctive NPI involved mindfulness meditation and cognitive engagement for chronic pain management. These activities were delivered through an immersive VR system or a laptop for the control arm, set up in participants' homes. Mindfulness applications were Virtual Meditative Walk and Wildflowers. Cognitive engagement activities were Obduction (OB: Cyan Ventures, Mead, USA) and Cape Lucem - Seize the Light (CL: Application Systems, Heidelberg, Germany). Carpe Lucem was VR-only; hence an alternative geometric puzzle solving application for the control group was used: The Witness (WN: Thekla, San Francisco, USA).

Primary outcome was the Visual Analogue Scale (VAS) for pain, a single-item linear self-reported pain scale from no pain (0mm) to worst pain imaginable (100mm) [4]. A weekly questionnaire was also used to assess Immersion, Presence, and Cybersickness for each activity. The 28-item questionnaire assessed visual and audio immersion, presence, and engagement using 5-point Likert scale items, with higher scores indicating greater immersion and presence.

This study was funded by the Lotte & John Hecht Memorial Foundation

Participants engaged in each NPI activity for 30min every day for a month, using one of the four activities for a week each in sequence, with one rest day between activities. Participants completed daily sheets including instructions to record the time spent each day, and their pre, during, and post NPI exposure VAS pain scores. At the end of the week's participants completed the Immersion and Presence questionnaire.

VAS and questionnaire responses were summarized using descriptive statistics (mean and standard deviation). Linear mixed effects modeling and Fisher's exact test was used to test for between group differences in VAS and Immersion and Presence questionnaire respectively.

III. Results

A total of 110 participants were recruited for this study, 100 from BC, 2 from Alberta, 7 from Ontario, and 1 from Quebec. The most common cancer types were breast cancer (n = 31) and lymphoma (n = 16). A total of 7 participants in the VR and 3 in the control group withdrew participation within the first week and were excluded from the analysis.

In total, 43 VR participants and 37 control participants reported clinically meaningful pain reduction (VAS decrease $\geqslant$ 10mm) on average for at least 1 week (Table 1). This decrease was experienced either during NPI exposure or immediately after. Across all activities, the mean change in VAS from pre to during NPI was –7.3 ± 9.5mm in the control group and –8.8 ± 7.4mm in the VR group. Within participants, these changes ranged from a mean decrease (for a given week/activity) of –43.5mm to a mean weekly increase of +13.3mm in the control group and –30.9 to +4.2mm in the VR group. The mean VAS changes from pre to post was –8.0 ± 12.4mm and –7.4 ± 9.2mm in the control and VR groups respectively; these changes ranged from a mean weekly changes of –43.9mm to +18.5mm and –33.7mm to + 12.0mm in control and VR groups respectively. Across all activities, no statistically significant between-group differences were observed: mean difference between groups during NPI was -0.47, 95% CI [-4.5, 3.4] mm and post NPI as 2.1, 95% CI [-1.9, 6.5] mm, adjusting for pre NPI VAS.

Whilst some participants reported benefits broadly, the VR intervention had mixed results. The majority of ratings were not statistically different between VR and Control (Table 2). Visual immersion was lower in VR for MW ($p = 0.027$) and higher for CL/WN ($p = 0.037$). Audio immersion was higher in VR for CL/WN ($p = 0.037$). Cybersickness was statistically higher in VR for MW and WF ($p < 0.001$).

TABLE I. Number of participants who responded with a mean decrease in VAS pain scores $\geqslant$ 10mm in either category of NPI

	VR	Control	Total
No Activities	7	13	20
Meditative Only	6	8	14
Cognitive Only	19	7	26
Mixed Responses	10	14	24
All Activities	8	8	16
Total	50	50	100

TABLE II. Summary of Immersion and Presence Questionnaire

	MW	WF	OB	CL/WN
Visual Rating				
VR	**3.6 (0.7)**	3.7 (0.6)	4.2 (0.5)	**4.2 (0.6)**
Control	**3.9 (0.6)**	3.8 (0.6)	4.0 (0.6)	**3.9 (0.5)**
Audio Rating				
VR	3.8 (0.8)	3.9 (0.7)	3.9 (1.0)	**4.1 (0.6)**
Control	3.8 (0.8)	3.9 (0.6)	4.0 (0.7)	**3.9 (0.6)**
Sense of Presence				
VR	3.1 (0.9)	3.4 (0.7)	3.6 (0.7)	3.7 (0.7)
Control	3.2 (0.7)	3.4 (0.7)	3.6 (0.7)	3.5 (0.6)
Cybersickness				
VR	**2.0 (1.3)**	**3.3 (1.5)**	2.4 (1.3)	1.8 (1.1)
Control	**1.3 (0.6)**	**1.3 (0.8)**	2.0 (1.6)	1.5 (1.1)

Bold pairs are statistically significant, two-tailed Fisher's exact test $p < 0.05$

IV. Conclusion

While participants in both groups experienced some therapeutic benefits in the form of decreased pain, these benefits. There was no significant difference between VR and laptop use control groups. While this study was not an equivalence trial, our findings suggest standard 2D-display based delivery of distraction therapy and mindfulness meditation may be equally as effective as VR. However, benefits were heterogeneous, reflecting personal influences, with some participants responding more to cognitive engagement and others to mindfulness meditation. Future work may explore how to best match people experiencing chronic cancer pain such applications based on taste, preferences, and responsiveness to VR.

Acknowledgment

We acknowledge Dr. Diane Gromala, Dr. Christopher Shaw and graduate students at SIAT, Simon Fraser University, Dr. Bechara Saab at Mobio Interactive, Cyan Worlds, and Hammer Labs for supporting the creation and use of VR applications in this study.

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Virtual Reality Exposure in Obsessive-Compulsive Disorder: Enrichment by Smell and Touch

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***Abstract*— The proposed feasibility study utilizes the virtual reality application for exposure and response prevention therapy and symptom provocation in patients with obsessive-compulsive disorder (OCD). The method was designed based on a dimensional approach to OCD symptomatology divided to typical four subtypes: 'contamination/cleaning', 'symmetry/ordering', 'fear-of-harm/checking', and 'hoarding'. The ongoing feasibility study aims to test the previously validated VR software 'OCD House' in combination with additional tools and methods, particularly the olfactory stimulation and tactile gloves. These methods are applied to test their effect on perceived presence in tested virtual simulations (scenarios). We hypothesize that the tactile or olfactory stimulation during simulated VR experience will enhance the perceived level of presence and potentially also increase the evaluated intensity of the symptoms provoked by this sensory enriched VR simulation.**

Keywords*— *obsessive-compulsive disorder, virtual reality, exposure therapy, olfactory stimulation, tactile gloves

I. Introduction

Obsessive-compulsive disorder (OCD) is defined by the presence of obsessions - intrusive recurrent and persistent thoughts, images or urges, and compulsions - repetitive behaviors (e.g., cleaning, checking, arranging of objects in a specific way) or mental acts (counting, repeating formulas) [1]. Compulsions are performed as a way of preventing obsessive thoughts or making them disappear [1], thus temporarily reducing anxiety. OCD symptoms take up a lot of time and strongly interfere with the person's work or social and personal life. As the OCD symptoms are very heterogeneous, a dimensional approach [2] has been used to organize them.

The most common treatment for OCD is a combination of antidepressant medication and cognitive-behavioral therapy (CBT). CBT integrates various approaches, including the exposure and response prevention (E/RP) - involving deliberate and voluntary exposure to the stimuli that triggers the obsessive thoughts, while the person is taught techniques to avoid performing the compulsive rituals (response prevention). VR exposure therapy seems to be a good alternative to in vivo exposure as some studies supported the suitability of VR environment to provoke OCD symptoms [3, 4, 5]. However, for VR exposure therapy it is crucial to choose the situation that corresponds as much as possible with the real-life situation that triggers the symptoms. Effective symptom provocation has also been reported in our previous studies using the 'OCD House' [6, Fajnerova et al, VIRE, under review]. The presented study aims to test the VR exposure simulation combined with tactile and/or olfactory stimulation and hypothesized beneficial effect on intensity of provoked OCD symptoms. This assumption is based on evidence showing the impact of sensory stimulation on VR presence tested in general population [7], and verbal reports of some previously tested OCD patients suggesting missing smells (e.g., open fire, gas stove) or tactile feedback (touching of contaminated surfaces).

II. Pilot Study Procedure & Results

Odor-relevant VR scenarios and their validity was already tested in a previous study (for illustration see Fig.1). During a pilot study we aimed to evaluate potential OCD - relevance in several olfactory stimuli, selected from perfume library and standardized set of odors used in olfactory testing (The Library of Fragrance, Sigma, etc.). All odors identified as relevant for OCD scenarios were later tested in a form of free odor identification test. This assessment showed wide range of responses, especially in identification of odors from the perfume library collection that combined more than one substance. This subset of ambiguous stimuli was therefore excluded. Small subset of odors was also tested in OCD individuals, who were during VR therapy exposed to a particular situation relevant for the tested odor (garbage disposal, cleaning of dog excrement,

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etc.). This helped us to identify scenarios relevant for the preselected odors and to test their congruence. The pilot study also helped us to identify suitable method for administration of odors, as the originally suggested stimulation with olfactometer has shown various complications. A standard aroma diffuser has been tested as effective at spreading odors during VR exposure.

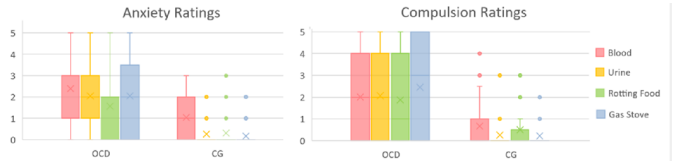

Fig.1 Subjective rating of anxiety and compulsive tendency in selected 'contamination' scenarios tested in OCD (n=23) and Control group (CG).

III. FEASIBILITY STUDY

A. *Technical equipment & sensory stimulation methods*

The head-mounted display HTC Vive Pro or Meta Quest 2 is used for immersing the participant into the VR experience. The 1st person perspective with visualization of virtual hands and teleportation is used. Additional VR equipment: The LucidVR gloves - Arduino/ESP32-based DIY SteamVR compatible Haptic gloves. Olfactory stimulation: A whole-body exposure with a commercially available home aroma diffuser with adjustable speed and remote control (Otello electronic diffuser) will be used with smells identified in the pilot study.

B. *'OCD House' software*

In the current study, we utilize the 'OCD House' virtual household simulation, created using Unity engine (https://unity3d.com/) for symptom provocation in OCD and validated in the previous study [7]. The virtual environment is designed in concordance with the dimensional OCD model and incorporates OCD-specific items/scenarios from above listed dimensions of 'contamination/cleaning', 'symmetry/ordering', 'fear-of-harm/checking', and 'hoarding'. The app allows free exploration of the VR environment but can be restricted by means of visible/active stimuli. The patient is guided to perform certain tasks corresponding with real-life situations (e.g., turning on a gas, touching dirty surface results in dirty hands etc.), but without performing corresponding compulsion (e.g., repetitive checking, washing hands).

C. *Experimental Design & Study Procedure*

The ongoing feasibility study sample will include at least 10 OCD patients (age 18-55 years) recruited from the Inpatient Ward or Day Care Center at NIMH. Each volunteer is giving informed written consent. Only preselected OCD House scenarios/stimuli that are specifically associated with smell or touch experience in real-life conditions will be used. The selected situations (for illustration see Fig.2) correspond to 'contamination/cleaning' dimension - contamination of surfaces by body fluids and cleaning, garbage disposal, or to 'fear-of-harm/checking' subtype - active fireplace or gas stove).

The study is performed in two separate (60 minutes long) sessions. The initial session is used to evaluate the severity of OCD symptoms and to determine the relevance of the four selected exposure stimuli/scenarios for the individual patient. During the second session, one stimulus per category is tested in individual patients, thus addressing one targeted dimension (relevant for the patient and triggering symptoms) and one non-provoking/control stimulus. Each stimulus (target and non-target) is tested in 3 conditions presented in pseudorandom order: 1) standard VR simulation, 2) VR with tactile stimulation and 3) VR with olfactory stimulation. The assessment is performed in a form of repeated short exposure to each of the selected stimuli, with short breaks to prevent transfer from the previous evaluation. During each stimuli exposure the patient is asked to rate individual stimuli by means of the current level of provoked anxiety and tendency to perform compulsion (Subjective Units of Distress/Compulsion Scale 1-10).

Fig. 2. Screenshots illustrating exposure situations within the 'OCD house' corresponding to 'contamination/cleaning' and 'fear-of-harm/checking'.

Questionnaires and psychiatric scales: The severity of OCD symptoms will be evaluated (The Yale–Brown Obsessive Compulsive Scale) in the initial session. The outcome measures will include the questionnaires assessing the sense of presence and simulator sickness.

IV. CONCLUSION

During the poster presentation we will report the preliminary results of the ongoing feasibility study, including more detailed pilot study results leading to the suggested study procedure.

ACKNOWLEDGMENT

We thank Mgr. Petr Adámek for assembling of the VR gloves.

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Immersive Virtual Reality vs non-Immersive Applications for Managing Chronic Cancer Pain, a Randomized Control Trial

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***Abstract*— While cancer survivorship is growing worldwide, chronic cancer pain remains a challenge. Virtual Reality (VR) is promising for delivering non-pharmacological pain therapy. This trial evaluated the efficacy of using VR-based therapy as adjunctive pain therapy for chronic cancer pain. Participants engaged in home-based pain therapy through 4 applications involving cognitive distraction and mindfulness meditation for 30min/day, 6 sequential days per application, for 4 weeks, either in VR or a laptop control. Daily pain scores were collected via visual analog scale (VAS) for before, during, and after exposure; weekly questionnaires evaluated immersion and presence. Across Canada, 110 participants were recruited; 100 were included in the analysis. Participants in both groups experienced pain benefits (VAS decrease ≥ 10/100mm) over at least 1 week (43/50 VR; 37/50 control). However, linear mixed effects analysis showed no statistical difference between groups. Immersion, but not presence, differences were observed in 2 applications. Cybersickness was greater in VR for 2 applications. Therefore, 2D-display based delivery of adjunctive pain therapy for chronic cancer pain may be similarly effective as VR. Recommendations for applications will depend on individual taste and preferences for cognitive engagement vs mindfulness meditation.**

Keywords*— *virtual reality, cancer, chronic pain, cognitive engagement, mindfulness, meditation, immersion, presence

I. Introduction

Cancer survivorship is growing rapidly worldwide with over half expected to live beyond ten years due to advances in treatments [1], yet chronic cancer pain remains ongoing challenge. Non-pharmacological interventions (NPIs) such as distraction therapy and mindfulness meditation have proved useful in reducing cancer pain with few adverse effects [1]. Virtual reality (VR) as an NPI for pain management is a promising new approach with successes reported in the treatment of acute pain [2]. VR technology can distract from pain by immersing users in computer-generated 3D environments with sensory stimulation, which can be calming or engaging. Combining mindfulness meditation within a VR intervention may help support acceptance and adherence to the practice while having a synergistic effect on pain reduction through immersive VR distraction. However, research exploring its use for chronic and cancer pain is limited, with few randomized controlled trials (RCT) [3]. This RCT was designed to explore the daily home use of VR for chronic pain in cancer survivors. This study aimed to determine the efficacy of VR-based therapy as an adjunctive NPI for managing chronic cancer pain in comparison to traditional non-immersive technology and identify any cybersickness effects from VR exposure.

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TABLE II. Summary of Immersion and Presence Questionnaire

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Control	**3.9 (0.6)**	3.8 (0.6)	4.0 (0.6)	**3.9 (0.5)**
Audio Rating				
VR	3.8 (0.8)	3.9 (0.7)	3.9 (1.0)	**4.1 (0.6)**
Control	3.8 (0.8)	3.9 (0.6)	4.0 (0.7)	**3.9 (0.6)**
Sense of Presence				
VR	3.1 (0.9)	3.4 (0.7)	3.6 (0.7)	3.7 (0.7)
Control	3.2 (0.7)	3.4 (0.7)	3.6 (0.7)	3.5 (0.6)
Cybersickness				
VR	**2.0 (1.3)**	**3.3 (1.5)**	2.4 (1.3)	1.8 (1.1)
Control	**1.3 (0.6)**	**1.3 (0.8)**	2.0 (1.6)	1.5 (1.1)

Bold pairs are statistically significant, two-tailed Fisher's exact test $p < 0.05$

IV. Conclusion

While participants in both groups experienced some therapeutic benefits in the form of decreased pain, these benefits. There was no significant difference between VR and laptop use control groups. While this study was not an equivalence trial, our findings suggest standard 2D-display based delivery of distraction therapy and mindfulness meditation may be equally as effective as VR. However, benefits were heterogeneous, reflecting personal influences, with some participants responding more to cognitive engagement and others to mindfulness meditation. Future work may explore how to best match people experiencing chronic cancer pain such applications based on taste, preferences, and responsiveness to VR.

Acknowledgment

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ISVR

International Society for Virtual Rehabilitation

Oral Session 3

Locomotion in virtual environments

16:30 to 17:45

July 23rd, 2023

The impact of walking and visual distraction on lexical decisions in single and multitask virtual reality settings

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***Abstract*— This study investigates how walking modulates concurrently performed cognitive tasks, such as language processing and visual control in an ecologically valid, yet controlled VR setting. Participants perform a lexical decision task (LDT) that is completed as (1) a single-task+, where the participant is seated while seeing the words overlayed on a static image of a cityscape with randomly appearing visual distractors and (2) a multitask, where the same task is done while walking on a self-paced treadmill through a dynamic VR city scape. Lexical decision patterns remain consistent, but responses are modulated by the addition of concurrently performed tasks Our current findings point to an interplay of both task-related and individual characteristics determining multitask performance.**

Keywords*— *Lexical Decision, Visual Control, Gait, Multitasking, Virtual Reality

I. Introduction

Given its complexity as a cognitive process and importance in ensuring safety during everyday interactions, much of the existing work on multitasking has focused on walking. As such, gait adaptation as a result of walking while concurrently performing additional tasks is well-documented in the literature. While walking is considered a relatively simple task for healthy adults, it is not a completely automated process, as evidenced by the variation of spatio-temporal parameters and stability measures during gait in dual-task contexts. Detrimental effects of concurrently performed tasks on posture and gait are

commonly referred to as cognitive-motor interference effects. By now, many studies conducted both in- and outside the laboratory suggest that when faced with a challenge, walking functions are prioritized over other cognitive demands resulting in gait adaptation [1]. Of relevance here, less is understood about how walking modulates concurrently performed tasks, such as language and visual processing or inhibition of distraction.

Current evidence suggests that the interference from additional tasks is associated with increased cognitive demands placed on both working memory and physical demands. These increased demands may also have detrimental effects on concurrent linguistic and visual tasks. In fact, multi-tasking has been found to reduce situational awareness and lead to inattentional blindness [2]. Crucially, the existing work on multi-task performance points to the importance of cognitive control in managing these complex situations. Thus, we argue that it is worthwhile to study both multi-task effects of visual and linguistic tasks on walking, and also the effects of walking on these tasks in order to gain a better understanding of multi-tasking as a matter of cognitive control. Furthermore, the virtual reality context allows us to investigate these effects in a controlled, yet ecologically valid setting.

In the current study, we present three tasks to gradually increase cognitive load, namely language processing (i.e., lexical decision task (LDT)), walking (i.e., self-paced treadmill) and visual processing (i.e., inhibition of visual distraction). Each task was completed in a well-controlled single-task condition, before being integrated in a virtual reality multitask context. This allows us to establish core effects in each of these tasks and characterize any changes due to the addition of concurrently performed tasks. Performance on the LDT, which reflects the complexity of the mental processes involved in classifying stimuli as words or nonwords represents our primary task. Participants typically respond fastest and most accurately to nonwords (words that do not exist and do not respect the orthographic rules of a language, e.g. “kjotd”), slightly slower and less accurately to real words (e.g., apple) and slowest and least accurately to pseudowords (words that do not exist but respect the orthographic rules of a language, e.g. “fillow”) [3]. Across two analyses, we will focus on three main questions: (1) Are speed and/or accuracy of lexical decisions affected in a multi-task condition compared to a single-task+ condition? (2) Is there an effect of additional visual distraction on lexical decisions in single- and multi-task conditions? And (3) To what extent are the observed effects modulated by individual differences in visual control?

II. METHODOLOGY AND ANALYSIS

A. Participants

To date, 22 young adults (11 female; 11 male) between 18-35 years of age (mean = 22.90) have participated. All were dominant English speakers, as assessed via the Language Background Questionnaire [4]. Furthermore, all had normal or corrected-to-normal vision, no neurological deficits, musculoskeletal injuries or pain during walking.

B. Session 1: Single-Task+

During their first visit, participants completed the LDT on a large screen, showing the letter strings overlayed on a static image of a city scape. Some trials included visual distractors (i.e., a red square). Participants also completed the VISSTA task [5], which assesses visual control, specifically divided visual attention and speed of processing, either while seated at a regular computer monitor or in front of the large screen.

C. Session 2: Multi-Task

During their second visit to our laboratory, participant performed a multi-task. Participants walked on a treadmill while completing the same LDT as in Session 1, including randomly appearing visual distractors. The self-paced treadmill creates an immersive experience by synchronizing the VR display showing the city scape scene with gait speed changes. Following the LDT, participants completed the VISSTA again.

D. Analysis

To assess performance on the single-task+ and multi-task, we analyzed both correct response times and response error rate on the LDT using linear mixed-effects (LME) models. For each dependent variable, we first computed models including a three-way interaction of word type, presence of a distractor and session, while controlling for order of presentation. In a subsequent analysis, we first computed a VISSTA composite score to capture a "distraction cost" for each participant (i.e., higher scores indicate more distraction due to increased task complexity). We then computed separate models for the single-task+ and multi-task sessions, including a three-way interaction of word type, presence of a distractor and VISSTA composite score, controlling for order of presentation.

III. RESULTS

Our analysis revealed that words were always responded to faster and more accurately than pseudowords, but slower and less accurately than nonwords. For error rates there was a significant interaction of the presence of a distractor and session (β=-0.72, SE=.32, p=.02), whereby participants made more errors overall when a distractor was present, although this effect was more pronounced in the single-task+ session than in the multi-task session (see Fig. 1). For correct response time, there was a significant effect of session, whereby participants responded faster overall during the multi-task session compared to the single-task+ (β=.04, SE=.00, p<.01) (see Fig. 2). The subsequent analysis revealed that during the single-task+ there was a significant three-way interaction of word type (pseudoword vs. word comparison), the presence of a distractor and VISSTA composite score (β=.74, SE=.33, p=.02), suggesting that participants who experienced higher “distraction cost” (i.e., higher composite scores) made more errors when a visual distractor was present, particularly on pseudowords. For correct response time, there was also a significant three-way interaction in the single-task+ of word type (pseudoword vs. word comparison), the presence of a distractor and VISSTA composite score (β=-0.03, SE=.01, p=.02), indicating that participants who experienced higher “distraction cost” (i.e., higher composite scores) responded more quickly, particularly on pseudowords when a visual distractor was present.

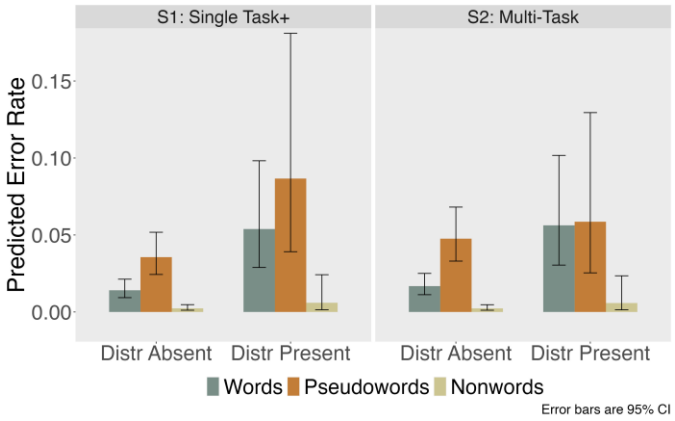

Fig. 1. Significant interaction of session and presence of a distractor. Participants make more errors when a distractor is present, especially in the single-task+ session.

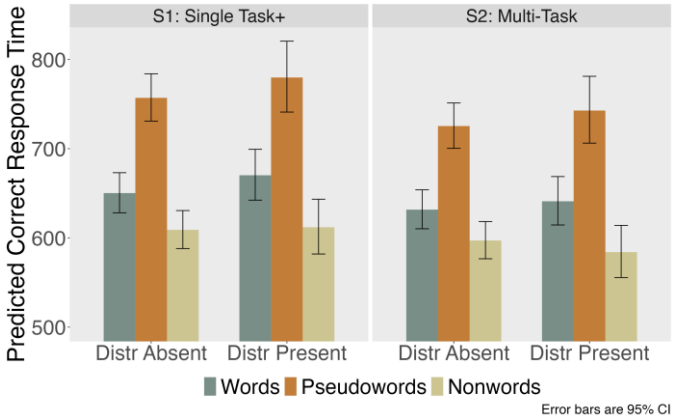

Fig. 2. Significant effect of session. Participants responded faster overall when the LDT was completed while walking than when seated

IV. Discussion

The current study examined how young, healthy adults manage demands of lexical processing, visual distraction and gait in a virtual reality multitask context. To this end we gradually increased the cognitive burden on participants making lexical decisions by adding visual distractors and concurrent walking. Our findings suggest that while lexical decision patterns remained consistent, overall response times and accuracy were modulated by the addition of concurrently performed tasks. Accordingly, when participants made lexical decisions while walking, they generally responded faster. In the single-task+ condition, participants made more errors when a distractor was present. On pseudoword decisions this effect was amplified for individuals whose visual control abilities were not as good. Importantly, none of the task conditions led to clear dual-task costs. Rather, behaviors appeared to adapt to increased demands in a specific domain. To conclude, our results suggest that the amount of overlap between cognitive domains involved in concurrently performed tasks, rather than the number of tasks, is determinant of multi-task performance. These findings provide important information that guides presently on-going studies with older participants and persons with stroke and consequent sequalae affecting cognitive control during multi-tasking.

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Using an Embodied Avatar in Immersive Virtual Reality to Increase Gait Variability in Rehabilitation: A Study in Development

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***Abstract*— Research on motor learning has found evidence that movement variability is positively correlated with the rate of motor learning. Enhancing motor variability during training could therefore be a promising method to improve rehabilitation outcomes. Here, we propose the use of visual disturbances through the manipulation of an embodied avatar's foot position to induce increased movement variability during gait training using immersive virtual reality technology. Previous research has shown that modulating the movements of an embodied avatar can lead to changes in the user's movements. This effect could be exploited to induce increased movement variability in the gait pattern, potentially leading to improved gait rehabilitation outcomes. The proposed study aims to investigate the effects on movement variability and users' motivation and embodiment of inducing a noise-like disturbance to the avatar's tracked foot position in the horizontal plane while walking on a treadmill. The virtual environment that healthy participants will walk through resembles a long, shallow river visualized from a first-person perspective using a head-mounted display. Through this experiment, we will gain a better understanding of the effect of visual disturbances using embodied avatars on movement variability as a first step toward its use in rehabilitation settings.**

Keywords*— Virtual Reality, Gait, Rehabilitation, Visual Disturbance

I. Introduction

Virtual Reality (VR)-based training has been shown to be an effective intervention for enhancing patients' motivation and rehabilitation outcomes, e.g., to regain balance and gait function [1], [2]. In conventional VR-based gait training, the virtual environment is usually displayed on a flat screen, and patients interact via a symbolic virtual representation of their limbs (e.g., a cursor).

With the recent rise of low-cost, off-the-shelf Head-Mounted Displays (HMD), there is a paradigm shift toward more immersive experiences. In such experiences, patients can see a virtual representation of their body (*avatar*) from a first-person perspective, which can be animated to follow their real-time movements [3]. This more immersive visualization allows for the embodiment of avatars, i.e., the processing of the avatar's limbs like the user's own [3]. The embodiment of avatars can, in turn, be employed to modulate the planning and execution of movements [4]. For example, Burin et al. showed that when there is a mismatch between the users' real movements and those of the avatar, users unknowingly move their limbs to match the avatar's movements [5]. Similarly, Gonzalez-Franco et al. conducted an experiment where they manipulated the mapping between the users' real and avatar movements and observed an effect they referred to as the *avatar follower effect* [10]. This effect is believed to stem from the brain's inherent adaptability to maintain a stable body image despite the ongoing changes in perceptual features, such as alterations in skin color resulting from sun exposure. The brain tends to optimize resources by adapting to deviations resulting from a mismatch between sensory signals, e.g., proprioceptive-visual incongruency between the real and virtual limbs [6], for example, by "following" the movements of avatars.

One potential application of the *avatar follower effect* is in the field of gait rehabilitation. By modulating the position of the virtual legs of an embodied avatar, changes in the leg kinematics and gait parameters of the real patients' movements could be promoted and leveraged to enhance rehabilitation outcomes. Although there has been initial research in this direction with healthy participants, the results have been inconclusive. Côté et al. investigated changes to hip flexion during walking due to the modulation of the flexion angle of the avatar's hip. They found no consistent differences in the participants' hip angles [7]. In a similar design, Agopyan et al. observed increased knee flexion when increasing the avatar's knee flexion. Although, this effect was not observed when the knee flexion of the avatar was decreased [8]. However, it is important to note that both studies used flat screens instead of an HMD. The use of a flat screen might have limited the embodiment of the avatar [9] and could have therefore limited the avatar follower effect [5]. Wilaert et al. did employ an HMD in an experiment in which they modulated the step length of an avatar viewed from a first-person perspective [10]. Their goal was to induce step length changes to reduce gait asymmetry in stroke patients. They found that participants tended to change their step length to match that of the avatar.

These previous studies support the idea that visual disturbances, i.e., incongruencies between the real and avatar visualized movements, can indeed be a promising tool to induce changes to the gait cycle when using HMDs. However, little attention has been put into exploiting the potential of visual disturbance to enhance movement variability during gait rehabilitation. High movement variability has been shown to be positively associated with accelerated motor learning [11]. Efforts in the field of robot-aided rehabilitation have shown promising results when enhancing the movement variability through haptic disturbance, i.e., random force pulses provided during step-like movements [12]. However, while adding haptic disturbances during training might increase movement variability, and thus motor learning, it might also decrease the participants' feelings of competence and hence their motivation, as the task becomes too challenging [13]. Motivation has been suggested to play an important role in motor learning and neurorehabilitation [14], and as such, it is important to prevent participants from getting frustrated during training.

We aim to overcome the limitations of haptic disturbance by leveraging the *avatar follower effect* to enhance the movement variability during gait training using visual disturbances while guaranteeing participants' motivation. We hypothesize that the avatar follower effect can induce increased movement variability in the user's gait pattern, which could lead to benefits in motor learning and gait neurorehabilitation.

To apply this visual disturbance, we propose to add a noise-like disturbance to the tracked position of the real feet and display these disturbed feet positions in the avatars' feet visualized from a first-person perspective using an HMD. This disturbance will comprise an offset occurring in the horizontal plane, which will only change during the swing phase of the gait cycle. We plan to run a within-subject experiment with healthy participants, through which we will compare the movement variability of the gait cycle with and without this proposed visual disturbance. Our research question is whether inducing a visual disturbance to the position of an embodied avatar's feet can cause increased *movement variability* in the user's gait pattern during natural walking while not hindering participants' *motivation* and *embodiment*. Here, we present our first steps toward answering this question.

II. Methods

A. Experimental Setup

The experimental setup for this study involves the use of the HTC Vive Pro Eye HMD (HTC Corporation, Taiwan) and five HTC-Vive 3.0 trackers (HTC Corporation, Taiwan) to track the movements of the participants' lower limbs while they walk on a treadmill; one tracker attached to the participant's waist (at iliac crest level), one tracker attached to each thigh (about ten centimeters above the knee), and one tracker attached on top of the midfoot of each foot (Fig. 1). The trackers will be attached to the participant using commercially available tracker straps. Additionally, participants will hold on to two HTC Vive Pro 2.0 controllers (HTC Corporation, Taiwan) to track their hands. Four lighthouses are positioned around the treadmill to ensure that all tracked devices are always visible by at least two cameras.

During the experiment, participants will walk on a treadmill, whose speed will be set to the participants' self-selected comfortable speed. To negate falling risks during the experiment, we will employ a bodyweight support system that does not hinder the natural pelvis movements of participants, thanks to its two actuated degrees of freedom in the human frontal plane [15]. The complete setup is shown in Fig. 1.

The virtual environment is built in the Unity Game Engine, release 2021.3.15f1 (Unity Technologies, USA). The virtual environment is configured to run at a minimum of 90Hz, corresponding to the refresh rate of the HMD, providing the participants with a smooth and immersive experience. We will run the experiment on a Windows 10 (Microsoft, USA) machine with an NVIDIA GeForce RTX 3080 GPU, 32 GB of DIMM DDR4 working memory, and an AMD Ryzen 5900X 3.70 GHz 12-Core processor (AMD, USA).

B. Virtual Environment

Two avatars, a male and female version, were developed via Ready Player Me (https://readyplayer.me/, 2023). The position of the avatar's limbs will be animated using the HMD, waist, and feet trackers' and (handheld) controllers' positions and orientations using a custom package developed by the authors. This package uses Unity's Animation Rigging package (Unity Technologies, USA, version 1.0.3) and implements inverse kinematics through a set of kinematic constraints. The trackers attached to the thighs do not influence the position of the avatar's

Fig. 1 Left: a participant wearing the trackers to be used during the experiment, consisting of 1) the trackers attached to the feet 2) the trackers attached to the thighs, 3) the controllers tracking the hand positions, 4) the tracker attached to the waist, and 5) the head-mounted display. Additionally, the bodyweight support and treadmill can be seen. Right: the male version of the avatar in the virtual environment that will be used for the experiment.

legs, and they are only used to gather the motion tracking data of the thighs, which we will use to calculate the joint-level variability. The virtual environment participants will walk through looks like a long, shallow river. Our reasoning behind the choice of this environment is that the water will act as an intuitive explanation for the visual disturbance of the feet' positions.

C. Visual Disturbance

The visual disturbance will be applied as a noise-like offset on the avatar's foot position in the horizontal plane that will only change during the swing phase of the gait cycle. During the stance phase, the offset will not suddenly disappear but remain constant, as otherwise, this would look unnatural and might break immersion or reduce the level of embodiment. The visual disturbance will be applied to both feet independently. We will carefully choose the magnitude and frequency of the disturbances to ensure they are hardly noticeable to the users. We do this to limit their potential hampering effects on the sense of agency, i.e., a subcomponent of embodiment that relates to the feeling of being in control over the own movements. The visual disturbance is illustrated in Fig. 2.

D. Experimental Procedure

First, we will provide participants with a general explanation of the experiment. After this, we will attach the five trackers to the participant (see Fig. 1). Participants will then wear the HMD and hold the two controllers. An experimenter then performs a brief, one-time calibration procedure in which the (gender-matched) avatar's height is uniformly scaled to match each participant's height. Additionally, offsets between the trackers and the tracked positions on the avatar will be calculated to match the avatar's body to that of the participants. We will apply the same offsets during the whole experiment. Finally, participants will be fitted with a bodyweight support harness, which will not bear any of their weight but will be a safety precaution to prevent falling. Once the setup is completed, we will ask participants to familiarize themselves with the setup and virtual environment by walking naturally for two minutes without any visual disturbances. During this time, they will be able to indicate a desired and comfortable walking speed which will be used for the rest of the experiment.

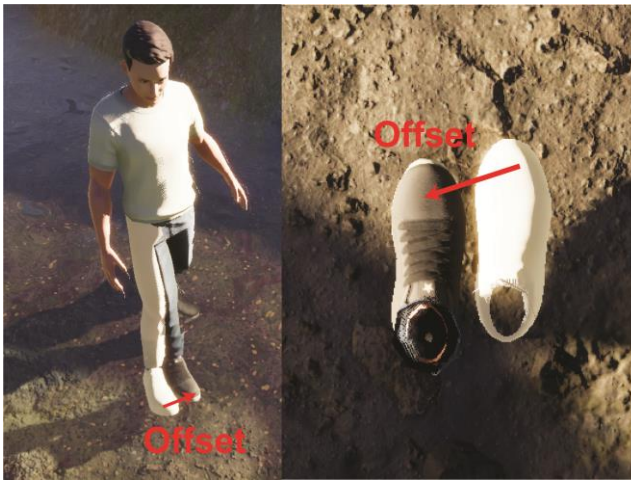

Fig. 2 Illustration of the visual disturbance. The white avatar leg and shoe represent the real foot position, and the colored versions represent the displayed avatar position. The offset occurs in the horizontal plane and can occur in both the lateral and longitudinal directions. To better demonstrate the visual disturbance, the image on the right shows only the avatar's foot. During the experiment, the full avatar will be shown.

Each participant will perform two five-minute walk tests, one with visual disturbance and one without visual disturbance. The order in which we present these walk tests will be counterbalanced between the participants to account for potential learning and exposure effects. After each walk test, we will ask participants to remove the HMD and answer a questionnaire. Before starting the next walk test, we will ask participants to rest for five minutes to mitigate any effects caused by fatigue. The whole experiment, including the questionnaires, will have an approximate duration of 20 minutes.

E. Outcome Metrics

Gait variability will be evaluated using various metrics. We will assess *stride time variability* by calculating the coefficient of variation, which is the standard deviation of stride time divided by the mean stride time for each walk test. We will also evaluate *stride-to-stride variability* by calculating the standard deviation of the distance between the footsteps of each walk test. Furthermore, we will measure *step width variability* by calculating the standard deviation of the lateral distance between the two feet at each step.

Joint-level variability and *ankle end-effector variability* will also be assessed using motion capture data from the trackers placed on the participant's legs. Joint-level variability will be calculated as the standard deviation of the range of motion for each joint (hip, knee, and ankle) using the waist, thigh, and foot trackers. The ankle end-effector variability will be calculated as the standard deviation of the 3D position values of the foot trackers across the steps for that walk test.

Motivation will be measured using a subset of six statements from the Intrinsic Motivation Inventory, focusing on perceived competence, effort/importance, and interest/enjoyment [16]. *Embodiment* will be measured using the Avatar Embodiment Questionnaire, which consists of 16 items that assess the level of embodiment experienced by participants when controlling an avatar in a virtual environment [17].

III. Conclusion and Outlook

Here, we presented the first steps toward a novel approach to enhance movement variability using visual disturbances through an embodied avatar in immersive virtual reality. By modulating the position of the avatar's feet in the horizontal plane during the swing phase, we aim to induce an increased movement variability in the user's gait pattern as a means to improve gait rehabilitation. We will also evaluate the users' levels of motivation and embodiment through questionnaires, as these factors have been suggested to play an important role in motor learning and neurorehabilitation. The proposed study will help to gain a better understanding of the potential of visual disturbances to enhance motor variability using an embodied avatar in immersive virtual reality.

Data collection is currently planned to start in late April 2023. We aim to present our preliminary results at the WCISVR

2023. In future work, we plan to study how this potential effect compares to and may be combined with- haptic disturbances in robotic gait rehabilitation devices. Through this follow-up experiment, we hope to investigate the optimal combination of haptic and visual disturbance that would result in the largest increase in variability without affecting the participants' motivation and embodiment.

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Are individuals with chronic moderate to severe traumatic brain injury able to safely walk in the community? Exploring the challenges of dual-task walking while avoiding virtual pedestrians.

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***Abstract*— Individuals with a moderate-to-severe traumatic brain injury (m/sTBI) present alterations in sensorimotor and cognitive functions that can affect their ability to perform the complex walking tasks required for independent community ambulation. Whether their ability to circumvent pedestrians under single and dual-task conditions is altered, however, remains unclear. The aim of this study was to assess cognitive and locomotor dual-task costs (DTCs) in m/sTBI individuals and healthy controls (CTLs) during a collision avoidance task involving virtual pedestrians (VRPs). Twelve individuals with m/sTBI and 12 CTLs performed the collision avoidance task with VRPs, as well as a cognitive (pitch discrimination) task, under single and dual-task conditions. Overall, CTLs showed negative DTCs (performance enhancement) for all locomotor outcomes, as opposed to positive DTCs (performance deterioration) for the m/sTBI group. Under dual-task conditions, the m/sTBI group demonstrated a delayed onset of trajectory deviation and maintained a smaller minimum distance from VRPs, as opposed to the CTLs who displayed an earlier trajectory deviation and a larger minimum distance. A larger positive DTC for cognitive task accuracy was found in the m/sTBI group vs. CTLs. Individuals with m/sTBI present altered collision avoidance strategies under dual-task conditions, which may contribute to their reduced community walking abilities.**

Keywords—Traumatic brain injury, Dual-task walking, Obstacle avoidance, Cognitive function, Virtual reality

I. Introduction

Walking in the community is a complex activity that requires one to perform ongoing adaptations of the locomotor behavior as a function of the physical and social environments [1]. Successful obstacle avoidance in particular is crucial for safe and independent community walking and it becomes especially challenging in situations where attention is divided, increasing the risk of collisions [2] and falls [3]. Obstacle avoidance requires the implementation of anticipatory and online locomotor adjustments that rely on the integration of sensorimotor information and higher-level cognitive functions [4].

Traumatic brain injury (TBI), a leading cause of death and disability globally [5], can lead to sensorimotor and cognitive impairments [6] that negatively impact the completion of daily life activities. Although chronic moderate-to-severe TBI (m/sTBI) survivors often present a good prognosis for locomotor recovery [7], walking in the community remains compromised [8]. When it comes to complex walking tasks, such as stepping over an obstacle, hopping, walking on irregular terrains, limitations become even more manifest [8, 9].

Despite of that, there is a paucity of research on complex locomotor tasks such as obstacle avoidance among the m/sTBI population [10], both under single and dual-task conditions. To date, only one unpublished study has investigated the strategies used by a m/sTBI population to circumvent (going around) obstacles [11]. Further investigation is needed, however, to extend the results of this study to a larger sample size and to a context representative of an ecological community environment, with moving pedestrians as interferers as opposed to objects. In addition, the previous study examined the impact of dual-tasking on obstacle circumvention using a visually-based cognitive task, thus interfering with the acquisition of visual information needed for the obstacle circumvention task [12]. Therefore, this study aims to determine, in individuals with m/sTBI vs. healthy controls (CTLs), the cognitive and locomotor dual-task costs (DTCs) associated with the simultaneous performance of an auditory-based cognitive task and a collision avoidance task involving virtual pedestrians (VRPs) ambulating in a community environment.

II. Methodology

A. Study design

This study used an experimental, repeated measure design.

B. Population

A sample of convenience of 12 individuals with a chronic m/sTBI (age=43.3±9.5 [mean±1SD], 3 females, 9 males) and 12 CTLs (age=41.8±8.3, 4 females, 8 males) were recruited. To participate in this study, individuals in the m/sTBI group had to be aged between 18 and 55 years, to be able to walk independently over 10 meters with a gait speed of 0.7 m/s or greater and to have sufficient cognitive function to provide informed consent and follow instructions. Participants in the CTL group were matched for age and sex and presented intact cognitive and locomotor functions. Additionally, both groups presented normal or corrected-to-normal visual and auditory acuity, as well as a primary education in English or French. The study was approved by the Research Ethics Board of the Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR).

C. Experimenal setups and procedures

This study took place at the VR and Mobility Laboratory at the Jewish Rehabilitation Hospital, which is a research site of the Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR). All participants were assessed while performing the following tasks, presented in a random order.

Single Walking Task

Participants walked overground while immersed in a virtual environment representing a Montreal subway station, which was displayed in an HTC VIVE Pro Eye head-mounted display (HMD). Three female VRPs were positioned in the far space in an arc fashion (middle (0◦), left (−30◦), and right (30◦)) in front of the participant (see Fig.1 A), with a theoretical point of collision (TPC) located 3.25m in front of the participant. Once participants began walking and reached a distance threshold of 0.5 m of forward displacement, one of the three VRPs located in the far space started walking toward the TPC while the two others took one step forward, turned around and walked away (see Fig. 1). Participants were instructed to walk towards the metro map (target) while avoiding colliding with any VRP, as applicable. Five conditions of VRP approach were presented in a random order (left, middle, right, none, all VRP turning back; 6 trials per condition). Locomotor outcomes for the left, middle and right VRP approaches were averaged together and considered in the analysis as part of this paper.

Single Cognitive Task

Participants were assessed while seated. They viewed the static virtual metro scene within the HMD that also provided audio capability. They completed auditory pitch-discrimination tasks with two levels of complexity. In the simple cognitive task, participants would hear the word "Cat" (or "Chat" in French) with either a high or low pitch. In the complex cognitive task, the words "High" or "Low" ("Haut" and "Bas" in French) were presented with a high or low pitch, creating a situation of potential interference between the pitch of the audio stimulus vs. meaning of the word (Stroop Task). In both tasks, participants verbally reported whether the pitch of the audio stimulus was high or low. Audio stimuli were presented at a variable stimulus interval of 1.5-1.9s. Three 50s-duration blocks for the simple cognitive task and for the complex cognitive task were presented.

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Dual Task Conditions

Fig. 1 – Frame captured from a trial with left VRP as an interferer, showing the virtual environment (metro station), the target (metro map) and the other VRPs walking away.

The dual task conditions required participants to perform both the locomotor collision avoidance task and the cognitive task (either simple or complex) concurrently, resulting in two dual task conditions: simple and complex. The set-up and procedure were the same as described above. Each of the dual-task conditions (simple or complex) comprised 30 trials and the order of presentation was randomized.

D. Outcome measures

The outcomes reported in this paper include the dual-task costs (DTCs) in terms of cognitive accuracy (DTC_cog), onset distance of trajectory deviation (DTC_onset), minimum distance (DTC_dist) and mean walking speed (DTC_speed). The DTCs were calculated as the relative difference between the single task and dual task conditions using the following formula: DTC (%) = (Single Task (ST) – Dual Task (DT))/Single Task (ST)*100. All locomotor outcomes were calculated in a time window comprised between the onset of VRP displacement and the point of crossing of the participant and VRP, with the exception of mean walking speed which was calculated as from 1m from the starting position to exclude the acceleration phase.

E. Statiscal analysis

Outcomes of DTCs were contrasted across conditions (simple vs. complex dual task) and groups (m/sTBI vs. CTLs) using generalized estimating equations (GEE). Statistics were performed in SPSS with an alpha level of significance set to $\rho<0.05$. Only collision-free trials were included in the statistical analyses.

III. Results

Overall, participants in the m/sTBI vs. CTL group did not significantly differ in terms of age (t=0.412, ρ=0.684) and sex (x^2=0.202, ρ=0.6530) but the overground comfortable walking speed as measured by the 10m Walk Test was faster for CTLs vs. m/sTBI (Δ=0.222m/s, t=2.289, ρ= 0.032). In this study 16 collisions were registered, which represents 1.25% of all trials analyzed. The m/sTBI group contributed with 9 collisions and the CLT group with 7. Seven collisions occurred in the single walking task, 3 in the simple dual task and 6 in the complex dual task.

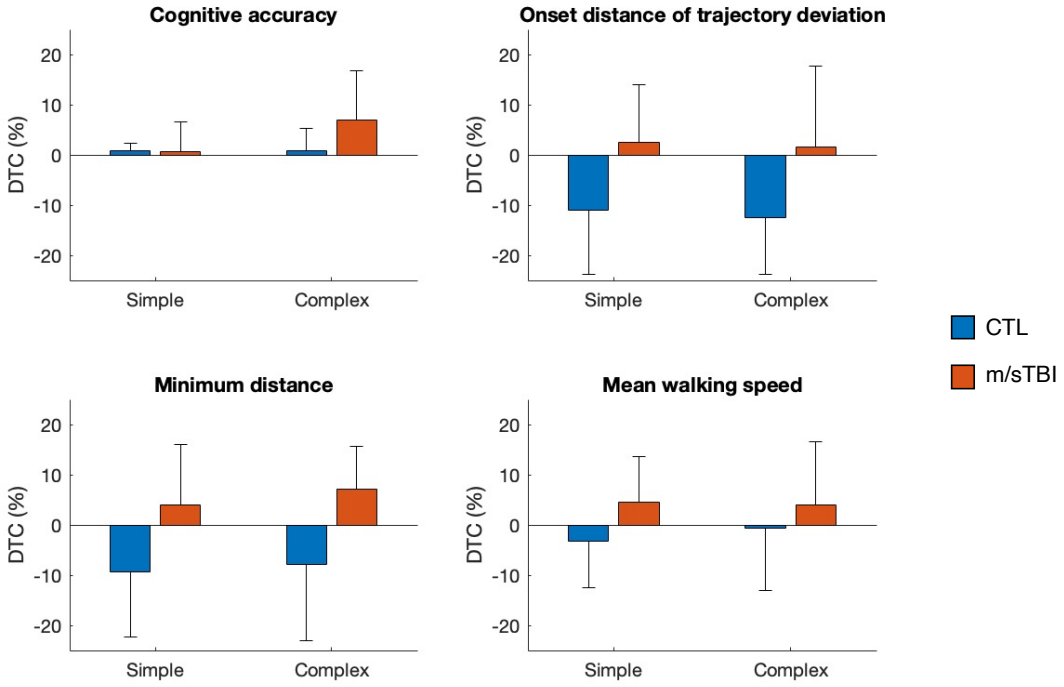

Fig. 2 – Mean±1SD for dual-task cost in terms of cognitive accuracy, onset distance of trajectory deviation, minimum distance, and mean walking speed.

A. Locomotor DTCs

Overall, CTLs showed negative DTCs (performance enhancement) for all locomotor outcomes, as opposed to positive DTCs (performance deterioration) for the m/sTBI group (Fig. 2). In addition, a statistically significant main effect of group was found for DTC_onset (x^2 (1,48) = 10.791, ρ=0.001) and DTC_dist (x^2(1,48) = 10.296, ρ=0.001), but not for DTC_speed (x^2(1,48) = 2.269, ρ=0.132). In other words, under dual-task conditions, the m/sTBI group demonstrated a delayed onset of trajectory deviation and maintained a smaller minimum distance from VRPs, as opposed to the CTLs who displayed an earlier trajectory deviation and a larger minimum distance. No significant main effects of task complexity or interaction effects of group * task complexity were observed for any of the locomotor outcomes (task complexity: ρ = 0.244 to 0.697; group * task complexity: ρ = 0.252 to 0.920).

B. Cognitive DTCs

Positive DTCs in cognitive task accuracy varying between 0.62% to 6.91% were observed in the two groups, meaning they experienced overall a small reduction in cognitive performance under dual-task conditions. A statistically significant main effect of group was found for DTC_cog (x^2(1,48) = 4.299, ρ= 0.038), with a larger DTC in the m/sTBI vs. CTLs. Furthermore, and while the discrepancy in DTCs between the groups appeared exacerbated in the complex dual-task condition, DTC_cog did not show a significant main effect of task complexity (ρ= 0.110) or interaction effect of group * task complexity (ρ= 0.109).

IV. Conclusion

The earlier trajectory deviation and larger interpersonal distances observed in the healthy individuals under dual-task conditions may reflect the adoption of a safer or more conservative avoidance strategy that has allowed minimizing changes in cognitive performance. At variance, m/sTBI individuals experienced an overall reduction in performance in both the locomotor and cognitive tasks under dual-task conditions. The delayed onsets of trajectory deviation and smaller interpersonal distances adopted under dual-task conditions could put those individuals at risk of collisions with pedestrians when navigating in crowded community environments, especially if carrying out a cognitive task simultaneously. Overall, present results indicate that dual-task walking abilities are compromised in individuals with a chronic m/sTBI who otherwise show a good recovery of their walking abilities. This highlights the need to assess and train such abilities in the context of locomotor rehabilitation.

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Gait Adaptations During Constrained Immersion: Assessing the Role of Virtual Boundaries

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***Abstract*—When immersed in a virtual reality (VR) environment, users have been shown to adjust spatiotemporal gait parameters in comparison to both non-immersed overground and treadmill-based locomotion. However, these differences are highly inconsistent, and key questions remain regarding the physical and virtual contextual factors that drive them. Here, we explore how manipulating physical objects and their virtual equivalents can impact the relationship between the observable environment and the motor strategies used to ambulate through it. Five unimpaired young adults were instructed to walk at a comfortable speed under several visual conditions on a self-paced treadmill. Treadmill handrails, both virtual and physical, were either implemented or removed to manipulate visual mediolateral constraints on the participant's explorable mediolateral space. Overall, participants demonstrated relatively small adjustments to gait strategy between VR and real-world visual settings while walking on a self-paced treadmill. However, the removal of the virtual boundaries was associated with a significant increase in walking speed via increased step length and decreased step time when compared to the constrained virtual space. Together, these results demonstrate a role for strategically controlling both the walking environment and cues in the virtual space to accurately measure gait changes between virtual and real-world contexts.**

***Keywords*—virtual reality (VR), head-mounted display, gait, biomechanics, self-paced treadmill**

I. Introduction

Recent improvements in virtual reality (VR) technology have expanded the potential applications for gait research and clinical rehabilitation, but studies of the biomechanical adaptations to walking in virtual environments remain inconsistent in their findings. Prior studies have demonstrated that gait adaptations in virtual environments are highly dependent on both the context of the physical and virtual environment in which they are observed (e.g. overground vs treadmill surface, treadmill controller if used, VR immersion type, and scene design). Walking in a VR-dome at a fixed treadmill speed can induce gait changes including reduced stride lengths, increased stride widths, and increased variability in stride velocity when compared to the real-world [1]. In contrast, when participants walked in a VR-dome with a self-paced treadmill, a few gait parameters were significantly altered, but not were large enough to be clinically relevant [2].

This study was funded, in part, by the Binational Science Foundation (BSF#2019222).

Fig. 1. The virtual environment viewed by the participant in a head-mounted display depicted an infinitely long school hallway. Virtual treadmill boundaries co-located with their phyiscal counterparts were either displayed for mediolateral reference, or removed for the immersive walking trials.

It is well established that the design of a virtual scene can modify the relationship between the environment and resultant behavior. Objects in the real world have associated affordances [3], or actions that are perceived as performable in the current context, that may be translated or adjusted in virtual settings. For example, virtual doorway interactions observed by a previous group exhibited similar affordances to their physical counterparts in terms of pass-through ability while participants dynamically explored the virtual space [4]. Although SPTs attempt to more closely mimic overground walking environments, there are affordances associated with mediolateral geometric constraints (i.e. treadmill handrails) that limit environmental exploration along the perpendicular axis of motion. Therefore it is unknown, whether or not virtual boundaries can impact gait adaptation in the same manner as real boundaries.

Furthermore, the immersive experience of wearing a head-mounted display (HMD) VR device may induce additional gait adaptations. Prior groups have identified decreases in walking velocity when walking overground in an HMD [5], although these differences may be reduced beneath significance with increased exposure to the virtual environment (VE) [6]. To our knowledge, there is little scientific evidence regarding the biomechanical adaptations of HMD displays measured in

an SPT environment. In this study, we aimed to characterize these changes by assessing several spatiotemporal parameters to identify the effects of HMD immersion on self-directed gait patterns. In the second aim of this study, we evaluated the role of geometric constraining via lateral boundaries on resultant spatiotemporal gait parameters in both a real-world and immersed SPT walking.

II. Methods

A. Participants and Experimental Procedure

Five young adults (1 female and 4 males; Age: 26.7 ± 4.07 years) without clinically significant gait or neurological impairments participated in a series of trials to examine biomechanical differences associated with constrained walking in virtual and real-world environments. Each participant performed four consecutive bouts of self-paced walking in a full-factorial design for controlled viewing environments (immersed in an HMD and viewing the real world) and visual contexts (with and without mediolateral treadmill boundaries). Prior to beginning the experiment, participants familiarized themselves with walking on the SPT both in a non-immersed and virtual environment during two 5-minute acclimation periods. Participants verbally confirmed that they felt capable of maintaining a comfortable speed on the treadmill after both acclimation periods. During each experimental block, subjects were instructed to maintain a steady, comfortable walking pace that they would adopt in a normal overground setting for 6 minutes. Kinematic data for 39 relevant anatomical landmarks was collected using a 16-camera motion capture system (sample rate: 120 Hz; Qualisys, Gothenburg, Sweden).

B. VR-Treadmill System

Participants performed all trials on an instrumented treadmill (Bertec, Ohio, USA) operating in self-paced mode. Briefly, a proportional-derivative (PD) control algorithm was implemented to minimize the relative displacement and motion of the user's center of mass (COM) along the anterior-posterior axis of the treadmill belt. COM movement was estimated in real-time using the average position of four motion-capture markers denoting the pelvis (bilateral anterior and posterior superior iliac spine).

The immersive VE was created in Unity game development platform (Unity Technologies, California, USA) and displayed on an HMD device (Oculus Quest; Facebook Technologies, California, USA). The translational velocity of the VE updated in real-time to reflect the motion of the subject using walking speed data from the PD treadmill algorithm. Visual reference objects in the scene (eg. doorways, lockers, benches) and wall distances were scaled isometrically in reference to the real-world laboratory setting of the experiment (Fig. 1). Treadmill handrails were virtually reproduced and co-located with the real-world positions for mediolateral spatial reference. These virtual objects were removed from the scene for the experimental conditions without boundary visualization, however the physical handrails were kept on during all immersed trial for additional subject safety.

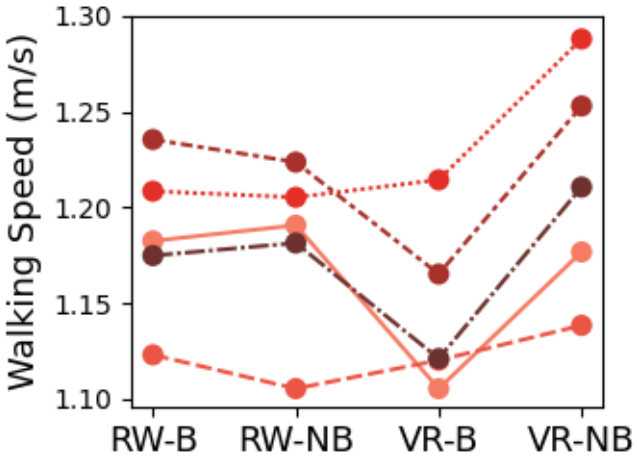

Fig. 2. Walking speed mean values for a 2 x 2 factor design to evaluate visual surround: real world (RW) vs. virtual reality (VR), and boundary presence: mediolateral boundary (B) vs. no boundary (NB) effects. Each marker represents the mean walking velocity of a single participant for each of the four experimental conditions.

C. Gait Analysis

Kinematic data obtained from the motion capture system was used to measure several spatiotemporal gait parameters throughout the duration of the trial. Step length (SL) and step width (SW) were calculated as the difference in anterior-posterior and mediolateral calcaneus position at each heel strike event respectively. An additional kinematic correction as previously described by the authors [7] was applied to the SL calculation to correct for the distance traveled during the push-off phase of motion on a translating treadmill surface. Walking velocity was calculated as the parallel distance traveled during each step (SL) divided by the amount of time taken for each step (ST). 30 seconds of data was discarded at the beginning of the trial to account for an initial acceleration period, and all remaining steps (304 ± 29.5) were analyzed for each 6 minute bout. We examined the interaction of visual surround and boundary presence on each gait parameter using a two-factor repeated measures analysis of variance (ANOVA). Post hoc comparisons were conducted using Tukey's HSD test and all statistical tests set significance level at $p < .05$.

III. Results

A. Real-World vs. Immersive Self-Paced Walking

A two-factor repeated measures ANOVA (2 visual surround conditions x 2 boundary presence conditions) demonstrated a significant main effect of visual surround on SW variability as measured by coefficient of variation (COV) [$F(1,4) = 39.69$, $p = 0.003$]. Tukey's HSD post hoc comparisons indicated a significantly lower SW COV value ($p = 0.003$) for trials conducted in an immersive environment (5.35 ± 1.50%) than when walking in the real world (7.15 ± 1.95%). This analysis revealed no significant effects of visual surround on all remaining measures of mean and COV values for SL, ST, SW, or walking velocity.

B. Boundary Presence in Virtual Environments

The two-factor repeated measures ANOVA revealed significant interaction effects between visual surround condition and boundary presence conditions for mean walking velocity [$F(1,4) = 15.21$, $p = 0.018$] (Fig. 2), mean SL [$F(1,4) = 9.66$, $p = 0.036$], and mean ST [$F(1,4) = 49.68$, $p = 0.002$]. Post hoc comparisons using the Tukey's HSD test revealed significant differences between virtual immersion trials with and without mediolateral boundaries for walking velocity ($p = 0.008$, B: 1.15 ± .04 m/s, NB: 1.21 ± .06 m/s), step length ($p = 0.043$, B: 60.61 ± 2.76 cm, NB: 62.18 ± 2.65 cm), and step time ($p = 0.018$, B: 0.53 ± 0.03 s, NB: 0.51 ± 0.03 s). No significant main or interaction effects were found for the remaining spatiotemporal measures.

IV. Discussion

Virtual environments have been shown to induce changes in spatiotemporal gait parameters in comparison to nominal walking values, although these adaptations are inconsistent across varying physical and virtual experimental set-ups. This study provides an initial investigation into the ways in which fully immersive VR alters walking biomechanics in a self-paced treadmill environment. Additionally, we characterized the impact of implementing mediolateral boundaries to identify relationships with exploration space constraints using virtual and physical objects.

Our results suggest that during comfortable walking on a self-paced treadmill, participants exhibit limited adaptations in spatiotemporal gait parameters when exposed to a virtual environment. Between visual contexts, only a single evaluated parameter, step width variability (COV), demonstrated a significant decrease from self-paced treadmill walking in the real-world visual surround to the virtual environment. This limited effect of VR on gait is similar to that observed by Sloot et al. [2], suggesting that self-paced treadmills may not elicit the expected increase in cautious gait patterns previously identified with VR use, regardless of immersion type.

Furthermore, by employing an HMD to facilitate immersive treadmill walking, we have identified a novel method for evaluating relationships between real and virtual objects in a self-paced environment. We observed that participants adapted their gait patterns to the geometric constraints of mediolateral boundary inclusion in the virtual environment, but not when viewing the real-world surround. Participants adopted a significantly faster-paced gait when the virtual boundaries were removed from the environment, modulated by both decreased mean step times and increased mean step lengths. We speculate that removing a visual cue in the peripersonal space, which may induce depth and self-motion underestimations, facilitates an increase in resultant speed. Therefore, the results of this study suggest a critical role for designing virtual spaces carefully to avoid unintended biomechanical consequences that may not be reflected in a real-world environment.

One limitation of our work stems from the fixed order in which each experimental trial was completed. Due to the nature of the physical experimental setup, trials were performed sequentially in the manner presented in each figure. As such, potential timing effects from both motor learning and fatigue cannot be discounted in our analysis. However, we aimed to mitigate timing effects through both the inclusion of an extended acclimation period, as well as verbal confirmation from each participant that they were comfortable walking in the environment. Additionally, the small sample size of this preliminary study limits the statistical power of the two-factor ANOVA used for analysis. Future work should aim to address these limitations and explore the further impacts of boundaries in virtual peripersonal space on the biomechanics of immersed locomotion.

Acknowledgment

The authors would like to thank Gregory Teodoro for his work in the development of the virtual reality scenes. This study was funded, in part, by the U.S-Israel Binational Science Foundation (BSF#2019222).

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ISVR

International Society for Virtual Rehabilitation

Poster Session 2

09:45 to 10:45

July 25th, 2023

Novel Evaluation Tool for Visuospatial Neglect by using eye tracker-implemented head mount display

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***Abstract*— The aim of this study is to develop a novel evaluation tool for strategy of head-eye coordination based on the virtual environment by using head mount display. We prepared simple visual search task with absolute and relative coordinate. While absolute coordinate resembles to real world situation, relative coordinate enable patient to use head movement for the visual search. Similarity and difference of the eye and head motion between two conditions would give us to know whether a patient utilize head-eye coordination or not. Our developed system effectively shows unique behaviour in patients with visuospatial neglect and enables us for the dissociative evaluation of eye and head motion without head restraint.**

Keywords—virtual reality, visual recognition, spatial neglect

I. INTRODUCTION

We acquire plenty of visual information in the daily living. Eye-head coordination is one of fundamental element for the selective attention and visual perception [1]. Visual search has been utilize as an effective tool for the better understanding human visual recognition and perception, and the classical way for the eye tracking is under the restricted head movement. Considering the importance of eye-head coordination, it is worth trying to implement the new technology for the visual research in the condition where the head and body can actively move [2]. If eye tracking is to be performed without physical restraints, accurate tracking of head position and rotation, synchronization of head and eye data, and integration of the coordinate systems between head-tracking and eye tracking devices must be performed with visual displays that reflect them [3].

Virtual reality (VR) technology, such as head mount display (HMD), is expected to utilize for analyzing visual behaviour, including head and eye movements, under unrestricted conditions. Also, due to the ease of presenting various materials, VR has advantages as an evaluation tool, as it can reproduce and repeat scenes that would be difficult to execute in real-world scenarios. In fact, a clinical attempt using HMD and eye tracking has been reported in patients post stroke for the detection of visuospatial neglect (VSN) [4]. VSN is a brain dysfunction mainly occur after injury to the parietal region. It has been reported that VSN patients are less likely to turn both head and gaze to the leftward, with the eyes deflecting to the right in relation to the head [5]. Research for VSN using a combination of VR environments and eye trackers is a novel area that has just began from 2020 [6].

In this report, we propose a new evaluation tool for the different reference frames (absolute and relative coordinate) to overcome the limitation of restricted head in conventional gaze analysis. We describes the system configuration and demonstrate the results of clinical tests for three cases of VSN.

II. MATERIALS AND METHODS

A. System Configuration

VIVE Pro Eye (HTC Corporation) was used as the main hardware for our measurement system. The spatial positions and rotation angle of the HMD were estimated by infrared radiation projected from two base stations. Unity 2019.4.21f1 was used to build the virtual reality environment. C# was used as the programming language, and a laptop computer with a 64-bit operating system, Intel Core i7-10870H, Windows 10 Home, was used as the host PC to operate the experimental environment. Eye tracking data was acquired via SRanipal SDK v1.1.0.1 (HTC Corporation). The display and recording sampling frequency was 90 Hz. In this system, the developed Unity application was integrated into WPF (Windows Platform, .Net Frameworks) in C# to implement an operation GUI system using TCP communication. The gaze position and the frontal position of the HMD during the task were visualized and feedback only to the operator's viewpoint image in the inspector's GUI as shown in Fig.1(A).

B. Environment Setting

We prepared a simple visual search task in the virtual space with the background of constant brightness and color [7]. In order to precisely and separately evaluate eye and head movements during the visual search task, we prepared distinct two virtual environmental modes: one is located the task panel in fixed position in the VR frame of reference (Absolute Condition), and another is located the task panel in front of the straight ahead position even though the subject move his/her head (Relative Condition). Fig.1(B) showed the task board on HMD reference frame (subjects were asked to search red-highlighted object as quick as they could), and Fig.1(C) shows the schematic explanation for distinct two visual search tasks.

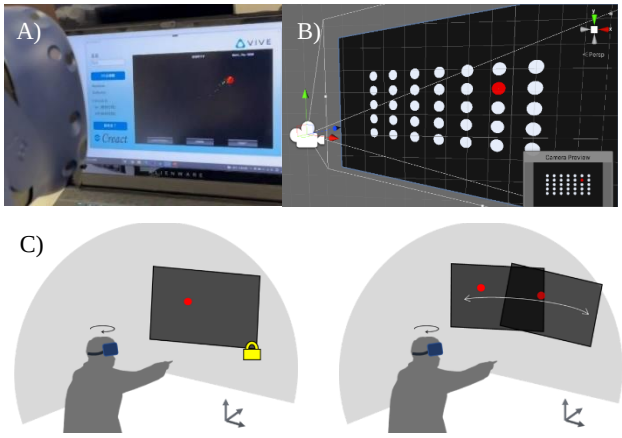

Fig. 1. Graghcal interface shows participant's view for operators(A). Task display board is located at a stationary position in front of HMD in rerative condition(B). These condition are set to capture eye and head movements(C).

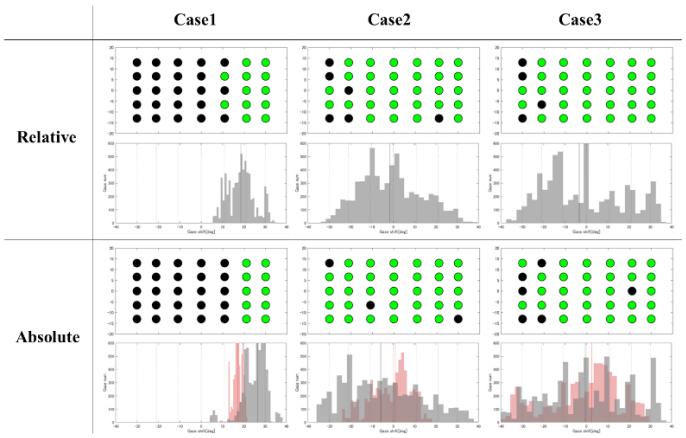

Fig. 2. Results of visual search tasks as the arrange of success (green) and failed (black). Gray and red bars in the histogram indicate eye and head movements, respectively

Visual stimuli were arranged as a transparent round optotype (target) placed in a 5 (rows) x 7 (lines) on a black plane in the VR space. Panel and targets were located vertically (in front of subjects) at the distance of 3 meters. The size of the panel was set to a radius of 1 meter. The order of red highlight in one of each object was set in completely random for each condition. The flashing was switched between red and transparent in 0.1 second increments.

C. Gaze and Head Movement Analysis

Recorded data are used to visualize the characteristics of behaviour in three patients post stroke. Data recordings and measurements were accompanied by a healthcare professional and the protocol of the measurement was approved by ethics committee of the National Rehabilitation Center for the Persons with Disabilities, Japan. All three patients had a diagnosis of VSN at the early stage of their recovery based on the clinical evaluation. In this study, the following time series data with different frame of reference (f.o.r.) were captured to evaluate the patient's head and gaze behaviour in each condition. By their nature, mobile eye trackers outputs gaze data in a head-centered frame of reference. Therefore, HMD-Eye Tracking is necessary to transform similarly the eye movement data into the world coordinate system in order to check what and in which direction the participants are looking in the world f.o.r [8].

We used the TransformDirection function provided in Unity C# to transform the 3D gaze vector in the HMD f.o.r output from SDK into a 3D scene f.o.r. Also, to evaluate the head rotation, a 3D vector head front vector was assumed. The intersection of the 3D gaze/front vector and the display board plane in the 3D scene f.o.r. was obtained by raycasting, and the intersection coordinates were converted to the relative coordinate system of the display board f.o.r in Unity C#.

III. RESULTS

Fig.2 shows the results of visual search task of both relative (top) and absolute condition (bottom). Green/black dots indicate success/fail of the object search. Gray and red bars in the histogram indicate gaze and head movements, respectively.

IV. DISUCCTION

With the utilization of eye tracker-mounted HMD, head rotation and eye movements can be easily and simultaneously recorded. The data obtained from Case 1 can be regarded as a typical behaviour in VSN. Case 2 and 3 could search almost all objects even under relative condition, but amount of gaze distribution tended to shift toward left space. The result of absolute condition in Case 2 is a typical behaviour of the leftward compensatory strategy (the patient recognizes his own neglect symptom).

The results of visual search task under distinct two, absolute and relative condition give us important materials to know the extent of eye movement and it's interaction of head movement. The above three cases involves not only the symptom of VSN but also unique compensatory strategy which can be recognized as an interaction between eye and head movements. Our developed evaluation tool which enables us for the dissociative evaluation of eye and head motion without head restraint.

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Constructing a gait analysis environment with virtual reality

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***Abstract*—**Along with the development and widespread use of virtual reality technology, a variety of physical activities are now able to be carried out with greater ease in more realistic visual environment. We focused on the gait control and investigated the effect of virtual visual information on gait. We built a gait analysis system using a head-mounted display and virtual environment and showed that modifying visual space by using virtual reality technology can influence gait control.

Keywords—gait analysis, virtual reality, visuospatial cognition, gait rehabilitation, 3D motion analysis

I. INTRODUCTION

Our movement is adapted to the surrounding visual environment. Two routes are considered to be involved in the processing of vision: one to recognize the object itself, and the other to recognize the spatial location of the object [1]. Walking is intended to occur subconsciously by using these two different pathways to gather visual information. It is supposed that the walker continuously pay attention to the visual information along the walking route, and that safe walking is maintained through a dynamic interaction between the body and the perceived visual information [2]. Predictive gait control works to avoid obstacles when visual information of obstruction is obtained while walking, with change in gait parameters such as walking velocity and cadence. In the patients with Parkinson's disease, walking velocity is adjusted when passing through a gap, suggesting that predictive gait control by visual information is exerted [3]. Changes in walking velocity are observed in these patients when a clear visual stimulus on the floor of the walking path is perceived during walking [4]. Hence, in addition to motor and sensory processes, various visual information may also affect our walking movement in both normal and pathological conditions. However, evaluations in real-world settings have limitations in changing visual information in detail to demonstrate its impact on the gait control. Here, we developed a virtual reality system to objectively evaluate the effect of modifying visual information on gait. The study was performed on elderly persons because it has been noted that motor function in the elderly may be more susceptible to the visual environment. [5], [6]. Specifically, this study aimed to reveal the effect of the width of the walking path and visual stimulus (stripe on the floor) on gait.

II. METHODS

Two male healthy subjects (73 years old and 77 years old) with no apparent cognitive decline participated in the study. As a control condition, subjects were instructed to walk as usual on a 5-m walking path. Then, they were randomly given the following visual conditions: (1) three different widths of the corridor in the virtual space (80 cm, 140 cm and 200 cm), (2) two different widths of the stripes on the floor of the corridor in the virtual space (50 cm and 25 cm) as visual stimuli. The subjects equipped a head-mounted display (VIVE Pro Eye, HTC), and were instructed to view the virtual space and walk on the corridor. The gait motion was recorded with a 3D motion analysis system (MAC3Dsystem, Motion Analysis Inc.). Gait parameters including walking velocity and cadence were calculated by using motion capture software (Cortex, Motion Analysis Inc.). We measured three times in each of the combinations of three widths of the corridor and the two widths of the stripes on the floor. Repeated measures analysis of variance (ANOVA) and Tukey's test were used to compare the gait parameters among the conditions. A *p-value* <0.05 was considered to indicate statistical significance. Statistical analyses were performed using SPSS Ver.24 software. This study was conducted after obtaining approval from the Ethical Review Committee of Osaka Yukioka College of Health Science. The subjects gave informed consent before participating the study. The overview of the experimental environment is shown in the Figure.

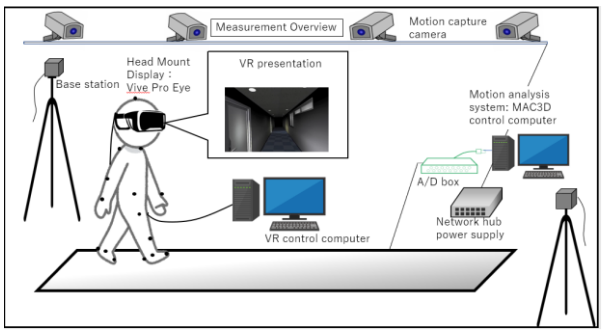

Figure. The overview of the experimental environment. The subject viewed virtual space through the head-mounted display. The motion of the subject is captured by eight cameras of the 3D motion capture system. A support person accompanies the subject to prevent falls (not shown in the figure).

III. RESULTS

Walking velocity and cadence in different visuospatial widths and floor patterns were shown in the Tables.

(1) The effect of the corridor width

There were no significant differences among the conditions in the walking velocity for both subjects, though in the subject 1, there was a trend toward decreased walking velocity in the narrower corridor condition. In the subject 1, the 80cm and 140cm width corridor condition showed significant increase in cadence compared with the control condition. In the subject 2, there was no significant difference among the conditions for cadence.

(2) The effect of the stripe width on the floor

There were no significant differences among the conditions in the walking velocity and cadence for both subjects, though in the subject 2, there was a trend toward increased walking velocity in the wider stripe stimulus.

Tables

(1) The effect of the corridor width

walking velocity m/min

	80cm	140cm	200cm	control
subject 1	47.0±5.6	46.4±3.3	49.4±6.4	52.0±4.4
subject 2	63.2±5.8	59.2±13.8	66.6±6.5	62.7±1.6

cadence step/min

	80cm	140cm	200cm	control
subject 1	53.7±0.6*	52.5±1.2*	50.6±2.7	45.6±3.2
subject 2	60.9±4.3	60.6±3.9	60.5±3.8	61.1±0.4

** p<0.05*

(2) The effect of the stripe width on the floor

walking velocity m/min

	50cm	25cm	control
subject 1	47.6±4.2	48.3±8.2	46.4±3.3
subject 2	84.4±17.6	73.9±6.7	59.2±13.8

cadence step/min

	50cm	25cm	control
subject 1	49.5±2.2	51.7±3.1	52.5±1.2
subject 2	58.9±0.7	63.9±3.0	60.6±3.9

IV. DISCUSSION

Although there were several previous studies conducting gait analysis in virtual environment while subjects were staring at a flat surface screen, this study is, as far as we know, the first report of gait analysis in immersive virtual space with a 3D motion capture system to evaluate the effect of modification of virtual visual environment. While the number of the subjects were limited and the preliminary results were not consistent in the subjects, the current experimental system was considered to be feasible to evaluate the effect of visuospatial cognition on gait.

V. CONCLUSION

Analysis of walking behavior in a virtual reality space is feasible with the presented experimental system.

ACKNOWLEDGMENT

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How do individuals with chronic traumatic brain injury avoid collisions with pedestrians presenting emotional gait patterns.

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***Abstract*— Avoiding collisions with surrounding pedestrians is necessary to navigate safely in the community. Adults with moderate-to-severe traumatic brain injury (m/sTBI) show less confidence in navigating complex environments and difficulty understanding the emotions of others. Thus, we aim to determine the modulatory role of emotional gait patterns of interferers on collision avoidance among m/sTBI individuals (n=10) and age-matched healthy controls (n=5). Participants performed a collision avoidance task to avoid virtual interferers displaying different emotional gait patterns in a virtual metro scene. Overall, the m/sTBI group adopted slower walking speeds and larger minimum distances compared to controls. A modulatory effect of emotional gait was also observed on walking speed, minimum distance maintained from interferers and onset distance of trajectory deviation, and this modulation was similar between groups. The observed changes amongst m/sTBI participants could reflect conservative collision avoidance strategies and underlying deficits in sensorimotor and cognitive functions.**

Keywords— Collision avoidance, emotions, locomotion, traumatic brain injury, virtual reality.

I. Introduction

A crucial requirement of independent community walking is the ability to avoid obstacles in the environment. When avoiding collisions with pedestrians, adjustments in parameters such as interpersonal space, direction, and speed of walking depend on both personal (related to the individual) and situational factors (related to the environment) [1]. A situational factor that affects one's locomotor behaviour is the presence of appetitive and aversive stimuli in the environment [2]. Emotional stimuli from surrounding pedestrians are expressed through changes in body movements and facial expressions [3]. In the context of pedestrian interactions, emotions arising from body movements would be especially relevant since they can be perceived at a distance [3]. A pilot study from our laboratory indicated that healthy young adults show a subtle modulation of interpersonal distances in response to pedestrians displaying different emotions of gait [4].

People with traumatic brain injury (TBI) often deal with cognitive and motor dysfunctions that interfere with their ability to adapt their locomotion to environmental demands [5]. The moderate-to-severe TBI population (m/sTBI) also experiences difficulties in understanding the emotions of others from cues like facial expressions and speech [6] and possibly body movements. In this project, we used virtual reality (VR) to simulate real-life scenarios and investigate the extent to which m/sTBI individuals, in comparison to age-matched healthy controls (CTLs), modulate their collision avoidance strategies in response to pedestrians presenting different emotional gait patterns. We hypothesized that compared to CTLs, individuals with m/sTBI would show less modulation of interpersonal distance and walking speed in response to different emotional gait patterns of virtual pedestrians (VRPs).

II. METHODOLOGY

To date, 10 participants with m/sTBI (age=44.5±13.4 yrs [mean ± 1SD]) and 5 healthy controls (CTLs, age=43.5±5.9 yrs) were recruited. Included m/sTBI participants were at least 6 months post-injury, could follow instructions and provide consent, and could walk without a walking aid at speed no less than 0.8 m/s. Additionally, participants of both groups presented

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normal or corrected-to-normal vision (EDTRS score of logMAR≥0.4).

Participants were assessed while immersed in a virtual metro station using a VR headset (HTC Vive Pro eye). They were asked to perform a collision avoidance task, wherein they walked overground to a goal located straight ahead while avoiding emotional VRPs. The VRPs approached from the midline (Fig. 1A), 45° left or 45° right, while displaying different emotional gait patterns (happy, sad, angry, and neutral). For this paper, only the middle approach, that is the most challenging condition in terms of obstacle avoidance [7], is reported. The Unreal engine was used to control the experiment, record (90Hz) the position and orientation of the participants' head, and calculate obstacle avoidance outcomes presented in this paper. Additionally, a 12-camera Vicon system recorded (120Hz) full body kinematics during the avoidance task. Minimum distance maintained from the approaching VRP, distance from the VRP at the onset of trajectory deviation (onset distance) and average walking speed (mean velocity) were contrasted between groups (2 levels) and emotional gait conditions (4 levels) using Generalized Estimating Equations (GEEs) in SPSS (29.0.0.0). Significance was set at $p<0.05$. When applicable, post-hoc pairwise comparisons with Bonferroni corrections were conducted.

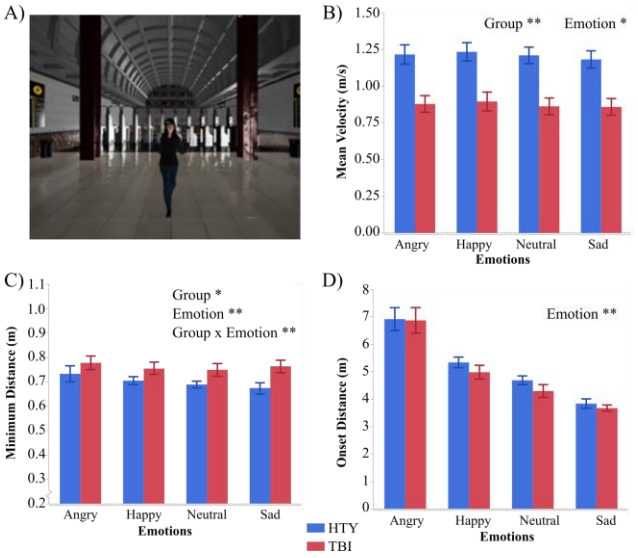

Fig. 1: A) An example trial with a virtual pedestrian displaying a happy gait pattern and approaching from the middle. Results showing means (±1SE) of the two groups for the 4 emotional gait conditions for: B) Mean velocity, C) Minimum distance and D) Onset distance. Significant results from GEEs are presented (* p<0. 05, ** p<0.001).

III. Results

The groups did not significantly differ (Wilcoxon rank sum test) in age (p=0.66) as well as comfortable (p=0.26) and maximum walking speed (p=0.85) measured by the 10m Walk Test. The prevalence of collisions was 1.38% and 4.16% for the CTL and m/sTBI groups, respectively. Collision trials were not analyzed.

During the collision avoidance task, the m/sTBI group exhibited slower walking speeds (p<0.001), larger minimum distances (p=0.027) and similar onset distances (p=0.357) compared to CTLs (Fig. 1 B, C & D). Emotional gait conditions significantly modified walking speed (p=0.03), minimum distance (p<0.001), and onset distance of trajectory deviation (p<0.001). A significant emotion X group interaction was further observed for minimum distance (p<0.001) but not for other outcomes (p=0.512 to 0.618).

Post-hoc comparisons revealed that both groups walked faster (p=0.005) in response to the happy vs. neutral gait condition. They further showed that the between-group difference in minimum distance was driven by the sad gait condition, for which the m/sTBI group maintained larger minimum distances from the VRP than the CTL group. The two groups also significantly varied in their onset distances of trajectory deviation for all pairs of emotional gait condition (p<0.001), showing progressively smaller values as they were exposed to the angry, happy, neutral and sad emotional gait conditions.

IV. Conclusions

In the context of a collision avoidance task, the emotions of gait displayed by VRPs acting as interferers affected circumvention strategies, as reflected by modulations of minimum distance from the VRPs, onset distance of trajectory deviation and walking speed. In contrast to our hypothesis, and although m/sTBI individuals maintained larger minimum distances and walked slower compared to healthy CTLs, their response to emotional gait conditions was similar to that of the healthy group. Overall, the observed changes in m/sTBI group may reflect underlying alterations in sensorimotor and cognitive functions and the use of a conservative circumvention strategy.

Acknowledgments

We thank Christian Beaudoin and Samir Sangani for their assistance with the VR experiment's programming and the virtual environment's design.

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Sit-to-stand kinematics in older adults under virtual height manipulation

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***Abstract*—Sit-to-Stand transfer is a critical component of functional independence and a targeted goal in motor training for elderly individuals with functional impairments. Manipulating ecological constraints during varied motor practice has the potential to optimize practice outcomes. Sit-to-Stand kinematics were assessed in fourteen older adults under two conditions of virtual height. Preliminary results did not show significant differences between virtual conditions, but did demonstrate specific relationships between sit-to-stand kinematics and personal characteristics such as balance self-confidence and anxiety.**

Keywords—Virtual reality, motor performance, balance, anxiety.

I. INTRODUCTION

Approximately 30% of older adults experience a fall every year [1], initiating a vicious cycle comprised of fear of falling and leading to decreased activity, and additional falls [2], [3] . The Five Times Sit-to-Stand test (FTSTS) [4] is an ecologically-valid assessment of lower limb strength, balance and functional capacity that has been shown to be a valid and reliable test in different populations, including healthy older adults [5], and is a predictor of falls and functional limitations in the older population .[6].

Environmental constraints have been shown to affect performance of Sit To Stand (STS) movements in both young and older adults [7] such that both groups were able to adapt to a threatening environment (risk of slipping) when performing STS, hence decreasing risk of falling in subsequent attempts. Thus, use of varying environmental constraints, including threatening environments, can be beneficial for training motor tasks such as STS.

Virtual reality (VR) is optimally suited for providing variation in environmental constraints for motor performance, given the ease of modifying visual information in virtual environments. This work aims to evaluate the effect of providing a threatening environment on the kinematics of the FTSTS task. Furthermore, we aim to quantify the relationship between personal characteristics (e.g. anxiety, balance self-confidence and functional mobility) with FTSTS performance in the different conditions.

II. METHODS

In this preliminary report of an ongoing study, 14 community-dwelling older adults were recruited for a single session where they performed the FTSTS in two VR conditions (VR-Low, VR-High) and one real-world condition (REAL), all while wearing an MVN Link motion capture full-body suit (Movella, Netherlands). In each condition the FTSTS was performed twice, allowing participants to rest between repetitions as needed. The trials were block randomized between participants using a Latin square design. The virtual environment, implemented using Unreal (Epic Games, United States) and displayed using an HTC Vive Head-mounted display (HTC, Taiwan) consisted of a room (with a chair, a door, sofa and lamps on the walls) viewed either at floor level (VR-low) or from a height of 3.2 meters (VR-high) (Figure 1). Participants rated the level of anxiety they felt following every trial using a Likert scale. Kinematics of STS, including movement duration, center of mass translation and smoothness, and peak hip flexion angle, were extracted from the MVN Link system as indicated below. In addition, participants completed questionnaires for trait anxiety [8] (Spielberger State-Trait Inventory; STAI), balance self-confidence (Activities-specific Balance Confidence questionnaire; ABC) [9] and completed the Timed Up ang Go test of functional mobility (TUG) [10].

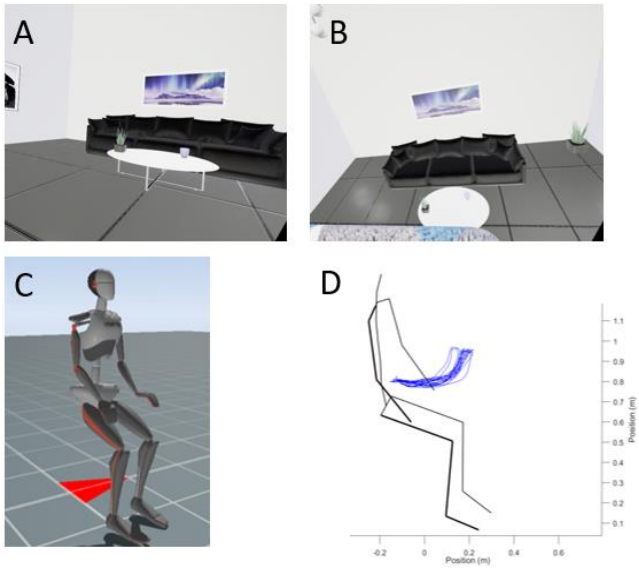

Fig. 1. (A, B) VR-Low (A) and VR-high (B) environments, set at height of 0 and 3.2 meters above ground. (C) XSens avatar during sitting (D) Stick figure sitting. Blue lines depict COM translation for 10 STS repetitions in REAL conditions.

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A. FTSTS kinematics

The following outcome measures were computed using custom-written Matlab code, separately for every STS repetition, following visual identification of the onset of each STS repetition: (1) *STS duration:* STS duration was defined as the time elapsed from initial trunk flexion to peak hip extension. (2) *COM translation:* the distance traveled by COM in anteroposterior and vertical directions. (3) *COM jerk:* defined as the number of peaks in the COM tangential velocity profile, (4) *Peak hip flexion:* maximal value of hip flexion during STS.

Kinematic measures were compared between VR-low and VR-high conditions using paired-sample T-tests, and correlations between personal characteristics and FTSTS kinematics in the different conditions was examined using spearman's correlation coefficients.

III. Results

All participants did not report significant anxiety during the experimental session (average self-reported anxiety <1 out of 10 and similar for all conditions).

TABLE I. PARTICIPANT CHARACTERISTICS (N=14)

Variable	***Value***
Sex	5M/9F
Age	69.7±4.7
Balance self-confidence (ABC)	87.0±12.7
Trait Anxiety (STAI)	29.5±6.4
Functional mobility (TUG, s)	9.32±1.9

No significant differences were found in movement performance between the real world and the VR-low condition, indicating fidelity between motor characteristics of both environments. When comparing the two VR conditions, a trend emerged for less vertical COM translation in the VR-high condition, with a moderate effect size ($t(13)=-1.8$, $p=0.097$, Cohen's $d=-0.48$). People with lower balance confidence and higher trait anxiety had larger peak hip flexion angles in all conditions (ABC: $r<-0.54$, $p<0.042$ for all conditions, STAI: $r>0.61$, $p<0.02$ for VR-low and a trend $r=0.5$, $p=0.07$ for REAL), and moved less smoothly only in the VR-High condition (ABC: $r=-0.55$, $p=0.04$; STAI: $r=0.56$, $p=0.04$). In addition, more anxious individuals took longer to complete each STS in the REAL ($r=0.56$, $p=0.04$) and VR-High ($r=0.59$, $p=0.03$) conditions, and lower functional mobility was associated with longer movement duration in the VR-low condition (TUG: $r=0.6$, $p=0.02$).

IV. Discussion

The environmental manipulation did not result in significant differences in motor performance. However, balance self-confidence and trait anxiety were both related to COM jerk in the VR-high condition and not in the other conditions. Thus, it seems that manipulating virtual height can expose some trait characteristics associated with anxiety in older adults. These results support the potential integration of the virtual environment as a valid tool of motor practice.

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Contrast Avoidance Model of Generalized Anxiety Disorder: Scenario Selection for Virtual Treatment

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***Abstract*— This study explores the potential therapeutic benefits of employing the contrast avoidance model (CAM) to treat generalized anxiety disorder (GAD). Long-lasting and challenging-to-control worry is a common symptom of GAD [1]. Despite the historically recognized efficacy of cognitive-behavioral therapy (CBT) with a GAD focus, its outcomes have not been optimal, emphasizing the urgent need for more effective interventions [2]. This research aims to create and test virtual reality (VR) exposure scenarios that could be utilized along with relaxation techniques in a randomized clinical trial to determine the effectiveness of the therapeutic strategy for treating negative contrast sensitivity. This paper describes the methodology and procedure for selecting GAD-relevant scenarios and developing their simulations in VR. The programming portion will employ the Unity Real-Time Development cross-platform solution to ensure the technology is portable and accessible to the general public. This approach will enable the technology to work with a wide range of devices, from phones to immersive professional headgear, making it accessible to a large population.**

Keywords*— *generalized anxiety disorder, virtual reality, exposure therapy, contrast avoidance model

I. Introduction

Generalized anxiety disorder (GAD) is a complex mental illness characterized by excessive worry that is long-term and difficult to manage. It can be accompanied by a range of somatic and psychological symptoms [1]. Several theoretical frameworks exist to account for persistent worry. Many consider anxiety a strategy to avoid processing fear and other distressing emotions (Cognitive Avoidance Model, Emotion Dysregulation Model, Intolerance of Uncertainty Model). In these models, anxiety is viewed as a mechanism for lowering arousal [3].

On the contrary, a growing number of studies show that worry tends to induce increased levels of arousal in both clinical and non-clinical individuals [4]. According to Affective Contrast Theory, the intensity of a perceived emotion is modulated by the emotion that precedes it; the greater the disparity one perceives, the greater the discomfort one feels [5]. Based on this theory, a Contrast Avoidance Model (CAM) of anxiety has been proposed [6]. According to this model, people with GAD deliberately focus on worry as the primary means of creating and maintaining negative emotional attunement, thereby actively reducing the impact of possible sudden negative events and avoiding strong emotional contrast that they perceive as threatening and unmanageable; this could also explain why people who chronically worry find this strategy useful and have positive beliefs associated with it [6].

Just approximately 50% of individuals with GAD respond to cognitive-behavioral therapy (CBT) [2]. Therefore, an intervention that more closely resembles exposure therapy (ET) combined with short periods of relaxation has been proposed [6]. In this method, patients with GAD are first put into a relaxed state until the parasympathetic system is activated, then they are exposed to adverse stimuli, creating a frightening contrast-related situation in a safe and controlled setting [6].

II. Study Design

The planned study aims to investigate the therapeutic potential of adopting CAM to treat GAD. For the proposed intervention, relaxation in virtual reality (VR) and exposure therapy (VRET) will be utilized. In this type of treatment, a head-mounted display (VR headset) is used to display realistic unpleasant stimuli. Because of its invariant architecture, relative ease of presentation of many positive and negative stimuli, and potentially global reach, VRET seems to be an appropriate way to administer such intervention.

Appropriate stimuli research is required to apply VRET to the treatment of GAD. Since VRET displays realistically unpleasant stimuli, such stimuli must be investigated in terms of their relevance to GAD. To determine whether this kind of treatment is beneficial, examining individuals' responses to these stimuli is necessary.

A. Investigating possible negative triggers

The stimuli used in the present study are based on existing research on aversive themes relevant to the GAD population and include only those replicable in VR. The list of considered scenarios was obtained from a scoping review of anxiety-related VR stimuli [7], which was cross-referenced with the Open Affective Standardized Image Set (OASIS) and The National Database of Virtual Reality Exposure (NDVR) to identify recurring universally unpleasant topics. Based on this process, we obtained a list of thirty items with brief textual descriptions

of scenarios that may be considered triggering by an individual with GAD. This list will be further researched to identify the five most universally valid scenarios.

B. Scoring and selection of stimuli

To narrow down the scenarios to the target amount of five, an additional study is being conducted. Two illustrative images per each potential scenario were generated using artificial intelligence (AI) Stable Diffusion v2.1 (https://stability.ai/). These visuals will be used along with textual descriptions in the questionnaire to evaluate the anxiety-inducing potential of the relevant scenarios. The images were made in black and white to reduce the emotional influence of color on the evaluator.

The universality of these scenarios is being studied among two distinct populations: 10 clinical professionals and 10 individuals diagnosed with GAD. The clinical professionals are assessing the applicability and generalizability of the scenarios for GAD patients. The GAD patients are providing an evaluation of emotional responses to imagined scenario exposure. After reducing the number of scenarios based on the assessments of both groups, the scenarios with the highest ratings (which all the participants regarded as triggering) will be employed in the study and implemented in VR. Fig. 1 compares the original AI-generated visuals evaluated by both groups (left) and the implementation in VR (right).

C. Used rating scales and questionnaires

The level of anxiety is measured using a validated research method based on one of the most standard tools for evaluating provoked anxiety, the Subjective Units of Distress Scale (SUDS). On a scale from 1 to 10, participants can rank the subjective intensity of their concern or distress of each situation, with 1 being the least and 10 being the most upsetting.

The Self-Assessment Manikin (SAM) is a scale adapted in the following validation of VR situations to quantify the emotional responses to them. The SAM is a visual analog scale that uses a series of images to measure participants' affective responses to stimuli. Participants can indicate their emotional intensity on a scale from 1 to 9, with 1 being the least intense feeling and 9 representing the most intense emotion for three distinct domains: valence, arousal, and dominance.

III. Results and Summary

During the time of the poster presentation, the results of the study will be presented, providing an in-depth knowledge of the applicability and generalizability of the scenarios employed in the research, specifically how they were received by two distinct populations. The outcomes of this study will be used to inform our future research study on anxiety-inducing virtual reality stimuli and their potential triggers.

A. Evaluating the environments and further steps

The overarching purpose of this project is to create and validate a therapeutic protocol, gather data, and assess its efficacy via a randomized clinical trial. To do this, the validation of the resulting VR scenarios by a new population of the participants will be conducted using the SAM scale to quantify their emotional responses. This will enable a more accurate evaluation of the participant's reaction to the situations.

Fig. 1. AI-generated visual of a crowded elevator (left) vs. in VR (right)

Additionally, the physiological reactions of the participants to the VR environments will be assessed to determine the efficacy of the exposure. To this end, the heart rate variability (HRV) measure will be employed to monitor stress levels, as low HRV is associated with GAD and can be used to track the severity of the condition [8]. The HRV measure will also be used to monitor the success of the intervention during the clinical trial, as an increase in HRV can be seen as a sign of improvement.

B. Conclusion

This study has outlined the ongoing process of selection and consecutive creation of anxiety-inducing virtual scenarios for therapeutic use. Through the use of AI and subjective evaluation, the scenarios are being validated and narrowed down to the chosen five. The efficacy of these scenarios will be further validated in a larger study, where the physiological reactions to the environments will also be measured. If successful, this study will open the door to the development of a CAM-based VR protocol to help individuals diagnosed with GAD.

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VirTele use intention: satisfaction with technology and interaction between therapist and participant

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Abstract—

VirTele, a personalized remote rehabilitation program combining virtual reality exergames and telerehabilitation, was developed to provide stroke survivors an opportunity to pursue rehabilitation of their chronic upper extremity (UE) deficits at home while receiving ongoing follow-up from a clinician. The objective of this study is to evaluate participants' satisfaction with VirTele and the support from clinician regarding the use of technology.

Keywords—treatment, technology, games, rehabilitation, stroke.

I. INTRODUCTION

Stroke is the leading cause of disability among older adults. The prevalence of stroke survivors living with disability is expected to continue increasing over the next 20 years[1]. One of the most common deficits following stroke is the reduction of arm, hand and wrist arm function due to weakness or hemiplegia, which limits function. Therefore, it is essential to develop interventions offering community-dwelling stroke survivors' opportunities for increased training tailored to the individual[2]. To optimize recovery, training should also be adapted to meet individuals' abilities, ensuring a continuous challenge[3]. However, access to intensive, ongoing and tailored rehabilitation programs corresponding to the person's abilities and preferences remains limited. Given this context we developed the VirTele program which aims to provide the tools for chronic stroke survivors to optimize arm recovery and use, through targeted exercises. The Virtele combines Virtual Reality (VR) with Telerehabilitation (TR) to optimize stroke recovery in the chronic phases. The Telerehabilitation is the use of information and communication technologies to provide rehabilitation at a distance and Virtual Reality is an interface that allows the user to 'interact' with and become 'immersed' in a computer-generated environment in a naturalistic fashion[4]. Although we strongly believe Virtele is a great tool to treat stroke survivors, in order for this technology to be effectively received, it is essential measuring participant's perception about VirTele and how those perceptions may impact usage. According the Technology Acceptance Model (TAM), perception about usefulness and ease of use a system affect attitude toward using the system and behavioral intention to use the system.

II. OBJECTIVE

Evaluate stroke's survivor satisfaction with VirTele and the interaction between therapist and participants.

III. MEHODS

A. Study design

This is a two-arm feasibility clinical trial.

B. Participation selection

Eligible participants included 1st time unilateral ischemic or hemorrhagic stroke, or no residual deficits from a previous stroke; evidence of residual UE impairment (score 2-6 Chedoke-McMaster arm component) and able to use the Jintronix system (i.e. able to move the game avatar with impaired limb); no longer receiving rehabilitation services. Evaluations were conducted at baseline prior to starting the intervention (T1), after the two-month intervention period (T2), and one (T3) and two months later (T4).

C. Outcomes measurements

Satisfaction with the technology and motivation to use VirTele were assessed by the *measurement scale for perceived usefulness (PU) and perceived ease of use (PEU).* Those are a 7-point likert-scales ranging from EXTREMELY LIKELY to EXTREMELY UNLIKELY. The *Health care communication questionnaire (HCCQ)* and the *Health care climate questionnaire (HCCQ perceived autonomy)* were used to assess interaction between the therapist and the participant. *HCCQ* is a 13-item questionnaire, comprising four components: problem solving, respect, lack of hostility, and nonverbal immediacy. *HCCQ* was developed to measure to what extent participants perceive their medical health care provider as autonomy supportive. Higher average scores indicated higher levels of autonomy support (total score is 65). Only those participants who were assigned to the intervention group responded to these

Canadian Institutes of Health Research [385297, 2017 and The Quebec Rehabilitation Research Network (REPAR)

questionnaires. The assessment happened during T2 (right after the end of the 8 weeks of training). The *HCCQ perceived autonomy* ranges from Strongly disagree to strongly agree.

D. Virtele program (intervention group) group

The experimental group received the VirTele program. VirTele is an 8-week home rehabilitation program, including Jintronix exergames for UE rehabilitation and OpenTera to conduct video conference sessions with the clinicians[5]. The experimental group received the VirTele equipment at home which included a computer installed with OpenTera, a Kinect camera, the Jintronix software, and a USB internet key (if needed). The Jintronix exergames included five games for UE training ('Space Race', 'Fish Frenzy', 'Pop Clap', 'Catch and Carry an apple', 'Kitchen clean-up'). The clinician adjusted the difficulty parameters of each game remotely (speed, duration, number of repetitions and direction of the trajectory, etc.), according to the participant's preference and functional abilities. Also clinician were be able to see the study participant playing the games (i.e. will see the screen in real time and see the participant). The training protocol included five, 30-minute sessions of Jintronix exergames per week, for 8 weeks, targeting 20 hours of training overall.

E. Analysis

Descriptive statistics (frequencies, means and standard deviations) were used to describe the results regarding satisfaction with VirTele program and the interaction between participants and clinicians.

IV. Results

A total of 8 stroke survivors were randomized and allocated to a treatment group (VirTele intervention or conventional therapy). Two of them did not complete the study. One was lost at follow-up due to inability to commit time and one discontinued the VirTele intervention due to difficulty using the technology (unable to use the mouse or the keyboard and to start the computer). Although 8 participants were allocated in the Virtele group, only 6 completed the T2 phase so far.

Outcome measure

**Satisfaction with VirTele program:* results from *PU* indicate that 100% (n=6) of the participants believe that using VirTele enable them to accomplish exercises more quickly, improve their performance, enhance their effectiveness on the exercises and is useful in their rehabilitation (EXTREMELY or QUITE LIKELY from perceived usefulness). For the productivity and facility to do the exercises, 68% perceived VirTele as EXTREMELY or QUITE LIKELY (32% [n=2] perceived VirTele as SLIGHTLY LIKE usefulness).

Regarding *PEU results* 84% (n=5) of our sample perceived VirTele as EXTREMELY or QUITE LIKELY ease of use. Only one participant (16%) reported difficult learning to operate the program and found SLIGHTLY UNLIKELY become skillful at using VirTele.

**Interaction participant-clinician:* HCCQ mean score was 62 (±3.74) showing participants had high level of interaction with the clinicians. Results from *HCCQ perceived autonomy* demonstrated that all the participants MODERATELY to STRONGLY AGREE they had autonomy support from their clinician.

Limitations

Regarding the effort, stroke survivors had encountered technological issues (e.g., the screen froze or slowed down, the sound or the Internet were cut off), which caused some frustration. The issues were managed either by the research team or the clinician (phone support) or by the stroke survivors themselves or with the help of a family member (restarting the computer, reconnecting, etc.).

V. Conclusion

VirTele has been demonstrated a great potential to be used at home. Participants demonstrated satisfaction with the program and perceived VirTele as usefulness and ease of use. Clinician's support also presented great results. Clinician support could not only influence stroke survivors' intention to use technology, but would facilitate the transformation of that intention into actual behavior.

Acknowledgments

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Combining virtual reality and a split-belt treadmill to induce freezing of gait in Parkinson's disease

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***Abstract*— Freezing of gait (FOG) is a phenomenon characterized by an involuntary interruption during walking. Though very debilitating to individuals with Parkinson's disease (PD), evidence suggests less than half of individuals with a history of FOG are observed with it in clinic. This can be due to its unpredictable nature but also to the patients' motivation and sensitivity to their environment (e.g., hospital). Creating a protocol that readily elicits discrete FOG episodes in individuals with PD, in a safe virtual environment, is an important step towards better understanding and treatment of this disabling problem. We created conditions where PD individuals who either experience FOG or not can display FOG-like behaviour on a split-belt treadmill in a virtual environment.**

Keywords—Parkinson's disease, virtual reality, freezing of gait

I. Introduction

Freezing of gait (FOG) is the feeling of the feet 'glued to the ground' despite efforts to step forward [1]. FOG is a phenomenon that affects most patients with Parkinson's disease (PD) beyond 5 years post diagnosis [2]. It is closely linked to falling [3] and a reduced quality of life [4]. However, despite its commonness and clinical impact, FOG remains difficult to manage relative to other parkinsonian symptoms. This is in part due to its variable response to medication [5]. Moreover, the unpredictable occurrence of FOG often makes it difficult to detect in clinical settings [6]. Indeed, reports suggest that FOG is observed in clinic in less than half of PD patients with history of FOG. Factors for this include the patients' sensitivity to the environment and motivation. Therefore, the central focus of this study is to develop a reliable means of safely and reliably evoking discrete FOG episodes at pace in a virtual environment (VE). Achieving this would help clinicians better understand it and provide new directions for treatment options.

It is believed that FOG-like behaviour is observed on a continuum [7] across FOG (FOG+) and non-FOG (FOG-) individuals, rather than a dichotomous state. By experimentally inducing FOG behaviors, we would gain further insights into the provoking factors, response to medication, disease specific features, and pathophysiological mechanisms that contribute to FOG. Moreover, though freezing episodes are often sporadic, we do know that several factors tend to elicit FOG including, dual tasking [8], gait speed increases, and walking through narrow paths, such as a doorway [9]. Although it is important to elucidate the characteristics of FOG stimuli, different of freezer subtypes [10] (e.g., akinetic vs. trembling in place) can make detecting it further challenging, especially when accounting for the medication response [11]. Therefore, an initial attempt at inducing FOG on a split-belt treadmill (SBTM) in a VE would be the first step towards standardizing an evaluation to measure the impact of clinical trials on novel and experimental treatments.

II. Methodology

A. Study Population

A total of 11 individuals (4 females) with a mean PD duration of 10.3 ± 3.2 years were recruited for this pilot study. The New Freezing of Gait Questionnaire (NFOG-Q) identified both FOG+ (n=7) and FOG- (n=4) individuals. All participants had stable medication for at least 1 month, Hoehn & Yahr off-medication scores to equal or less than 3, and were able to walk independently for at least 2 minutes.

TABLE I. FOG inducing paradigms in the VE

Combinations of FOG inducing conditions		
Belt Configuration	*Additional Task*	*Walking Speed*
Symmetric – Tied Configuration	None	Normal
	Narrow Pathway	
BSR – Split-Belt Configuration	Dual Task	Fast
	Dual Task / Narrow Pathway	

BSR - 25% best side reduction of lease affected leg. Fast – 25% speed increase

B. Virtual Environment and Split-Belt Treadmill Set-up

The GRAIL system (Motek, Netherlands) was used to create the VE for the study. It combines the SBTM and a 10-camera motion capture tracking system (Vicon, UK). The virtual scene was front-projected onto a screen located approximately 3 meters form the participant (see figure 1). The SBTM, virtual scene, and motion capture cameras were all powered by the D-Flow program (v.3.34.0 Motek, Netherlands). Motion capture was sampled at 100 Hz for all spatiotemporal and kinematic outcomes.

C. Inducing FOG in a VE on a split-belt treadmill.

Participants were fastened to a safety harness and walked in 2-minute walking conditions featuring speed changes (25%

increase), cognitive dual tasking, best side reduction split belt, visual perturbations (narrow pathway), or combinations of these conditions.

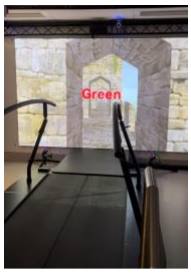

Fig. 1. Experiemental set-up consisting of the VE (with dual-task/narrow pathway condition displayed on screen) the SBTM (Motek, Netherlands), and motion caption cameras (Vicon, UK).

D. Analysis of FOG.

For each condition, episodes of FOG were identified via video review and kinematic and dynamic data from motion capture and force plate data from the treadmill. The video data was assessed for the number and duration of episodes. For a definition of FOG on the SBTM, a previous study [12] identified interruptions in heel elevation to kinematically identify FOG episodes.

III. Results

A. FOG episodes on the SBTM in VE.

A subset of FOG+ and also FOG- participants showed evidence of freezing behavior on the SBTM. In total, five of the 11 participants froze on the treadmill to the various conditions described. Of the individuals who froze on the treadmill, 4 were FOG+, while one FOG- individual showed signs of FOG-like behaviour. Average gait speed for the FOG+ group was 0.6 ± 0.3 m/s, while the average for the FOG- was 1.0 ± 0.1 m/s ($t(9)=-2.07$, $p>0.5$). Moreover, averages for both ABC and PDQ-39 scores were greater in the FOG- (72.7 ± 35.4 and 51.8 ± 33.9, respectively) compared to the FOG+ average scores of 57.4 ± 13.1 for the ABC and 46.7 ± 16.7 for the PDQ-39.

B. Evidence of FOG in FOG+ PD.

Figure 2 A-B illustrates portions of walking trials for two types of freezing responses for FOG+ individuals. The diagrams illustrate bilateral heel elevations (mm) and vertical ground forces (N) during a portion of a walking trial where subjects walked on a condition combining the dual-tasking, narrow pathway, and fast walking (see Fig.1). The first individual (2A) displays a transient freezing episode of approximately 1.5 s (highlighted in the red square) after walking largely unhindered prior to the FOG episode. The second FOG+ (Fig. 2B) displays multiple sustained freezing episodes as heels are often elevated, and more time is spent with both feet (i.e., toes) contacting the ground simultaneously as seen with the force data.

C. Evidence of FOG behaviour in FOG- PD.

Figure 2C also illustrates time series data depicting heel elevation with the corresponding step length, per stride, below. Over the course of the condition (BSR/dual-task) heel elevation gradually increases with progressively increasing step length at the same time. The participant eventually took on a stooped posture while walking more on the toes. This walking behavior would be consistent with the sequence effect.

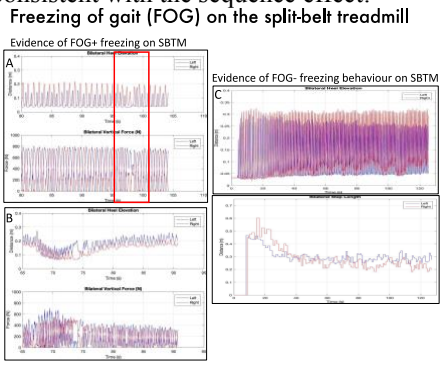

Fig. 2. **A:** Bilateral heel elevation and force plate data for an occasional freezer. A transient freezing episode can be seen at ~98s. **B:** A more sustained freezer where heels are almost constantly raised with both feet often making ground contact simultaneously. **C:** Bilateral heel elevation and step length data for a non-freezer. The heels continually rise with decreasing in step length.

IV. Conclusions

It may be feasible to elicit FOG on a SBTM and VE set-up in both FOG+ and FOG- individuals. However, more salient and challenging conditions may be needed to reliably induce FOG.

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Feasibility and use of a short-term error augmentation training program in virtual reality for upper limb rehabilitation in stroke survivors

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***Abstract* – Stroke leads to long lasting deficits in upper limb (UL) sensorimotor function. Many people with UL problems after stroke experience a decreased range of elbow extension leading to the use of compensatory movements to assist reaching. Motor learning, like implicit learning, can be harnessed to improve elbow extension. Error augmentation (EA) is a feedback modality based on implicit learning. EA has been used in people with stroke to improve endpoint performance of a reaching task but changes in movement quality have not been reported. We studied the effects of short-term training with EA vs. no-EA on increasing the range of active elbow extension during a reaching task in people with stroke. Patients with stroke practiced reaching with or without EA feedback in a virtual environment 3x in 1 week. Preliminary results show that both groups improved in joint and endpoint kinematics during reaching. The results of this study will inform the design of training interventions that use enhanced intrinsic feedback for sensorimotor recovery of the UL after stroke.**

Keywords – kinematics, reaching, intrinsic feedback, implicit motor learning

I. INTRODUCTION

Stroke can lead to persistent problems in using the upper limb (UL) despite intensive rehabilitation (1). A common major UL sensorimotor impairment is a decreased range of active elbow extension leading to the use of compensatory shoulder and trunk movements to assist in reaching (2). To improve reaching capability after stroke, emphasis can be placed on increasing the range of active elbow extension closer to what was present before the stroke (3). Approaches to improving elbow extension involve the use of motor learning principles. Implicit learning is thought to lead to better long-term retention and automaticity of a motor skill compared to explicit learning (4). Error augmentation (EA) is an implicit feedback modality that provides subjects with enhanced intrinsic feedback to improve motor performance. EA has previously been used in patients with chronic stroke resulting in improved precision and speed of UL reaching movements (5). However, accompanying changes in UL movement quality (joint movement patterns) was not reported. Implicitly incorporating an increased range of active elbow extension into reaching tasks may promote sensorimotor recovery better than traditional training approaches.

We incorporated EA feedback about the range of elbow extension during reaching, that was customized to the individual's level of motor impairment in a virtual reality (VR) program. VR was used to create a challenging, engaging and motivating platform for augmented training, to enhance motor learning (6).

The objective of this study was to compare the effects of training with EA feedback versus training without EA feedback in VR on increasing the range of active elbow extension during a reaching task in people with stroke. We hypothesized that people with stroke who train reaching movements with EA feedback about elbow position would improve and retain a greater active elbow range of movement a real-world reaching task better than those who train without EA feedback.

II. METHODOLOGY

A. Population

20 subjects (≥18 y/o) with chronic stroke (≥6 months; Fugl-Meyer Assessment of the UL (FMA-UL): 32-66/66) have been recruited to date, with the final sample size being 48 subjects. Subjects were excluded if they had other medical problems that interfered with task performance,

marked proprioceptive issues, visuospatial neglect, or depression.

B. Short-Term Training Protocol & Test Task

We used a custom-made semi-immersive VR program developed in UnReal Engine (version 4.25) that could include EA feedback of elbow joint position to implicitly encourage the use of greater elbow extension during reaching. Subjects viewed an avatar depicting their arm and hand on a large screen 2 m in front of them, while vision of their physical arm movement was blocked by specialized glasses to minimize visual-proprioceptive mismatch. The arm and wrist were supported during training using a low-friction horizontal manipulandum. The position and angles of the depicted arm were determined using input signals from real-time data collected from active markers and rigid bodies that were continuously recorded using NDI First Principles and a 2-camera bar Optotrak Certus system (Northern Digital, Waterloo, Ontario).

Subjects trained with the VR program three times in one week for 30 mins either with or without EA feedback (150 trials/session). Prior to each training session, the horizontal arm workspace was calibrated to determine the space in which targets would appear so that only the elbow extension range that was not affected by excessive muscle coactivation was engaged during reaching. The active reaching zone was defined by identifying the location of the tonic stretch reflex threshold (TSRT) of the elbow flexors (7) and reaching movements were constrained to occur in the inner elbow extension range from 0 degrees to the angular limit defined by the TSRT. During training, if EA was enabled, an elbow flexion error of 30° was incorporated into the arm avatar so that the subject viewed their arm as moving less than in reality. Thus, the subject would have to incorporate more elbow extension in their actual reaching to successfully hit a target. For subjects training without EA feedback, the arm avatar represented their actual arm movement. Circular targets appeared randomly in the calibrated horizontal arm workspace. To successfully hit a target, the subject was required to hold the position of the midpoint of their palm over the target for 1 second. Feedback in the form of task success (visual and auditory) was presented at the end of each reaching trial to increase motivation and engagement. Task difficulty was increased by decreasing target diameter (from 6cm to 1cm) and allocated reaching time (from 5s to 1s) based on Fitts' Law (8). Breaks between blocks were given based on subject fatigue level, measured as ≥60% on a visual analog fatigue scale.

To evaluate the effect of training with EA feedback, UL, trunk, and endpoint (speed, smoothness, straightness) kinematics were assessed as well as the index of performance, a measure of reaching success related to endpoint precision, speed and task difficulty. The size of the active reaching zone was recorded by the VR program. Outcomes were assessed before training, after training, and one hour after training to evaluate motor improvement and learning during a standardized functional reaching task (i.e., Test Task; 20 trials). The Test Task involved reaching to a cone (or cube, depending on ability to open their hand), placed at a sagittal distance of 2/3rd arm's length, as quickly and as accurately as possible.

III. RESULTS

Preliminary results show that both groups improved UL kinematics and made faster, smoother, and straighter reaching movements. The results from both groups show a wide variability in elbow extension during the Test Task, particularly those with a more severe UL impairment (EA: 4.10° ± 10.19, no-EA: 1.40° ± 8.94). Subjects who trained with EA feedback tended to have larger percent change in the size of the active reaching zone compared to those who trained without EA feedback (EA: 15.26% ± 34.14, no-EA: -5.68% ± 25.75). The large variability is likely due to the small sample size. The final sample size will reveal if there are differences in elbow extension between training groups.

IV. CONCLUSIONS

Data collection for this project is ongoing. The results from this study will inform the design of effective training protocols using enhanced feedback for people with post-stroke UL deficits.

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Engaging Patients with COPD in Pulmonary Rehabilitation Program Using Virtual Reality

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***Abstract*—Lack of motivation combined with low health literacy in patients with chronic obstructive pulmonary disease (COPD) has been shown to be a significant deterrent to effective participation in pulmonary rehabilitation (PR) programs. We developed a VR app driven by adult learning theories to help COPD patients better understand the benefits of pulmonary rehabilitation and empower them with personalized knowledge about the role of PR in COPD management. The objective of this mixed-design study was to assess attitudes of COPD patients toward using the VR app and its impact on PR knowledge (PRK). VR-naïve patients with a history of COPD exacerbations were asked to complete the PRK survey before and after using the VR app and then undergo semi-structured qualitative interviews to provide their feedback on using the VR app. The mean age of the patients was 74±7 years ranging between 61 and 84 years old. The qualitative analysis showed that the VR-based technology received positive feedback from patients, especially for how engaging and immersive it was. A statistically significant increase in PR knowledge ($p<0.05$) was found after using the VR app. This study offers an in-depth analysis of COPD patient perspectives on using VR-based technologies and its effect on PR knowledge.**

Keywords—virtual reality, health literacy, pulmonary rehabilitation

I. Introduction

Pulmonary rehabilitation (PR) is a comprehensive non-pharmacological treatment that aims to address symptoms of chronic obstructive pulmonary disease (COPD) by providing patients with health education, guided exercise training, and psychosocial support [1]. Due to transportation constraints, lack of motivation, disease burden, lack of knowledge and understanding about the PR benefits, traditional center-based PR programs continue to have a low rate of compliance and adherence. Therefore, the development of novel and engaging methods to facilitate PR is essential for broader PR acceptance.

In our previous work, we demonstrated that interactive patient education driven by the major constructs of adult learning theories results in significant improvements in patient health literacy, disease-specific knowledge, and engagement in self-care [2]. The virtual reality (VR) technology has been identified as a viable option for implementing personalized, motivating, and engaging content for the management and rehabilitation of chronic conditions [3]. Despite the clear benefits of VR, its application to improve understanding of the benefits of pulmonary rehabilitation has not been systematically assessed in patients with COPD. The purpose of this study was to investigate COPD patients' attitudes, perspectives, and beliefs regarding the use of a VR-based system and its ability to increase patient understanding of the benefits of PR.

II. Methods

A VR headset (Oculus Meta Quest 2) was used for patient empowerment and engagement. The interactive educational curriculum consisted of a sequence of short video clips followed by easily digestible facts and quizzes presented in an interactive virtual reality environment. The curriculum design followed the patient education and empowerment framework, which was previously shown to be effective for the education of patients with low health literacy [4].

VR-naïve patients with a history of COPD exacerbations were asked to use a VR app and then undergo semi-structured qualitative interviews to provide their feedback on using the VR app. Recruitment continued until information saturation was reached or no novel or relevant information was discoverable from the available data. Data collection consisted of one in-person visit where a trained researcher provided an initial demonstration and practice session of the VR app. At the beginning of the visit, patients completed the BRIEF Health Literacy Screening Tool (BRIEF), and pulmonary rehabilitation knowledge (PRK) survey. After completing the VR-based educational curriculum, the patients were asked to complete the PRK survey again, followed by the System Usability Survey (SUS) and semi-structured qualitative interview. The qualitative data collected during the semi-structured interviews were analyzed using a thematic analysis method to organize, identify, and interpret critical patterns and themes. Content, interface, and process were the three domains of usability that were assessed in the semi-structured qualitative interviews.

III. Results

Nine COPD patients completed the study. The mean age of the patients was 74±7 years ranging between 61 and 84 years old, 33% were males, 67% were African Americans. The BRIEF score was 16±7 indicating marginal health literacy typical for patients who struggle with understanding educational materials. There was a statistically significant 9% increase in the PR knowledge score after completing the VR-based education based on the paired t-test ($p<0.05$). The mean SUS score was 96±8 indicating high usability of the VR app and user acceptance of the VR interface.

Participants were asked to discuss their thoughts about the educational content provided by the VR app. A summary of thematic qualitaitve analysis is provided in Table 1. The

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educational content was received with overwhelming approval, with all participants stating they enjoyed or were satisfied with the educational content provided by the VR app. When asked about their thoughts about using the VR app to learn about the telerehabilitation program, most participants (8/9) stated approval or thought using the VR app was a great idea. One participant reported being interested in using the VR app because of its novelty. All participants agreed that using the VR app to engage in pulmonary rehabilitation was beneficial. When participants were asked to describe the best feature or benefit of the VR app, most patients highly valued the engagement and immersive experience. One participant responded that having a visual demonstration of the information rather than reading was beneficial. Another participant thought the ease of use of the VR app was beneficial, one patient mentioned that the VR app helps seniors learn about the benefits of pulmonary rehab.

TABLE I. PATIENT FEEDBACK ON USING THE VR APP

Theme	Comment
Interactive experience	"The best thing is that you feel that people are there with you. They are talking to you, it's interactive"
Increase in engagement	"I feel more interested and less stressed, COPD is a boring disease, I like this, a video format, feels like you are in a movie and took me completely out of this world."
Ease in navigation	"The screen is just right in front of me, perfect right there, I love the controller is really good, I can see my finger, and can see what I am pointing at, the pointer is very helpful."
Visibility of the guided exercise instructions and demonstrations	"In VR you can see it and do it, the explanations are right there in front of your face, it should show some video on how to do exercise, it's much easier to see it, to hear it and do it. I do not like print paper, for a senior person like me we do not want to read instructions. We need people to show us and for us to follow"
Improvement in focus	"I think it get me focused – it brings you in. I think that's the most amazing thing about it. You don't need to think about taking the garbage out or something else. You do what you do."
Accessibility for senior patients	"The best thing about it is helping people like us, the senior people. It is not easy for us to go out and visit, not easy to go to the hospital, you need other people's help, when you get old you can't easily walk around. We do need more information to know how make us to breath well."
Locating the VR app	"I have no problems understanding the app, but I did have some problems finding the app, it didn't see COPD at the first if you don't point to it. it has many different apps inside; I was expecting only one app inside"
Volume	"Overall, I think they make it very clear and very easy to understand, but in the last video the volume is low. The person explains it pretty well and the volume was good but suddenly during the last video, it goes down"
Locating the 'Next' button	"I had a hard time finding the 'Next' button in the beginning, I was only watching what is in front of me, I was not looking at the side, and after you let me know where it is. I can find it straight forward"

IV. DISCUSSION

Lack of motivation combined with low health literacy in patients with chronic obstructive pulmonary disease (COPD) has been shown to be a significant deterrent to effective participation in pulmonary rehabilitation (PR) programs. Virtual reality (VR) applications offer engaging and interactive media to promote health literacy and empower patients. We developed a VR app driven by adult learning theories to help COPD patients better understand the benefits of pulmonary rehabilitation and empower them with personalized knowledge about the role of PR in COPD management. The goal of the current study was to explore COPD patients' perceptions while using a VR-based learning tool to understand the advantages of PR treatments. We performed semi-structured qualitative interviews with 9 patients. To deductively identify emerging themes across the content, interface, and process, the qualitative data gathered during the interviews were analyzed using thematic analysis. The main themes that emerged from the qualitative data were related to convenience, increase in focus and attention on the exercise material, improvement in motivation, confidence, and engagement with a PR program. Patients reported feeling comfortable using the VR app to acquire instructional and instructive information. The immersive virtual environment allowed for the removal of distractions, which was highly valued by patients. Suggestions to improve the VR app included the addition of more personalized information about exercises, the addition of music choices, and the option to take a break and return. Our findings corroborate the recent reports on VR app acceptance by older adults [5-6].

V. CONCLUSION

We assessed the acceptance of a VR-based system to facilitate patient education about the benefits of participating in a PR program. Even though the study subjects were represented by VR-naïve older adults, the COPD patients have enthusiastically embraced the VR-based system, rating it highly for usability, satisfaction, and engagement. The findings from the thematic analysis demonstrate that COPD patients highly approved of utilizing a VR system to support self-management education. Future studies will aim to evaluate the degree to which VR-based technology motivates COPD patients to engage in PR programs. This insightful patient feedback will be considered during the further development and implementation of a patient-centered VR system to educate about the benefits of participating in a PR program and improve patient engagement.

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Family-Centered Virtual Reality Games Room

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***Abstract*—Virtual reality (VR) can be used in pediatric rehabilitation to enhance traditional approaches and promote family-centeredness. Our goal is to implement and pilot-test a family-centered VR games room for children with physical disabilities and their caregivers. *Methods:* Using a case study mixed-method study design, we will engage five (n=5) dyads (child and parent) in parallel VR sessions using the Oculus Quest. Compatible games will be selected to target upper extremity motor functions and/or trunk control (for child) and relaxation/stress reduction (for caregiver). Measures of feasibility, acceptability, satisfaction, improvements in motor functions (child) and mental health outcomes (caregiver), and users' perspectives will be collected and analyzed using descriptive statistics and a qualitative analysis approach. *Contribution*: To the best of our knowledge, this is the first study to implement VR in a family-centered approach, where the needs of the child and that of the caregiver are addressed. The findings of this pilot proposal will guide future efficacy trials.**

Keywords— virtual reality, pediatrics, family-centered.

I. Introduction

Neurodevelopmental disabilities (NDDs, e.g., cerebral palsy) are common causes of physical impairments that are associated with a substantial burden, where children face significant life-long challenges affecting their daily activities and overall quality of life [1-4]. Moreover, over 50% of the caregivers of children with NDDs are known to experience mental health concerns which could be a major barrier to a thriving family and child [5]. This highlights the need for not only effective, but also family-centered approaches, where the needs of both parties are addressed.

The use of virtual reality (VR) to enhance traditional pediatric rehabilitation is rapidly gaining popularity worldwide. [6-8]. Recent systematic reviews outlined positive effects of VR-based pediatric interventions [8, 9]; however, existing studies either use non-immersive platforms that are presently discontinued [10-13] or non-standalone immersive set ups that are not readily generalizable into clinical settings [14, 15]. Moreover, a family-centered approach has yet to be incorporated and explored in pediatric VR interventions. The general objective is to implement and pilot-test a VR-based, family-centered games room for children with physical NDDs and their caregivers using the Oculus Quest (Facebook Technologies). Specific objectives are to: 1) Identify suitable and engaging games/applications that are compatible with the Oculus Quest and that target physical functions (e.g., upper extremity motor abilities, trunk control) in children with physical NDDs; as well as stress, well-being, mood and affect in caregivers; 2) Describe the feasibility and effects of using the Oculus Quest in family-centered VR-based sessions (15-30 mins, 1-2 times/week for 4 weeks); and 3) Explore participants' perspectives (i.e., satisfaction, engagement, acceptability, and influential factors) about the VR games room.

II. Methods

A. Study Design

For objective 1, we will use a patient-oriented methodology [16] by working in collaboration with patient-partners and clinical experts. For objectives 2 and 3, we will employ a mini-ethnographic case study design [17-19], incorporating a convergent parallel mixed-method approach [20].

B. Study Population

Using a convenience sampling technique, we will recruit five (n=5) dyads (child and caregiver). For the child, the inclusion criteria are to be between 10-21 years old; to have a physical NDD diagnosis (e.g., cerebral palsy, spina bifida); normal or corrected to normal visual acuity; to present with impairments in postural control and/or upper extremity motor function; to be able to engage in a upper extremity tasks while seated for 15-30 mins; and to speak and understand instructions in English and/or French. Exclusion criteria are to have a health condition that would prevent participation in a moderate intensity VR exercise and to present with an intellectual and/or behavioral disability that could prevent safe engagement. Eligible caregivers will need to able to understand and speak English and/or French, and to have normal or corrected to normal visual acuity.

C. Study Procedures

For objective 1, we will engage key stakeholders (n=4 parents of children with NDDs; n=2 young adults with physical NDDs; n=2 expert clinicians). In a format of structured meetings with these partners, we will present the Oculus Quests games/applications that are potentially suitable and discuss their pertinence for the target population. The selected set of applications will be translated into a collection outlining their therapeutic content, trained construct(s), environment, duration, adaptability factors (e.g., choice of language, speed/location of objects, feedback/score, level of difficulty), and what, if any, traditional neurorehabilitation principles are reflected in the VR-activity (e.g., bimanual training). For objectives 2 and 3, participants will be scheduled to attend the VR games room sessions as an "add-on" to their usual therapy.

VR sessions will be provided for 15-30 mins/session (active engagement excluding preparation time and breaks), 1-2 times/week for 4 weeks to reflect current evidence-based knowledge [8, 9].

D. Measurement and Data Analysis

Feasibility and usability will be examined by collecting data on number of eligible and included participants, characteristics of participants, description of VR-games room use (total intervention time, number of sessions and frequency, games/applications used) and presence of adverse events. At the end of each VR session, user experiences will be captured. Employing a child-friendly Visual Analogue Scale (VAS with faces [21]), child-participants will be asked to rate how much fun they have had performing the VR game. Caregivers will be asked to rate their relaxation/comfort level and satisfaction with the session using VAS. The following child- and caregiver-related health outcomes will be measured pre- and post-intervention: upper extremity motor function (Manual Ability Classification System [22], Quality of Upper Extremity Skills Test [23]) and trunk control (Trunk Control Measurement Scale [24]) for the child; and measures of stress and mental health (Parental Stress Scale [25], Depression, Anxiety and Stress Scale 21 [26]) for the caregiver. Lastly, semi-structured interviews will be conducted with caregivers to explore their perspectives (facilitators, barriers, perceived impact, and acceptability) about the games room.

Descriptive statistics will be used to analyze demographic variables and all the quantitative measures. Changes in child- and parent-related outcomes of interest will be analyzed via non-parametric statistics on a case basis. For the semi-structured interviews, the audio recordings will be transcribed verbatim and imported in the NVivo software for analysis and a hybrid inductive-deductive approach guided by a reflexive thematic analysis [27, 28] will be performed.

III. Contribution

The VR games room could become an efficient add-on to existing therapies and promote family-centeredness. Our findings will serve to identify needed modifications to the intervention protocol and knowledge gaps that can be pursued in future efficacy trials of a larger scale.

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Comparison of immersive and semi immersive cycling on exercise intensity and user experience during a bicycling task: Persons with Parkinson Disease

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Abstract— This study contrasts the experience of persons with Parkinson Disease who exercised in a both a semi and fully immersive virtual cycling environment. The objective was to determine if the mode of presentation- fully or semi immersive influenced exercise intensity, enjoyment and perception of effort. Neuromuscular intensity and perception of effort were greater in the fully immersive environment. However, the neuromuscular intensity difference was not clinically meaningful. Participant preference was equally divided between presentation. For this task semi and fully immersive environments appear comparable in stimulating exercise intensity. The user experience was comparable.

Keywords—neuromuscular intensity, cardiovascular intensity, enjoyment, perception of effort, Parkinson disease, virtual reality

I. INTRODUCTION

The introduction of low-cost head mounted displays have facilitated the delivery of virtual environments using a fully immersive presentation. Semi-immersive environments coupled with an exercise bicycle have been shown to increase the neuromuscular intensity of bicycling for Persons with Parkinson Disease. [1] However, in the context of exercise for Persons with Parkinson Disease it is not known whether a fully immersive experience is superior to a semi-immersive experience. These are important considerations when designed intensive training experiences that participants may adhere to. The objective of this study was to determine if the mode of presentation- fully or semi immersive has a different effect on neuromuscular and cardiovascular intensity, enjoyment and perception of effort.

II. SYSTEM AND SIMULATION

The V-CYCLE developed in a previous study and adapted for the goals of this study consists of a bicycle outfitted with a Wahoo cadence sensor interfaced via Bluetooth to a PC. The fully-immersive condition was delivered with a HTC VIVE head-mounted display. The semi-immersive condition was viewed on a large screen- projected two meters in front of the rider. The simulation created in Unity 3D used a first-person perspective as the cyclist navigated through a forest landscape. Visual feedback using road markers prompted riders to maintain a target cadence of 25-40% faster than their comfortable bicycling cadence.

Figure 1. VCYCLE Simulation

III. METHOD

A. Participants

Participants were sampled from the community and screened with the PARQ for exercise reading and the Geriatric Depression Scale . They were included in the study if they had mild to moderate Parkinson's Disease, were between the ages of 45 and 75 years old, able to ride a bicycle, and passed the screening for the study. They were excluded if they 1. had a recent history of severe heart disease, severe lung disease, uncontrolled diabetes, traumatic brain injury or neurological disorder other than Parkinson Disease. 2. Were unable to follow directions or sign a consent form 3. Did not have adequate vision or hearing ability to see or hear a television 4. Had an unstable medical condition or musculoskeletal disorder such as severe arthritis, recent knee surgery, hip surgery, or any other condition that the investigators determine would impair the ability to ride the bicycle 5. Had any other medical condition that prevents bicycling. 6. Had moderate depression. The study was approved by the Rutgers University and New York Institute of Technology review boards.

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B. Protocol

Motor performance was assessed with the Unified Parkinson Rating Scale Section III (UPDRS-III). Exercise Profile was assessed using the Physical Activity Scale for the Elderly (PASE). Participants were familiarized with bicycling conditions prior to data collection. A baseline cycling rate was established individually for each participant. Participants executed each condition for five minutes with the semi-immersive condition preceding the immersive condition. They were instructed "to cycle fast enough to turn the road marker to blue" – which was 25-40% faster than their baseline. During both conditions, cycling cadence and heart rate (HR) as a percentage of maximum HR were recorded at 1 Hz [2]. Rating of perceived exertion (RPE) was recorded at the start, middle, and end of each condition. [3] At the end of each condition, participants completed an Intrinsic Motivation Inventory (IMI). [4] After completing both trials, participants were asked which condition they enjoyed more and in which they felt they worked harder.

C. Data Analysis

Data were assessed for normalcy and then analyses of differences were performed with paired t-tests for: average % of maximum HR, average cadence, changes in RPE from start to end of trial, enjoyment subscale of IMI, total IMI as well as ratings of enjoyment and effort after the trials were completed. Wilcoxon Signed Rank Tests were used for IMI-effort subscale and the z proportion for change in RPE category.

IV. RESULTS

A. Participants

Thirty participants with mild to moderate Parkinson Disease (based on the UPDRS) with a mean age of 64 years completed the study. Their characteristics are summarized in Table 1.

Table 1 Participant Characteristics

	n	Mean
Age	30	64 (7.9)
Previous VR Exp	28	32.1% (9/28)
Bike for Rec/Sport	28	57.1% (16/28)
PASE	30	158.2 (79.9)
GDS-15 Score	30	1.7 (1.4)
UPDRS-III	29	37.59 (12.51)
Mild	11	37.9% (11/29)
Moderate	16	55.2% (16/29)
Severe	2	6.9% (2/29)
Tremor	13	43.3% (13/29)
PIGD	16	53.3% (16/29)
Indeterminate	1	3.3% (1/29)
Dyskinesias	30	26.7% (8/30)
H&Y Stage 2	29	79.3% (23/29)
Stage 3		20.7% (6/29)

VR: virtual reality, PASE: Physical Activity Scale for the Elderly, GDS: Geriatric Depression Scale UPDRS: Unified Parkinson Disease Rating Scale, PIGD: Posture and Gait Disorder, H and Y: Hoehn and Yahr.

B. Exercise Intensity and User Experience

In the fully immersive condition participants had significantly greater neuromuscular exercise intensity and perception of effort. All others variables were not different. See Results in Table 2.

	n	Fully-Immersive	Semi-Immersive	p-value
HR (% Max)	29	58.9% (7.0%)	57.8% (7.6%)	0.215
Cadence (% > baseline)	29	31.1% (2.8%)	29.6% (2.5%)	0.001
IMI Enjoyment	27	5.26 (1.3)	5.31 (1.1)	0.801
IMI Total	27	88.3(14.4)	86.8 (13.1)	0.716
Liked More	28	50% (14/28)	50% (14/28)	NSD
IMI Avg (effort)	26	5.48 (1.04)	5.20 (1.16)	0.076^
IMI Tot (effort)	26	27.38 (5.22)	26.00 (5.79)	0.078^
Worked Harder	27	74.% (20/27)	26% (7/27)	0.006
RPE (end-start)	23	5.08 (2.10)	4.70 (1.77)	0.445
RPE Category Change	27	10/27 (41%)	6/27 (22%)	0.146^^

Table 2: Measures of exercise intensity, enjoyment, and effort for persons with Parkinson's Disease. ^ Wilcoxon Rank Test ^^ Z proportion. HR Heart rate, Cadence in Revolutions/minute, IMI Intrinsic Motivation Inventory. RPE Rate of perceived exertion

V. DISCUSSION AND CONCLUSION

Participants with mild to moderate Parkinson Disease had comparable neuromuscular and cardiovascular intensity while cycling in semi and fully virtual environments. The statistically significant differences in neuromuscular intensity lack clinical meaning. Participants also reported comparable levels of enjoyment and half the participants expressed a preference for each mode of delivery. Interestingly the perception of effort was greater more participants had a category change in their RPE during the fully immersive condition. These findings do not support that for Persons with PD immersive environments are superior to semi-immersive environments to promote exercise intensity or enjoyment during a cycling task.

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Novel assessment tool for driving capability with head/eye tracking-implemented drive simulator

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***Abstract*— In order to establish an environment for behavioral evaluation during car driving, we developed a novel drive simulator that consists of a head/eye tracking device and custom-made 3D CG modeling based on the drone-captured test-driving field. With the use of head tracking-based view manipulation, users can get a wider field of view even though the system only has a single display. The developed drive simulator has been tested for evaluation in a patient post-stroke, such as visuospatial neglect, attention deficit, and hemianopia. Since head/eye tracking data and recordings of the steering and pedals give us plenty of information for car driving, our developed system would effectively work for the detection of whether patients have the potential to re-issue driving licenses or not.**

Keywords—virtual reality, car driving, eye/head tracking

I. Introduction

Loss of driving skills and capability due to an incidence of brain injury inevitably lead to decreased participation in the social community, reduced access to medical care, and increased healthcare costs [1]. Akinwuntan et al [2] reported that the ability to drive is largely affected after stroke: while approximately 33% of stroke survivors will be able to return to driving with little or no retraining, 35% will require specific rehabilitation before they can resume safe driving again, and others cannot get permission of driving. Although there are some attempts to evaluate driving ability, there is still no standardized protocol for post-stroke driving. While on-road driving performance might be significantly related to performance on neuropsychological tests of attention and information processing, on-road test scores have limited reliability and neuropsychological tests lack validity, and are insensitive to the effects of driving experience and domain-specific compensatory skills. There is a consensus that neuropsychological tests alone are not sensitive to the detection of driving capabilities. To improve the validity of the assessments of driving capability in the sense of its potential to predict safe driving performance and behavior, drive simulators could play an important role. Drive simulator, as a clinical application of training for drivers with specific disabilities and/or deficiencies, enables to evaluate and testing of patients' capacities of car driving. The virtual environment offers a specific driving training program and behavioral analysis based on the recorded data of steering and pedals, and head/eye tracking. Moreover, the patient will be encouraged to master his disabilities and offset his deficiency after taking much practice on the simulated condition in various aspects of driving abilities. In this report, we introduce a novel driving simulator that consists of a head/eye tracking device and custom-made 3D CG modeling based on the drone-captured test-driving field.

II. Materials and Methods

A. System Configuration

The configuration consists of a main PC with a wide curve-shaped 35-inch display and a car operation system consists of a force-feedback steering wheel, accelerator, brake pedals, and shift lever components. A head/Eye tracking device (PCEye5, Tobii) was mounted in front of the display. To realize a wider field of view under a single display, head tracking-based view manipulation was performed (Fig.1A). A custom-made 3D-CG modeling based on the drone-captured driving test field was built by Unity 2019.4.21f1. The GPU-mounted PC performed graphical/rendering simulated traffic, and perform realistic driving scenes in accordance with the control of steering, accel/brake pedals, and head orientation. Necessary information about driving (digital s peed meter, winker sign, status of shift lever, etc.) was continuously monitored on a graphical user interface for the simulator operator.

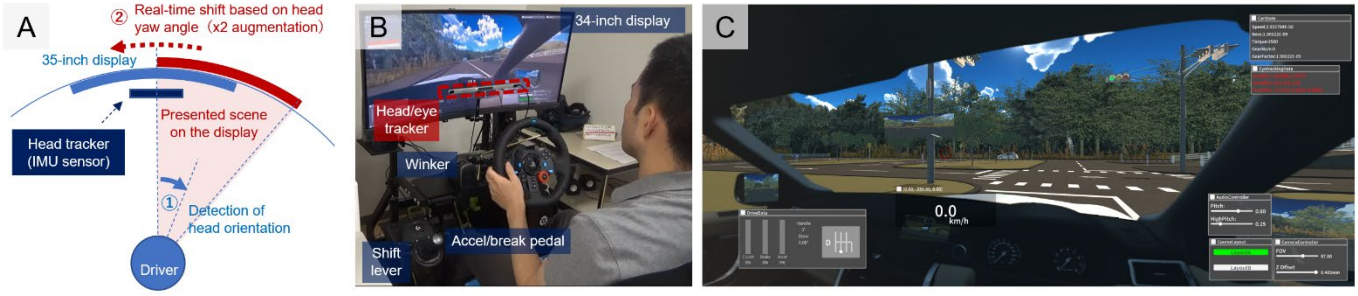

Fig. 1. View from the mock-up in the Swing Drive. The simulator car is approximately in the middle of the right lane here.

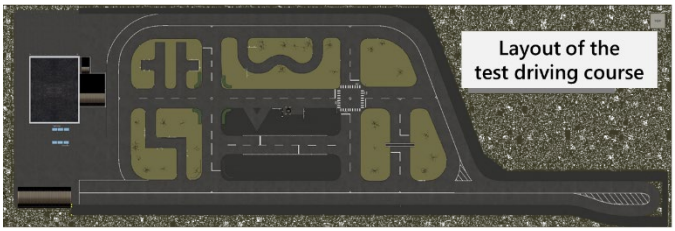

Fig.2. Layout of the test driving course that exactly resembles the real testing course of the National Rehabilitation Center for Persons with Disabilities. The 200-meter-long straight road was virtually added for the basic skill test.

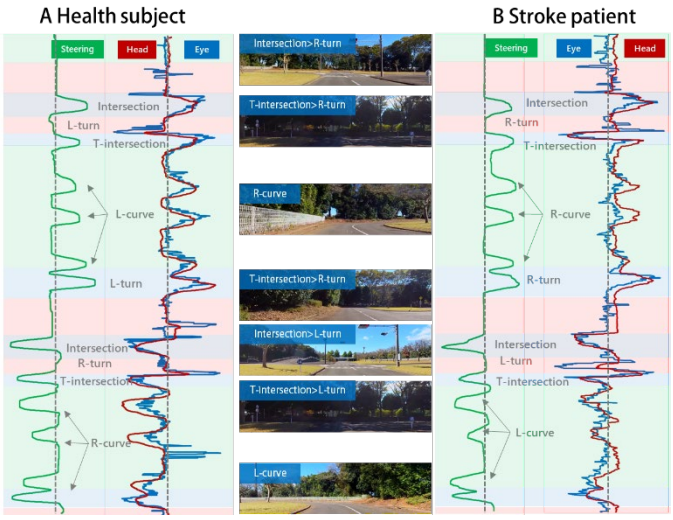

Fig.3. Time series data of steering (green line), and head/eye movement (red /blue line) in both healthy subjects (left) and stroke patient (right). The horizontal color highlighted background shows the time range of stop (red), driving on the road (green), and at the intersection (blue).

B. Environment Setting

The test requires driving in the virtual testing course which is exactly resemble the real test course of National Rehabilitation Center for Persons with Disabilities. The 200-meter-long straight road was virtually added for the basic skill test (Fig.2). Continuous stream of traffic from the opposing direction but no traffic on the lane of the simulator driver. In order to precisely and separately evaluate head and eye movements during car driving, a Head/Eye tracking sensor was mounted at the center position with 200mm height from the bottom of the display. The distance between the sensor and the user was set at 0.8 meters.

C. Test measurements and data calculation

A 47-year-old healthy subject and a 35-year-old patient who had a diagnosis of aphasia and hemianopia due to left hemisphere damage were selected as drivers for test measurement. The patient has experience of driving before the stroke, and has a strong need and motivation for driving. The patient was instructed to drive at his or her preferred speed, following the instructions spoken by the operator taking into account traffic signs and signals, and obeying the traffic rules. Test driving was operated with a preference for automatic transmission. Recorded data were used to visualize the characteristics of driving behavior. During test driving, the position of steering and actions of accel/brake pedals, and head/eye tracking data are continuously recorded. Operational driving skill was evaluated by the controlling speed and the timing of accel/brake pedals, and deviation of the road center line during the test driving course by the calculation of steering behavior. Test measurement and data recording were accompanied by the protocol of the measurement approved by the ethics committee of the National Rehabilitation Center for Persons with Disabilities, Japan.

III. Results

During test driving, gaze strategy and interaction with the optic flow environment gave drivers natural, both test drivers accurately followed the instruction and traffic signs and signals. Motion sickness is very infrequent, even in persons without driving simulator experience. Subjectively, the test is easy to understand and perform. Fig.3 shows time series data of steering and head/eye movement obtained from each healthy subject and stroke patient. The test drivers drove on the simulator at the free speed and generally adapted well to the instruction, always keeping a safe road position and stable course without any line crossing. The patient sometimes stacked if the operator gave verbal instructions about the right/left turn at the intersection. It was difficult for him to transiently judge the right/left direction, and told us to make sure “Which is right/left?”, or “LEFT is this way (with his finger judge), right?”. A most remarkable feature of this patient is that head orientation generally shifted toward the right direction which is assumingly due to the compensation for the visual deficit.

IV. Discussion

The reason for using a driving simulator is not only to utilize it as a process of assessment but also to get observation that stroke individuals can be much safer and smoother drivers than expected based on their visual information processing capacities as assessed with clinical evaluations. Interestingly, the simulator test can sometimes elicit a very abnormal performance which is quite important to understand a resultant behavior due to a specific neurological syndrome, such as attention deficit, visual neglect, hemianopia, etc. Some patients were excessively slow in correcting the surrounding environment and some others showed failed detection of the sign and traffic from the opposing direction. Our developed driving simulator enables us for a better understanding of the typical symptomatic behavior during car driving.

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ISVR

INTERNATIONAL SOCIETY FOR VIRTUAL REHABILITATION

Oral Session 4

Telerehabilitation

10:45 to 12:15

July 25th, 2023

Motivation to perform telerehabilitation training: A qualitative assessment of the Home Virtual Rehabilitation System

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***Abstract*—Patients post-stroke utilized the Home Virtual Rehabilitation System to perform home-based, gamified UE rehabilitation over 12 weeks. Outcomes related to adherence and clinical improvement were collected, and semi-structured interviews were conducted to assess intrinsic and extrinsic motivators that impacted engagement with the system. Qualitative analysis generated seven themes that both positively and negatively influenced each subject's experience with HoVRS, including challenge as a primary intrinsic motivator and pursuing additional therapy and/or a return to higher functional status as a key extrinsic motivator. Findings were consistent with recent related literature.**

Keywords—Telerehabilitation, Engagement, Motivation, Gaming, Qualitative Assessment

I. Introduction

Engagement is an affective quality of experiences [1] that refers to the extent or quality with which participants are committed to and actively involved in an experience [2]. A wide variety of elements, including interactivity, choice, exploration, reward, and appropriate levels of complexity and challenge have been associated with higher levels of engagement in learning as well as rehabilitation activities [3]. Engagement has been linked to higher levels of motivation to perform activities more often and for longer periods of time [4], key elements in increasing the volume of practice associated with higher levels of motor learning and neuroplasticity [5].

Affective responses to human /computer interaction are difficult to measure quantitatively. These responses are typically measured indirectly via autonomic nervous system functions such as changes in blood flow to the skin, pupil dilation and constriction or the speeding up /slowing down of heart rate [6]. These responses vary across people and environments [7]. This variability is compounded in persons with central nervous system dysfunction such as stroke [8]. This increased variability across subjects will tend to require large sample sizes to allow for meaningful quantitative / statistical analysis [7].

The Home Virtual Rehabilitation System (HoVRS) was designed to provide an engaging rehabilitation experience by 1) designing simulations that provided rich feedback, 2) affording broad scaling of movement abilities and the use of scaffolding and success algorithms that consistently provide users with an optimal level of challenge and 3) providing a comprehensive set of activities that allows users to work on specific aspects of hand movement that limit their ability to function in the real world [9]. Early study of HoVRS supports that it is sufficiently engaging to elicit satisfactory levels of adherence to training by patients in their homes with minimal supervision [10]. A preliminary qualitative examination of subjects demonstrating the highest and lowest levels of adherence to a twelve-week training program highlighted the differences in motivation driven by extrinsic factors between subjects with high and low levels of adherence [11]. Through a basic qualitative research approach [12], this study explored the HoVRS gaming experiences of participants to generate knowledge about the intrinsic and extrinsic factors that impacted their engagement in training.

II. Methods

A. Participants

Inclusion criteria were (1) 40–80 years of age, (2) unilateral right- or left-sided stroke, (3) score of 22 or greater on the Montreal Cognitive Assessment, (4) no hemispatial neglect or proprioceptive loss, (5) Upper Extremity Fugl-Meyer Assessment (UEFMA) of 36-58/66, and (6) no receptive aphasia. Exclusion criteria were (1) UE orthopedic pathology and (2) other central nervous system pathology.

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B. Training system and program

The Home Virtual Rehabilitation System (HoVRS) was developed to provide game-based rehabilitation of the upper extremity for people with central nervous system dysfunction. The system combines a Leap Motion Controller with a suite of 16 games that train different facets of upper extremity movement, both in isolation and combination. Avatar movement is scaled to user active range of motion using a calibration program. In addition, other task parameters (e.g., speed, sensory loads, accuracy requirements etc.) can be adjusted to challenge patients appropriately. Participants in this study utilized HoVRS unsupervised in their homes over 12 weeks, with virtual or in person follow up visits with a physical therapist and a technologist every 1-2 weeks or as needed for technical support and to adjust game parameters. Initially, a therapist and technologist visited subjects in their home to set the system up and ensure each subject could navigate and successfully play their prescribed games. They were instructed to play as much as possible, with a goal of at least 20 minutes each day.

C. Adherence and demographic data collection

Adherence was assessed via each participant's total training minutes over the 12 weeks and average number of sessions completed per week. Demographic information was collected, including occupational history, educational history and living arrangement.

D. Post training interviews

After subjects completed the 12-week intervention period, they were interviewed to gather information across 4 broad topics: (1) technologic competence and previous technology use, (2) elements of intrinsic motivation, (3) elements of extrinsic motivation, and (4) system and game usability. Two distinct aspects of motivation were assessed. When motivation to participate in a certain behavior lies in the nature of the activity itself, this activity is said to be intrinsically motivating. Intrinsically motivating behaviors do not supply an external reward, but rather the reward of internal satisfaction or enjoyment. In contrast, behaviors that are extrinsically motivated result in obtaining an external (tangible or intangible) reward, such as receiving a preferred item or meeting a goal [13].

Interviews were conducted by trained research assistants who had no previous role in recruitment, data collection and analysis, or delivery of the intervention. Interviewers followed a semi structured interview guide to ensure comprehensiveness, but also encouraged subjects to speak freely about all aspects of their experience with HoVRS. Interviews were recorded and transcribed using Temi, a web-based voice to text transcription system, then checked manually for accuracy. The Sort and Shift approach was implemented for data analysis [14]. This included creating a data inventory by entering quotations from the transcripts table. From this table, team discussion occurred to identify patterns and connections in the data. Then an episode profile or summary of each participant was created containing a series of quotes that best represented each of the 7 themes generated. As a means to establish trustworthiness (qualitative reliability), the episode profiles were analyzed by three independent analysts and the themes generated were later discussed for concurrence and refinement [15].

III. Results

Twenty subjects ages ranged from 34 to 82 with a mean and median age of 57 (SD=12.7). Time since stroke ranged between 6 and 264 months with a mean of 57 months (74.5) and a median of 26 months. Baseline Upper Extremity Fugl Meyer score ranged between 15 and 66 with 14 subjects' baselines exceeding 34. Mean improvement in UEFMA score was 5.8 (2.3), with 16 subjects making improvements that were equal to or greater than 4.25, the published MCID for persons with chronic stroke [. Total training time ranged between 299 and 2020 minutes over the twelve week training period with a mean total training time of 909 (495) and a median of 832. See TABLE I for subject demographics.

TABLE I.

Subject characteristics:	
Age (years)	Mean (SD): 57 (12.7)
Time since stroke (months)	Mean (SD): 57 (74.5)
Severity of stroke (FMA-UE score)	Severe (0–15) n=1 Severe-Moderate (16–34) n=5 Moderate-Mild (35–53) n=11 Mild (54–66) n=3
Amount of use:	Minutes of use: 909 (495) # of sessions: 44.9 (18.1)
Living arrangement:	Single family home: n= 12 Other: n= 8
Highest level of education:	High school: n=6 Trade school: n= 2 Undergraduate: n= 3 Graduate: n= 9
Occupation	Administration n=6 Information Technology n=2 Blue-collar occupations n=5 Healthcare n=1 Education n=2 Other white-collar n=4 Self-employed n=5 Not self-employed n=15
Computer literacy:	Novice: n= 2 Basic: n= 2 Intermediate: n= 8 Advanced: n= 8

Four themes related to intrinsic motivation, 1) Challenge, 2) Feedback, 3) Progress and 4) Fun and three additional themes related to extrinsic motivation, 1) Additional therapy, 2) Return to prior level of function and 3) Altruism were identified.

A. Challenge

Challenge was the theme related to intrinsic motivation that was commented on most. Nine subjects (1, 4, 6, 8, 11, 13, 15, 18, and 20) cited challenges posed by the games as having a positive impact on their motivation to start and continue playing. The fact that games presented an adequate level of difficulty was important to four of these subjects (1, 4, 13, and

15) and three of these subjects (6, 11, and 18) cited games that were difficult for them as their favorites. Two of these subjects (8 and 20) made both positive and negative comments surrounding challenge, indicating that, while some games were adequately challenging, others were not as enjoyable due to a lack of challenge. Eight out of these nine subjects demonstrated above average total minutes of use and included the top 6 users.

Seven subjects (2, 7, 8, 10, 14, 16 and 20) made comments related to insufficient challenge having a negative impact on their motivation to train. All five subjects who spoke only negatively of challenge were below average in total minutes of use. Three subjects (2, 14, and 16) described a lack of new challenges as having a negative impact on their motivation and specifically commented on a lack of higher levels of difficulty. All three of these subjects were members of the algorithm-controlled group, suggesting that these subjects were not aware of the fact that they had mastered lower-level skills and were working on more difficult tasks. Two subjects (7 and 20) also expressed that games involving only one or two movements were not sufficiently challenging.

B. Feedback

Two subjects (2 and 19) discussed the value of feedback provided by the system. Subject 2 was motivated by progress as shown by earning points and increasing scores and strove to improve performance in each subsequent training session. Subject 19 utilized multiple forms of visual feedback to correlate his hand motion with the resulting game changes. Of note, subject 19 demonstrates proprioceptive impairment in his UE that may make him particularly appreciative of additional compensatory feedback mechanisms that enable him to attend to the game screen and participate without visually tracking his hand motions. While these two subjects spoke positively of the system in this way, they were the bottom two users for total minutes of use. In addition, subjects 2 and 19 were the two youngest participants and both had an extensive history with recreational video games.

C. Progress

Six subjects (5, 7, 8, 10, 13, and 18) cited the fact that they made progress in their ability to play the games as a factor that made them enjoy the games and want to play them more. Two of these subjects cited feelings of self-efficacy generated by making progress in their ability to play the games as having a positive effect on their willingness to try other things in their lives (outside of the games) that were difficult for them. All of the subjects making positive comments related to progress also made clinically significant improvements in motor function as measured by the UEFMA. One subject (7) who was motivated by game progress suggested that some games could be improved by additional markers of progress.

D. Fun

Five subjects (3, 5, 9, 13, and 14) cited the fact that they enjoyed playing the games. Three of these subjects (3, 5, and 13) specifically cited the fact that the games were more fun than exercising or doing therapy. Conversely, another subject (13) stated that he enjoyed the HoVRS games more than commercial games because they also had a therapeutic value.

Six subjects (5, 6, 8, 9 12, and 18) made negative comments related to enjoyment or fun. Five of the six (5, 8, 9, 12, and 18) specifically used the word boring when they talked about playing the games over a twelve-week period. Two subjects (5 and 9) also expressed that the games became repetitive and boring with sustained use. Interestingly, there is no discernible pattern in adherence to the protocol based on comments related to enjoyment. Subjects that made only positive comments played the game 701, 1062 and 1154 minutes. Subjects that made only negative comments played the games 655, 1000, 1071 and 1208 minutes, and subjects that shared mixed comments played the games 384 and 598 minutes.

E. Additional therapy

In response to the question Why did you enroll in this study?". Thirteen of the twenty subjects (1, 2, 4, 5, 6, 9, 10, 12, 13, 14, 16, 18, and 19) made specific comments related to the opportunity to perform additional therapy. We separated these comments from those of subjects that expressed a desire to return to prior levels of function or to "get better" without alluding to an opportunity to work at it. Three of these thirteen subjects (6, 9, and 19) made comments surrounding both being motivated by additional therapy time and returning to prior levels of function. Two subjects (2 and 19) noted that the fact that this additional therapy was unconventional was particularly appealing. One subject (4) also spoke specifically to appreciating that HoVRS could bridge the gap after traditional therapy services end and provide an alternative for therapy that could be completed independently.

F. Return to prior level of function

The other seven subjects described some aspect of function that they hoped to return to (subjects 3, 8, 17, 20, as well as subjects 6, 9, and 19 who also discussed pursuing additional therapy.) One subject (20) spoke directly to decreasing his dependence on his family members for assistance. The four subjects who spoke only to returning to prior functional status were in the top half of users per their total minutes of use and number of sessions completed. One subject (11) expressed discouragement regarding a lack of "results" towards reaching his prior functional level. Interestingly, this subject used the system for the most total number of minutes.

G. Altruism

Eight subjects reported the desire to help others as a reason for participating in the study. Four of these subjects (5, 15, 18, and 20) wanted to improve rehabilitation for future patients with stroke, three subjects (1, 11, and 13) specified that it was motivating to be assisting the research team, and one subject (7) was motivated by assisting both future patients with stroke and the research team. Of the eight subjects motivated by altruism, seven were at or above the average age of participants. These eight subjects also included the top three total minute users (1, 11, and 20).

IV. DISCUSSION

This study explored the experiences of 20 patients post-stroke utilizing HoVRS for home-based UE rehabilitation to identify intrinsic and extrinsic motivators that affected the subjects' engagement in training. Analysis revealed four themes related to intrinsic motivation and three themes related to extrinsic motivation that influenced subjects' experiences with HoVRS.

In terms of intrinsic motivation, the level of difficulty of HoVRS games was a primary influence. While many subjects were motivated to engage with games they felt were amply challenging, others felt the games were lacking in difficulty, which decreased their engagement. Perceived challenge appears to impact adherence, as subjects who felt adequately challenged tended to demonstrate above average total minutes of use, while those who felt unchallenged fell below this average. These findings are consistent with a review by Neibling et al. investigating factors that affect adherence to technology-aided home-based UE rehabilitation [16] as well as other recent studies with patients post-stroke by Kilbride et al. [17] and incomplete cervical spinal cord injury by Bell et al. [18]. Bell et al.'s subjects also found games incorporating more than one movement to be more enjoyable than games focused on one movement [18]. In addition, the level of enjoyment or fun that subjects reported both positively and negatively impacted their experiences. However, there was no significant difference in adherence when comparing subjects who report a high degree of enjoyment with those who reported feeling bored. Consistent with our findings, previous studies have reported repetitiveness, lack of variety, and boredom as barriers to enjoyment and engagement [16, 17, 18]. Lastly, and congruent with Neibling et al., progress made with the system motivated not only increased engagement in training, but also prompted increased use of the impaired UE and functional ambition in life outside of training [16].

Analysis of extrinsic factors that influenced engagement led to a subtle yet important distinction of being motivated by an opportunity to perform additional therapy versus a desire to return to a previous level of function or activity. Therapeutic benefits and improvements have been reported to increase motivation to engage with technology-aided rehabilitation [18, 19]. Unexpectedly, eight of 20 subjects also reported altruistic intentions for participating in this study, wishing to benefit future patients' post-stroke and/or assist the research team.

Limitations of this study include that subjects were exposed to one of two training programs that differed in game graphics and presentation of difficulty changes. However, sample size did not allow for comparison of these two groups, though game version may have impacted each subject's experience and engagement. Future studies will focus on modifying game characteristics to maximize patient experience and adherence.

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A Clinician-Guided Physical Movement Exergame for Individuals with Muscular Dystrophy

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***Abstract*— This study introduces a VR exergame for physical therapy and reversal of inactivity tailored for individuals with Duchenne muscular dystrophy (DMD). DMD is a rare disease that causes progressive muscle weakness and decreased opportunities for physical activity and movement. Management of the disease may require frequent clinical visits to specialized healthcare professionals for slowing the progressive muscular and cardio-respiratory effects of the disease. Limited availability and/or proximity to such resources are obstacles to optimal care and can lead to missed rehabilitation opportunities and reduced quality of life. We propose a physical activity VR game with remote telehealth applicability that incorporates: 1) shared patient-clinician VR interaction, 2) physiological sensors that provide real-time metrics of health outcomes to the patient and clinician, and 3) life-like virtual avatar interactions through depth camera body tracking technology; and 4) quantitative kinematics. The system was evaluated among 12 individuals, including 3 participants with DMD. Feedback through surveys, interviews, and focus group discussions with participants, accompanying family members, and clinicians demonstrated the feasibility of this VR tool for telehealth or as part of a home exercise program.**

Keywords*— *virtual reality, rehabilitation, exergame, telehealth, muscular dystrophy, exercise, immersive healthcare, social interaction, video games, rare diseases

I. Introduction

More than 25-30 million individuals in the United States are affected by one of approximately 7,000 rare diseases identified by the National Institutes of Health (NIH) [1,2]. Duchenne muscular dystrophy (DMD) is one of the more common rare disease that causes progressive muscle weakness and wasting in children and young adults [3]. As the most common and severe type of muscular dystrophy, DMD progressively affects the muscles of the extremities and trunk, leading to functional movement impairments [3]. By the age of 12 years, most individuals with DMD require a wheelchair [3]. Rehabilitation techniques focus on managing symptom progression and improving quality of life through encouragement of physical activity and engagement.

Effective healthcare delivery for rare diseases requires treatment plans that are multi-disciplinary and tailored to the severity and temporal course of symptoms specific to each affected individual [4,5]. A challenge in meeting these health needs is the limited number of clinics that specialize in rare diseases, rendering routine treatment either inaccessible or exorbitantly expensive for affected individuals and their families amidst sometimes long and frequent travels [4,5]. There remains a critical need for greater access to rare disease healthcare specialists without the additional costs that currently burden individuals with rare diseases.

Virtual reality (VR) technology has the potential to alleviate this burden by providing accessible and affordable rehabilitation directly to the home of individuals with rare diseases by delivering interventions through engaging game-based exercises—which can otherwise be repetitive and boring, especially for children. The use of VR in physical therapy has the potential to improve exercise adherence, and facilitate motor relearning [6]; particularly among individuals who are confined to their home for a majority of time and for whom exercise would otherwise be difficult to achieve; however, further research is required to establish efficacy. A limited number of gamified therapies for physical rehabilitation and exercise have been proposed, studied, and shown to benefit individuals with rare diseases such as DMD [7, 8], and pediatric chronic pain disorders [9], and none provide parameterization for physiologic outcomes or immersive clinician interaction. Furthermore, current systems have yet to provide quantitative feedback of whole-body movements or bridge the gap between standalone VR games and simultaneous telehealth interaction where biofeedback analytics can be monitored in real-time and the clinician can engage with the user to guide therapy.

To meet these health needs, we are developing a multi-modal immersive VR system tailored for individuals with DMD that will enable healthcare providers to remotely evaluate clinical

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outcome measures related to motor and cardio-respiratory function for managing patient therapy. The VR system provides a stimulating and enjoyable exergame medium tailored for enhanced engagement in children and young adults. The key components of our prototype system include: 1) clinical grade health analytics within the VR architecture; 2) life-like virtual avatar interactions driven by whole body tracking using RGB-D imaging technology; and 3) interactive, dynamic, and customizable game environments that facilitate clinical evaluations of physical exercises. The goal of this study is to demonstrate the feasibility of the prototype VR system based on its ability to engage children and young adults in carrying out upper-limb motor rehabilitation exercises tailored to individuals with DMD, provide objective outcome metrics, and support remote interaction with a clinician during the session.

II. Methods

A. System Component Architecture

We designed and implemented a VR system architecture that comprises (1) a VR Control Utility (VCU) to manage the connectivity between multiple input and output devices to facilitate real-time sensor analytics, (2) a custom data processing engine to derive sensor analytics from electromyography (EMG), electrocardiography (ECG), respiration and whole-body movement, (3) whole-body movement-driven avatar renderings, and (4) a game server for designing an engaging VR environment and implementing the game mechanics. The input devices included Delsys Trigno™ physiological sensors (EMG, ECG, Respiration strap) and Kinect Azure depth sensor for whole-body movement tracking and output devices included Manus Haptic Prime X gloves for real-time haptic feedback. All input-output devices communicated with the VR headset (Oculus Quest 2) using serialized middleware. Additional capabilities such as voice integration were also implemented using Vivox Voice & Text Chat package from Unity to enable the clinician and the participant to interact during gameplay.

B. Data Processing Engine

Physiological outcomes (respiration, heart rate, and muscle activity) measured from our input sensor devices were integrated into our game server using a custom-designed, real-time data processing engine. Raw data from a respiration sensor (for sensing inhalation and exhalation excursion), EKG sensor (for heart rate), and EMG sensor (for proximal shoulder muscle activity) were processed through a series of algorithms to derive health metrics of respiratory rate (breaths per minute), heart rate (beats per minute), heart rate variability, and muscle activation strength (volts). These physiological outcomes—along with physical movement outcomes of limb range of motion and symmetry from the 6-DoF body tracking—were subsequently displayed in the VR environment as a "real-time health analytics dashboard" for clinical feedback.

C. VR Exergame Game Design and Rendering

We collaborated with pediatric neurologists from Lurie Children's Hospital (Chicago, IL, USA) and rehabilitation professionals from MGH Institute of Health Professions (Boston, MA, USA) to derive design recommendations for the game, target specific movements of interest for individuals with DMD, and identify a set of feedback analytics and metrics useful for clinical evaluation. A physical activity game (referred to as Space Commander) was designed with virtual backgrounds and visual stimuli, in which participants interact with the virtual environment by reaching with their upper- or lower-limbs for targets indicated within their visual field of view. Specifically, upon entering the VR game, the participants full-body avatar is positioned in front of a virtual spacecraft control panel and is instructed to move their limbs and press various buttons, levers, or foot pedals in the display (Fig. 1). The avatar features, such as avatar height, color, and apparel were adjusted for the participant as needed. The game instruction required the participant to reach the required targets in a specific sequence that is displayed on the spacecraft monitor. Success is indicated by the target lighting up and the presence of a new target on the monitor. Haptic gloves were used to relay touch sensations back to the participant after each button press.

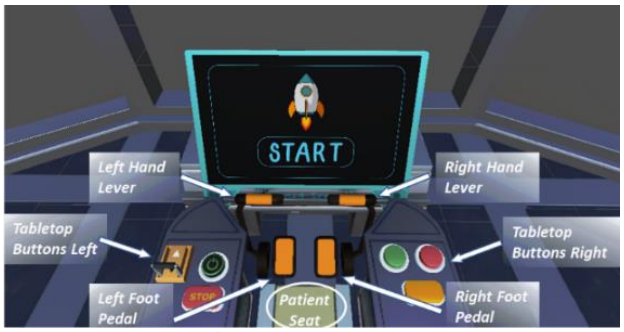

Fig. 1. Unity-based 3D asset for Space Commander demonstrating a spacecraft cockpit.

Respiration, cardiovascular, and muscle activity measures from the participant along with a 2D view of the participant's gameplay were displayed for the clinician within a real-time clinical dashboard projected onto a computer monitor. Voice chat capabilities were used to enable a clinician to remotely interact with the participant during gameplay.

III. Clinical Feasibility Evaluation

A. Participant Demographics

Twelve participants took part in the study (5 males, 7 females, 12.8 +/- 3.6 years). Three of the participants were diagnosed with DMD, while the remaining nine reported no history of motor impairment (controls). Of the 3 participants with DMD, 2 scored a 9 out of 10 on the Vignos Functional Scale [10], requiring a power wheelchair for mobility. One participant with DMD scored a 4 out of 10 on the Vignos Functional, and reported occasional use of a power wheelchair.

B. Experimental Protocol

The participants were seated in a chair (or wheelchair for DMD) with upper limbs resting on a table (Fig. 2). They were then instrumented with the physiological sensors, following which they donned the Oculus Quest 2 VR headset (Facebook, Cambridge, MA) and headphones in preparation for VR gameplay. The clinician was seated in a separate room from the participant to simulate a remote telehealth use case. The clinician's view (clinician dashboard) included a 2-D projection of real-time participant gameplay with overlaid health analytics (Fig. 2).

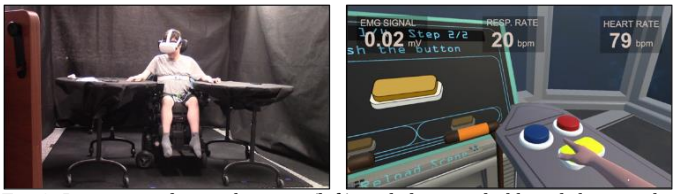

Fig. 2. Participant playing the game (left), and clinician dashboard showing the participant's game view and a health analytics overlay (right).

During the game, the clinician guided the participant through a series of movement tasks to select targets as a means of promoting exercise while assessing physical activity and 3-D limb workspace. A total of 12–20 targets were presented in a single game session that were randomly sequenced. The gameplay session consisted of two 3-5 minute rounds: 1) where the clinician guided the participant to search for, reach to, and select targets, and 2) where the participant followed game prompts on their own to simulate standalone gameplay (e.g., as a home exercise therapy device).

C. Feedback

After each game, the participant completed 2 surveys: 1) VR Sickness Questionnaire (VRSQ) – used to assesses feelings of *headache*, *blurry vision*, and *nausea* on a scale from 0 (none) to 3 (severe) [11]; and 2) system usability and engagement scale survey – an 8 question survey to characterize their experiences during the game (Table I), which was adapted from items in the System Usability Scale [12] and simplifying the language for children. The survey captured Likert ratings from 1 (worst) to 5 (best) for each question in the form of kid-friendly smileys (Fig. 3).

TABLE I. ADAPTED SYSTEM USABILITY SCALE SURVEY ITEMS.

Question	Item
Q1	This game was easy to play.
Q2	The rules of the game were easy to follow.
Q3	This game would be easy for my friends to play.
Q4	I was happy with how I played the game.
Q5	Playing the game helped me to *relax*.
Q6	I feel that I can improve my *breathing control* in the game with practice.
Q7	It was nice to be able to chat with the clinician.
Q8	I liked this game and would want to play it again.


Fig. 3. Likert scale images used in the SUES survey.

Statistical analysis of the survey results was performed for each question across the sample population via a Wilcoxon signed-rank test comparing mean survey rankings to a hypothesized score of 0 for the VRSQ, and 3 (neutral) for the adapted SUS. An alpha level of 0.05 was used for significance testing for each model. Effect sizes were estimated for significant models using Cohen's d.

To obtain feedback from the participants and their guardians pertaining to the design of the VR game and the perceived value of remote therapy, guided interviews were administered by research personnel. Our clinical team of pediatric neurologists and rehabilitation professionals also provided feedback on the potential clinical impacts of our game through focus group discussions.

IV. RESULTS

A. Participants' Perspectives via Survey

Statistical analysis on VRSQ responses revealed no statistically significant differences between participant sickness ratings and the hypothesized value of 0 ($p > .05$). One participant reported a slight headache and moderate nausea. No participants reported severe sickness or any degree of blurry vision following gameplay. Average modified SUS survey ratings (4.0 ± 1.2) relayed positive overall perceived usability and engagement. The game yielded statistically significant ($p < .05$) medium-to-large ($d \geq 0.5$), improvements over neutral for Q2-Q8, as shown in Table II).

TABLE II. SINGLE-SAMPLE WILCOXON SIGNED-RANK TEST RESULTS EXAMINING PERCEPTUAL GAMEPLAY RATINGS FROM THE ADAPTED SUS ON EACH GAME FOR 12 PARTICIPANTS. EFFECT SIZES ARE SHOWN VIA RANK BISERIAL CORRELATIONS ($p < .05$)

Items	*M*	*SD*	*W*	*p*	*d*
Q1	3.5	1.1	23.0	.070	–
Q2	4.7	0.5	78.0	<.001	1.00
Q3	4.0	1.1	34.5	.009	0.12
Q4	4.1	0.9	62.0	.004	0.59
Q5	4.2	1.5	67.5	.009	0.73
Q6	3.9	1.2	64.0	.024	0.64
Q7	4.8	0.4	78.0	<.001	1.00
Q8	3.8	1.4	36.5	.049	-0.64

B. Structured Interview Results

Upon obtaining survey-based participant feedback, one-on-one discussions between the researcher, participant and guardians were conducted as a series of recorded structured interviews to assess the proposed technology's perceived benefits, and areas of improvement. Feedback and recommended improvements were then categorized to highlight features of usability, accessibility, and engagement of the game (Table III).

TABLE III. EXCERPTS FROM THE INTERVIEWS WITH PARTICIPANTS. FEEDBACK IS SHOWN AS EITHER DIRECT QUOTES ("") OR ITALICIZED SUMMARY.

	Participant Positive Feedback	Participant Improvements
Impact	"If it was in real life, I would go 'I can't do that' and I would already shut down, but in a video game we could find a way to adapt it for me" "I could do things in video games that I can't do in real life"	*Recommended making the game more challenging by* "Doing two buttons at the same time, or a sequence [of buttons]" *Would like it if you earned points based on getting it right or how fast you got it*
Engagement	*Thought the game was fun and liked that it was in outer space.* *Would play the game* "until the year 3000."	"Could have been cool if each button would actually do something on the screen for example shoot lasers." *Noted that audio feedback would be helpful if you pressed a button,* "wind chimes or a ding or a bell."
Usability	*Stated that they would use it for a remote therapy session,* "If I didn't want to go one day, that could be an alternative." *Noted that it was easy to figure out the button you were supposed to press.*	*None Noted*

The guardians echoed the participant feedback and appreciated the potential for this technology for at-home therapy. They

requested options for either joining the VR session or visualizing it on a 2D screen for social engagement.

C. Focus Group of Clinicians

The clinical teams endorsed the potential use of the Space Commander game for aiding physical therapy and saw the game as a multi-purpose clinical tool that could provide assessment, performance tracking and intervention. Verbal feedback was collected from focus group sessions and categorized to highlight three themes: usability, impact, and scalability, presented in Table IV.

TABLE IV. EXCERPTS FROM THE STRUCTURED INTERVIEWS WITH THE CLINICAL FOCUS GROUP. FEEDBACK IS SHOWN AS EITHER DIRECT ("") OR ITALICIZED SUMMARY.

	Clinician Positive Feedback	Clinician Improvements
Usability	*Stated that gamifying therapy enhanced engagement as kids find PT boring and video games fun*	"There should be a way to track performance over time (bigger picture incentive- is the child making progress)" *Ability to parameterize the game targets in VR environment.*
Impact	"Very useful to have a clinician seeing what the child is seeing." *Noted that they perceive this as a clinical tool rather than just a game.*	*Requested more comprehensive outcome measures:* "Useable workspace measure could give great feedback about how much the children are able to move and to play the game."
Scalability	*Stated that they see great potential for use of the game for assessment and intervention.* "offers an opportunity for recovery rehabilitation outcome assessments for upper body surgeries"	*None Noted*

V. DISCUSSION AND CONCLUSION

In this work, we designed and evaluated the feasibility of a VR exergame designed to encourage and practice upper and lower limb use through a telehealth platform, for individuals with DMD. Overall, our results provide a strong foundation to support the feasibility of creating an easy-to-follow game that stimulates physical exercise in an engaging manner, while providing physiological outcomes. Exergame therapy as presented in this study could serve as a means for encouragement to the individual, especially through its capability to scale the targets to limited participant movement capabilities (e.g., sliding their hands on the table to buttons or reaching for levers above the table), alleviating some of the mental barriers to exercise in their daily life through gameplay. In that same vein, its usefulness could be to provide periodic activity sessions on their own from home, to break up long periods of sitting stationary in a wheelchair by providing incentives to move their upper and lower limbs or adjust their posture. The DMD population is known to comprise avid video game users but other than distraction the current remote based video games provide little activity beyond moving a few digits on a controller. The physical therapy game presented in this study uses the whole-body movements as inputs to the VR game, thereby providing a greater opportunity for physical exercise while maintaining the distraction and engagement elements of traditional games.

Compared to current literature pertaining to the use of gamified therapies for DMD rehabilitation, the work presented in this paper is the first to utilize a whole-body immersive VR environment with multi-sensor data fusion. Other studies describing games designed for individuals with DMD [7, 8], often utilized a 2D screen as interface, or an augmented reality setting. Furthermore, none of these studies described the integration of clinician-patient communication abilities in the game, nor the use of physiological sensors. While these studies generally concluded positive outcomes, either in terms of participant feedback or observed improvements in performance, their use as a telehealth tool is not established. Similar to the findings of this study, the discussed literature work endorses the use of gamified therapy for improving patient engagement and motivation.

In conclusion, the VR exergame platform designed in this study shows promise as a clinic-based, telehealth, or home-exercise tool, enabling patient-clinician interaction and providing objective physiological and performance metrics. The impact of this work is in the potential to increase healthcare accessibility for individuals with DMD, to provide clinicians with movement and physiologic assessment tools, and provide engagement to the patient for in-home use.

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Perspectives on Digital Health Technologies in Pediatric Care and Rehabilitation

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***Abstract* — Digital health technologies are increasingly adopted by healthcare professionals working in pediatric hospital and rehabilitation settings. Multiple factors may affect the acceptance and implementation of digital health technologies in these settings. This study aimed to explore the factors that promote or hinder the use of digital health technologies (mobile learning applications, virtual/augmented reality, serious games, robotic devices, telehealth, computerized assessment tools, wearables) among pediatric healthcare professionals. An online survey documenting opinions on current use and future intentions to use digital health technologies was completed by 107 professionals at Canada's largest mother-child hospital and rehabilitation centre. T-tests and linear regression results indicate that the attitudes promoting the intention to increase the use of digital health technologies vary according to technology type. Healthcare professionals who report wanting to increase their use of digital health technologies have a more positive attitude regarding benefits in clinical practice and patient care, but are critical of the impact on patient-professional relationships. The factors that hinder successful usage are lack of training (β=0.303; p=0.033) and inadequate infrastructure (β=0.342; p=0.032). Study results underscore the importance of addressing training and infrastructure needs when elaborating technology-specific strategies for adopting digital health technologies.**

Keywords—technology, augmented reality, virtual reality, healthcare, digital health

I. Introduction

Digital health technologies are increasingly available to healthcare professionals working in hospital and rehabilitation settings [1-4]. Although there is no consensual definition of digital health technologies, they are often described as any technology that either directly or indirectly supports or provides healthcare, or promotes improved health [5,6]. Such technologies include, but are not limited to, mobile and tablet learning applications, virtual or augmented reality, serious games, robotic devices, mobile health (mHealth; e.g. virtual care by telehealth), computerized assessment tools, and wearables. As digital health development and use progress and access to virtual environments becomes more affordable, interest in using interactive and immersive systems and in exploring the therapeutic value of such systems has grown [7]. Digital health technologies can assist healthcare professionals for diagnostic, evaluation, treatment, intervention, education, entertainment, and distraction purposes [8,9]. In pediatric settings, digital health technologies present numerous potential advantages over conventional tools. The interactive nature of digital health technologies such as VR, AR and serious games, in particular, enhances the motivation and engagement of pediatric patients participating in rehabilitation interventions [10,11]. Given that children growing up in the current digital age typically have high digital literacy, health care systems could benefit from developing innovative digital health applications for care provision [7], with the goal of improving intervention uptake and compliance, as well as, quality and efficiency of care.

Nonetheless, multiple factors may affect acceptance and implementation of digital health technologies in pediatric health care settings [4]. Previous studies focus on identifying facilitators specific to certain technologies, such as VR [4], or concentrate on particular healthcare professions, such as occupational therapy or nursing [4,12]. To our knowledge, no study has yet examined such factors in the global context of pediatric healthcare, including multiple health professions, or with regard to a broad sampling of digital health technologies.

II. Objectives and Hypotheses

The general objective of this study was to explore the factors that promote and hinder the use of digital health technologies by surveying the attitudes and opinions of pediatric healthcare professionals. Specific objectives were to (a) evaluate the attitudes that promote the intention to increase the use of digital

health technologies and; (b) identify factors associated with usage of digital health technologies. The hypotheses were: (a) the intention to increase the use of digital health technologies is associated with more positive attitudes and; (b) technical problems, lack of training, inadequate infrastructure, time constraints, and other problems affect perceived usage success.

III. Methods

The data were collected as part of a feasibility study regarding the implementation of digital health technologies in pediatric hospitals and rehabilitation centers (the InteRV Project). The project was approved by the local human research ethics committee.

A. Setting

A survey was completed by healthcare professionals at a Canadian pediatric hospital facility (CHU Sainte-Justine, including the Marie Enfant Rehabilitation Center, Montreal, Canada) who work with or are likely to work with digital health technologies. CHU Sainte-Justine is Canada's foremost hospital dedicated to mothers and children, and is the second-largest pediatric research institute [13]. The affiliated rehabilitation center provides specialized services in the areas of adaptation-rehabilitation, integration and social participation for children and adolescents with motor or cognitive disabilities [14].

B. Participants

Specific services, units, and departments were targeted for survey dissemination to ensure the relevance of the survey for potential participants in terms of likelihood of current or projected use of digital health technologies, and to ensure data generalizability to other pediatric hospitals and rehabilitation centers. Choices were made by the research team in collaboration with clinical collaborators and the hospital directorship to ensure a global perspective. After consultation, the services, units and departments included psychology, nursing, special education, pain management team, psychiatry, speech therapy, physiotherapy, occupational therapy, neurotraumatology, anesthesia and intensive care, orthopedics, and neurotrauma. The survey was distributed to approximately 1558 healthcare professionals via departmental distribution lists and weekly bulletins.

Ultimately, participants (N=107) were 75 healthcare professionals working at the hospital, and 33 working at the rehabilitation center. The most frequent occupations were nurse (28.7%, n=31), physician (17.6%, n=19), and occupational therapist (9.3%, n=10). The majority of respondents were women (90.7%, n = 97) and were aged between 25 and 34 years (33.3%, n = 36) or between 35 and 44 years (32.4%, n = 35). All participants provided informed consent for participation at the beginning of the survey.

C. Online survey

The custom-designed survey was built and distributed using the REDCap platform. The survey focused on the following digital health technologies: mobile and tablet learning applications (APP), virtual or augmented reality (VR/AR), serious games (SG), robotic devices (RD), telehealth (TH), computerized assessment tools, and wearables (W).

Completion time was approximately 10 minutes. A pilot test of the survey was completed by three research assistants and questions were adjusted based on their feedback. Questions included information on current digital health technology use, usage intentions and attitudes towards digital health technologies, and obstacles encountered or perceived in relation to using digital health technologies. Four-point Likert scales with anchors on 'Total agreement' and 'Total disagreement' were used for questions specific to attitudes, while anchors on 'Success, no obstacles' and 'Failure, too many obstacles' were used for opinions related to usage success.

D. Statistical analysis

Analyses were run in IBM SPSS Statistics 28.0. Data were analyzed using parametric statistics. For each digital health technology, respondents were divided into two groups: healthcare professionals who intend to increase their use of the technology and those who do not. Independent samples t-tests were used to compare the two groups on the following attitudes regarding each digital health technology: "I think it is an asset in my clinical practice", "I find it easy to use", I don't think it adds anything to my clinical practice", "I think it can have a positive impact on the patient and their care", I think it harms the quality of the patient-professional relationship", "It allows for therapeutic goals that would be unattainable without it". Bonferroni correction was applied to independent samples t-tests; p-values lower than 0.0083 were considered significant.

Multiple linear regression analyses were used to determine predictors of usage success among technical problems, lack of training, inadequate infrastructures, lack of time and other problems. Regression analyses included the diversity of digital health technologies used, years of work experience, and job position, to control for associations with technology experience.

IV. Results

Healthcare professionals reported mostly using mobile and tablet learning applications (n=43, 38.1%), telehealth (n=49, 43.4%), and computerized assessment tools (n=33, 29.2%). Some also used virtual or augmented reality (n=16, 14.2%), serious games (n=9, 8.0%), robotic devices (n=11, 9.7%), or wearables (n=5, 4.4%).

TABLE I. COMPARISONS BETWEEN PROFESSIONALS WHO INTEND AND DO NOT INTEND TO INCREASE THEIR USE OF DIGITAL HEALTH TECHNOLOGIES

Attitude	t-values					
	APP	***VR/ AR***	***SG***	***RD***	***TH***	***W***
I think it is an asset in my clinical practice.		3.06*	3.26**		2.80*	
I find it easy to use.			3.10*			
I don't think it adds anything to my clinical practice.	-2.84*			-3.23**	-5.15**	
I think it can have a positive impact on the patient and their care.		-4.02**	5.67**	4.25**	4.67**	3.71**
I think it harms the quality of the patient-professional relationship.	2.67*	3.24**	2.67*		3.88**	
It allows for therapeutic goals that would be unattainable without it.		-5.33**	-2.70*		-3.48**	-2.70*

*p<0.0083; **p<0.0017

Funding for this project was provided by the Ste-Justine Hospital Foundation Neurotrauma Research Funds.

TABLE II. PREDICTORS OF USAGE SUCCESS

Predictors	Results		
	β	***t***	***Sig.***
Technical problems	0.249	1.892	0.065
Lack of training	0.303	2.191	0.033
Inadequate infrastructure	0.342	2.207	0.032
Lack of time	-0.024	-0.160	0.874
Other problems*	0.184	1.271	0.210

*For example: difficulties with the therapeutic alliance and delays incurred

A. Attitudes promoting the intention to increase the use of digital health technologies

Table I presents group differences between healthcare professionals who aspire to increase their use of digital health technologies and those who do not. Across the majority of digital health technologies, those who intend to increase their use were more in agreement with the following statements than those who do not: "I think it is an asset in my clinical practice" (*ts* between 2.80 and 3.26, $p<0.01$), "I think it harms the quality of the patient-professional relationship" (*ts* between 2.67 and 3.88, $p<0.01$). They were also more in agreement with the statement "I think it can have a positive impact on the patient and their care" (*ts* between 3.71 and 3.26, $p<0.01$), except for virtual or augmented reality ($t=-4.02$, $p<0.01$). They were, however, less in agreement with the following statements: "I don't think it adds anything to my clinical practice" (*ts* between -5.15 and -2.84, $p<0.01$), "It allows for therapeutic goals that would be unattainable without it" (*ts* between -5.33 and -2.70, $p<0.01$). Only healthcare professionals who intend to increase their use of serious games were more in agreement with the statement: "I find it easy to use" ($t=3.10$, $p<0.01$). No significant results were found for computerized assessment tools (*ts* between -0.785 and 1.626; *ps* between 0.054 and 0.443).

B. Predictors of successful usage

Linear regression results pertaining to obstacles that promote or hinder successful digital health technologies use are presented in Table II. Lack of training ($\beta=0.303$; $p=0.033$) and inadequate facilities ($\beta=0.342$; $p=0.032$) were significant predictors of a less favorable evaluation of usage success.

V. DISCUSSION

Healthcare professionals who plan to increase their use of digital health technologies in their practice generally had a more positive attitude regarding their benefits in clinical practice and patient care compared to those who did not plan to incorporate digital health technologies into their practice. Healthcare professionals who plan to increase their use of digital health technologies nonetheless viewed the use of digital health technologies as more detrimental to patient-professional relationships and deemed them to be non-essential for practice.

These results suggest that professionals who plan on using digital health technologies are aware of the potential drawbacks and acknowledge the obstacles involved in their implementation, but they remain reasonably enthusiastic about the future use of these technologies. The fact that they acknowledge that digital health technologies such as mobile/tablet applications, virtual or augmented reality, serious games and telehealth, may be detrimental to patient-professional relationships could be explained by the considerable amount of equipment that needs to be handled. This could detract from efficient human interactions, as they may be preoccupied with setting up equipment. Second, they do not view digital health technologies as essential to the attainment of therapeutic goals. This may be due to the perception that the current treatments they are using are already effective enough to treat patients' health conditions, and that the addition of digital health technologies may not significantly contribute to the outcomes of the treatment. Previous studies on specific conditions (e.g. diabetes) report digital health technology advantages for patient motivation and entertainment, but not necessarily in terms of their therapeutic value [15]. A review suggests that intervention benefits of some digital health technologies may be more limited for some clinical populations (e.g. ADHD, ASD, eating disorders, psychosis, PTSD) [16]. However, work focussing on robotic devices has shown a significantly therapeutic value compared to traditional treatments for children living with physical conditions affecting their health [17]. Current and previous findings suggest that perceptions of therapeutic benefit need to be considered with respect to each individual technology. Previous also highlights discrepancies between patient and healthcare professional attitudes toward digital health technologies. In general, healthcare professionals and managers exhibit more resistance towards technology compared to patients [18]. Importantly however, the current findings suggest that professionals' awareness of digital health technology disadvantages does not diminish their inclination toward their use.

The attitudes promoting the intention to increase the use of digital health technologies varied across types of technology. These results again underscore the importance of concentrating on each type of digital health technology separately and elaborating specific strategies for adopting and implementing individual technologies. More specifically, healthcare professionals who intend to increase their use of virtual or augmented reality were less inclined to think that this technology can have a positive impact on the patient and their care, as opposed to other technologies. Professionals may be more guarded in their opinion on potential benefits because of the novelty of the technology and ongoing evolution in its functionalities and applications [19]. Additionally, virtual and augmented reality may not be suitable for all patients or medical conditions, and healthcare professionals may need to carefully evaluate each case to determine appropriate treatment options. For example, they may have concerns about the potential risks and side effects of the technology on children, such as cybersickness or disorientation [20].

The main obstacles identified in the current study that affect successful use of digital health technologies and their widespread adoption are inadequate infrastructure and lack of training. A previous review of facilitators and barriers to virtual reality use similarly reports challenges related to environmental context and resources, such as treatment space issues, time to learn how to use, and time to use [7]. Lack of familiarity with new digital health technology or lack of the necessary skills to use it effectively could lead to resistance to adopting technology or slow uptake. The results underscore the importance of upgrading infrastructures in order to ensure healthcare

professionals have the resources they need to use technology [21]. Without the proper infrastructure and its correct functioning (e.g. facilities, maintenance, updates, networks), digital health technologies may not work as intended, leading to further resistance and discouragement.

Overall, the successful use of digital health technologies requires a comprehensive approach that carefully considers attitudes, infrastructure, training, and support necessary for their effective implementation and adoption in pediatric care. Each site may need to assess local infrastructure to ensure that it can accommodate the use of digital health technologies before acquiring new equipment or encouraging professionals to adopt innovative tools. Appropriate training programs are essential to ensuring digital health technologies do not have negative impact on patient care and provider-patient relationships. Given their differences and the main barriers to their use, the findings emphasize the importance of establishing training and implementation tailored specifically to each type of technology being used and not assuming that the barriers or facilitators generalize across tools.

While this study provides insights into the opinions of healthcare professionals in a pediatric facility on a broad range of digital health technologies, some limitations should be considered. First, the study had a modest sample size and especially small sampling from the rehabilitation center. This may impact generalizability. Second, a custom-made survey was used. Validated surveys for exploring technology use exist, for example ADOPT-VR [4]; however, a custom survey was chosen to address a broad range of technologies and ensure applicability to the pediatric healthcare setting where the study was conducted. Third, some t-tests were based on unequal sample sizes when were small (e.g. serious games, robotic devices). Conclusions regarding these technologies should be interpreted with caution. Finally, other digital health technologies, such as those related to data management for example, were not addressed in this study. Including a wider range of technologies could have encouraged the participation of a greater number of healthcare professionals or managers in the study. Future research with larger sample sizes should be conducted in multiple facilities to further investigate the differences between healthcare professionals working in hospitals and rehabilitation centers. They should also explore the key factors that contribute to inadequate infrastructure and focus on developing strategies to improve them.

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Hybrid tele-rehabilitation for children: Initial results of a scoping review

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***Abstract*—This paper describes initial results of a scoping review of hybrid tele rehabilitation of allied health professions for children. The review focuses on the characteristics and outcome measures used in 20 studies.**

Keywords—tele rehabilitation, hybrid, pediatric, allied health professions

I. Introduction

Hybrid tele rehabilitation is a service modality that combines in-person and remote services, thus potentially reaping the demonstrated benefits of both. However, the research literature is limited by the inconsistent use of terminology and sparse critical reviews of service models, outcomes, best practices, and evaluation of service effectiveness, particularly for pediatric rehabilitation. In order to further standardize research methodologies, an investigation of knowledge gaps regarding pediatric hybrid program evaluation measures is warranted. The current report's guiding research question was: What were study characteristics and outcome measures used for program evaluation of hybrid allied telehealth rehabilitation interventions for children?

II. Methods

A scoping review methodology was used following Arksey and O'Malley's [1] five main scoping review stages with refinements as recommended by Levac et al. [2]. A rigorous and iterative search was carried out in multiple databases: Medline (Ovid), Embase, CINHAL, PSYcinfo, Cochrane, WoS. After consultation with a librarian, the key words included: (remote OR online OR telehealth OR telemedicine OR mhealth OR ehealth OR digital) AND (rehabilitation OR occupational therapy OR physical therapy OR physiotherapy OR speech therapy OR psychology OR Ergotherapy OR Speech language pathology OR Exercise therapy OR Exercise physiolog* OR Respiratory therapy OR Kinesiotherapy OR Music therapy OR Family therapy OR Art* therapy OR Social work OR Recreational therapy OR Child life therapy OR Dietician OR dietetics) AND (hybrid OR combin* OR blend* OR multimodal OR integrat*). Inclusion criteria were: 1) English language; 2) published in peer-reviewed journals and conference proceedings; 3) articles published since 2011; 4) participants were children receiving healthcare services by allied health professionals. 5) articles document a hybrid intervention. Exclusion criteria were: 1) articles in which interventions do not include professional monitoring of the tele-rehabilitation component(s) (e.g. an exercise program which is given for at-home training, but its performance is not documented); 2) systematic reviews and meta-analyses and 3) medical, nursing or educational interventions. Covidence software (Covidence, 2018) was used to perform study selection and data extraction. Following the initial selection of studies, only studies with children and/or adolescents were included for further analysis.

III. Results

A total of 9868 papers were screened. After removal of duplicates, 6155 papers remained, and 6106 were excluded based on abstract screening. Forty-nine papers were assessed using full-text and 29 were removed due to intervention type not meeting the inclusion criteria (n=14), unavailable full text (n=11), adult population (n=3) and language other than English (n=1).

Program characteristics: A total of 20 studies were included in this scoping review. Nine out of the 20 studies

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(45%) originated from the United States. An additional 2 papers (10%) originated from Australia [3], [4], and the remaining 45% of papers originated in Europe.

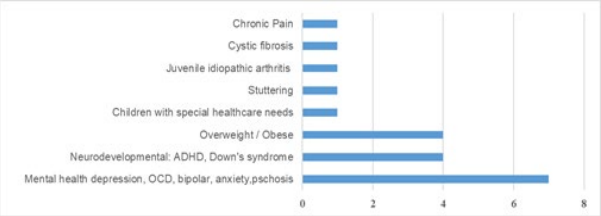

Figure 1. Distribution of clinical conditions for participants in hybrid treatment

The included studies involved diverse health professionals (Figure 2). Thirteen studies involved mental health professionals. Within these studies, most (10 studies, 77%) reported the intervention to be Cognitive Behavioral Therapy (CBT). An additional study [5] used CBT administered by a speech and language pathology graduate student. Intervention duration was longer than 15 weeks in 3 studies [6]–[8], less than 5 weeks in 3 studies [4], [9], [10], and from 5-15 weeks in the rest; duration was not specified in one study [5].

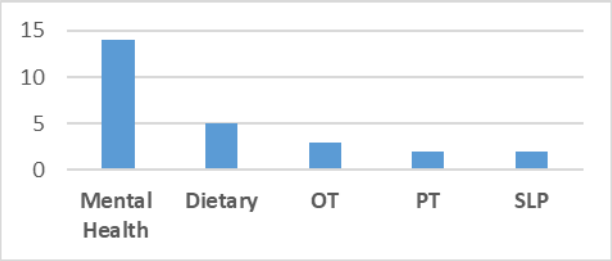

Figure 2. Distribution of healthcare professions in hybrid treatment

Study designs varied across the 20 included articles. Most studies (16 papers, 80%) used experimental or quasi-experimental designs. A control group was included in 13 studies [3], [4], [6]–[8], [11]–[18], over half of which (7 studies) used randomization for group assignment [3], [6]–[8], [14]–[16]. Two of the RCT studies reported only on the hybrid programs without between group comparisons [15], [16]. Three papers were case reports or case series [5], [9], [10] and one study [4] was a retrospective observational study.

Program evaluation outcomes: The initial analysis of the scoping review focused on program evaluation outcomes, including feasibility and acceptability, client satisfaction, therapeutic alliance, professional feedback, economic effectiveness, and safety (Table 1). Clinical outcomes were not included here given the diversity of the study populations examined. Results demonstrated a very large range of study outcomes used by many allied health professionals.

TABLE 1. PROGRAM EVALUATION OUTCOMES

Construct	Measure
Program feasibility assessment	Program completion [9], [16] Participation in online sessions [9], [17] Compliance [19] Attendance [15], [17] Use of learned strategies [10] Recruitment [19] Retention [15] Acceptability [17], [19] Usage [17] System Usability Scale (SUS) [20] Client Evaluation of Services Questionnaire (CSQ-8)[20] Questionnaire for the evaluation of treatment (FBB) [21] Number of technical problems [16]
Client satisfaction	Client Satisfaction Questionnaires [15], [16], [19]–[21] Overall feelings [9]
Therapeutic participant-therapist alliance and interaction	Working Alliance Inventory [15] Emails and chat sessions with instructors [16]
Professionals	Caring Professional Scale (CPS) [18] Summary Therapist Feedback Form [21]
Cost effectiveness	Cost for clients: The Family Cost Survey (Researcher developed, Nonstandard) [18] Monitoring the financial consequences for the participants [16] Distance and travel time from home to hospital [3], [4], workdays missed [3] Cost for service provider: cost of program development, staff costs [16]
Safety	Documenting adverse events [3], [4], [19]

IV. DISCUSSION

Diversity of study designs, of the populations included in the studies, the professions treating these populations and the outcomes used was the most notable finding of the scoping review.

A major limitation in comparing the relative pros and cons of hybrid tele rehabilitation programs for children, is the diversity of the study designs and reported results. For example, their selection of different outcome measures severely limits generalization of findings. As listed in the table, the reported program evaluation outcomes included feasibility and acceptability, client satisfaction, therapeutic alliance, professional feedback, economic effectiveness, and safety. Moreover, although many of the 20 papers in this scoping review recognize the importance of performing a cost-effectiveness analysis as a key outcome measure, only four [3], [4], [16], [18] made progress in this direction, albeit by focusing, in most cases, on the costs of remote intervention rather than on the costs relative to service effectiveness.

V. CONCLUSIONS

The non-inferiority of tele rehabilitation has been well established in the literature. Following the surge of use of tele rehabilitation during COVID-19, many studies suggest

that hybrid service models (combined in-person and remote services) may be an effective solution for tele rehabilitation in children. This scoping review identified shortcomings in current means of documenting and measuring hybrid tele rehabilitation programs. Given the breadth of populations and professions involved in hybrid interventions and in order to advance the level of evidence it is important to agree upon outcome measures to evaluate programs We will present an analysis of these limitations as well as recommendations aimed at ensuring greater uniformity of data collection in future reports.

ACKNOWLEDGMENT

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ISVR

INTERNATIONAL SOCIETY FOR VIRTUAL REHABILITATION

Oral Session 5

Sensory function and balance

13:45 to 15:15

July 25th, 2023

Validation of portable virtual reality-based assessments of balance and vestibulo-ocular function

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***Abstract*—This validation study of a battery of virtual reality (VR) head-mounted display-based balance, oculomotor, and vestibular assessments compared the novel VR tests to standard validated measures currently available in clinic for evaluating individual with signs or symptoms following a concussion. Forty-eight healthy adults except for having a history of concussion (n=18), were tested in both standard and novel VR assessments. Correlation coefficients revealed that the VR balance significantly correlated with the gold-standard SOT posturography measure (r=0.300-0.672, p< 0.01), the VR vestibular assessment correlated with the traditional measure of dynamic visual acuity (r=0.570, p=0.014), and the VR measure of near-point convergence correlated with the manual measure (ρ = 0.454, p< 0.001). Comparing those with a history of concussion to those without, revealed no between group difference. The current findings support criterion measure validity. Further testing is needed to establish sensitivity to visual, vestibular, or balance deficits.**

Keywords—balance, vestibular, assessment, concussion

I. INTRODUCTION

The impact that vestibular and oculomotor control systems have on balance are well-studied. These systems are important for sensing angular and linear acceleration of the head and eyes, which enables a moving individual to maintain gaze on a stable target or a stationary individual to focus on a moving target. When walking the impact of each footstep sends a biomechanical wave of forces up to the head, yet multiple vestibular reflexes and feedforward motor processes stabilize the head and eyes allowing one to maintain a stable visual perception of the environment. Given the documented effects that mild traumatic brain injury (mTBI, i.e. concussion) can have on these processes, highlights the importance of assessing their functional integrity [1-6]. An objective assessment or battery of assessments that could help isolate whether the underlying cause of concussion symptoms are vestibular, visual-vestibular, or some other etiology would certainly add to the clinician's ability to effectively treat a recovering patient.

The current project focuses on creating a tool that is based on virtual reality (VR) head-mounted display (HMD) technology that can be used for assessing balance and oculomotor function in various patient populations. A comparison of these novels assessments relative to validated criterion-measure clinical measures will determine if sensitive and specific outcomes can be reliably acquired. Such objective measures can allow for research-grade measurements but with increased inter-rater reliability, portability, and usability, which can enhance clinical care. In this project only healthy individuals and those with a history of concussion were tested.

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II. METHODS

A. Subjects

Forty-eight subjects, n=30 with no history of mTBI (27.5±7.6yrs), and n=18 with a history of mTBI (25.0±6.1yrs) were tested in this IRB approved protocol. All subjects were tested on all assessments described below. The order of testing was the same for all subjects.

Inclusion criteria:

1) 18 - 50 years old.
2) normal or corrected-to-normal vision.
3) able to give informed consent.
4) able to ambulate without any physical assistance.

Exclusion criteria:

1) history of neurological disorders with known etiology unrelated to TBI (history of concussion >6 months post-injury, was not an exclusion criteria).
2) any lower limb, cervicospinal, or musculoskeletal injury, or recent surgery, which may affect balance.
3) concurrent anatomic abnormalities of the eyes and vision resulting in monocular vision or a visual field deficit.
4) vision worse than 20/40 with corrective lenses (in both eyes) or other visual deficits.
5) inability to stand independently for periods lasting at least 10 min.

B. Assessments

All VR tests were performed wearing an HMD (Pico Neo 3). Inertial measurement units (IMU) and inside-out camera tracking built into the HMD was used to measure all kinematics. Movement of head has been shown to be a valid measure of postural sway [7].

Balance assessments

The following balance assessments were meant to systematically measure the use of the vestibular, visual, and somatosensory systems and how well the postural control system adapts to changes in sensory reliability.

Sensory Organization Test (SOT) – The SOT protocol uses the NeuroCom® posturography device to objectively measure

changes in the center-of-pressure (COP) anterior-posterior sway range across six postural conditions:

1) EO fixed - eyes open with fixed support surface
2) EC fixed - eyes-closed with fixed support surface
3) SRv fixed - eyes-open with SR (i.e., discordant) visual input on a fixed surface
4) EO SRs - eyes open with unstable, sway-referenced surface
5) EC SRs - eyes closed with unstable, SR surface
6) SRv SRs - eyes-open with discordant visual input on an unstable, SR surface.

The SR conditions (visual and/or support surface) directly follow the sway of the subject so that information normally derived from these sensory channels is discordant and unreliable. In the SR surface conditions, the NeuroCom floor surface can tilt in the toes-up/toes-down direction (tilt max = 10º). During these conditions, the force plate will tilt toes-down 1º when participant's COP moves forward 1º. The SOT has been validated for concussion testing of balance [8].

VR Sensory Integration in Balance (VRSIB) test – Participants performed a series of static balance tests with shoes off with feet positioned at a comfortable distance apart (~20-25 cm). Participants were instructed to look straight ahead and maintain an upright stance as stably as possible. Eight 20s trials were performed in the following order:

1) EO firm - Standing on firm surface (i.e., floor) with eyes open, VR screen earth-fixed
2) EC firm - Standing on firm surface with eyes closed
3) SR firm - Standing on firm surface with eyes open, VR scene sway referenced (SR) to the subject
4) Spin firm - Standing on firm surface with eyes open, VR scene displaying roll-axis rotation clockwise or counter-clockwise.
5) EO foam - Standing on foam surface (i.e., foam pad) with eyes open, VR screen earth-fixed
6) EC foam - Standing on foam surface with eyes closed
7) SR foam - Standing on foam surface with eyes open, VR scene sway referenced to the subject
8) Spin foam - Standing on foam surface with eyes open, VR scene displaying roll-axis rotation clockwise or counter-clockwise.

Vestibular assessments

Manual DVAT – assesses the ability to stabilize vision as the head moves, which evaluates vestibular ocular reflex (VOR) function [9]. This test was performed while seated and the subject performed active headshaking movements. Vestibular integrity is measured by comparing the ability to accurately identify visual targets (tumbling "E") during a head stationary task compared to when head is being actively rotated. Head rotation occurs in yaw (i.e. left/right, as if shaking one's head "no") or pitch (i.e. up/down, as if "yes") direction, turned at least ±20°, with the metronome set to induce head rotation velocity that exceeds 120°/s. The participant reads the tumbling-E chart placed 2m away and verbally reports the direction of the tumbling-E. If a participant loses more than 2 lines (0.2 logMAR) relative to the stationary test, then this is indicative of vestibular hypofunction [10-11].

VR Dynamic Visual Acuity Test (VR-DVAT) – this test emulates the standard DVAT, but here a custom-designed program run in an instrumented HMD automatically and objectively measures head velocity, amplitude, and subject response. Both left/right and up/down headshaking directions were tested separately with a metronome and messages to guide head amplitude (±20°) and head velocity. Peak velocity needing to exceed 120º/s before the visual target appeared for 75ms. During this task, the participant attempts to indicate the direction of a visual target (i.e. a tumbling-E) using a directional thumbstick. After correct answers the E automatically gets smaller by 0.1 logMAR.

Oculomotor assessments

Manual near-point convergence (NPC) test – during this assessment an accommodative ruler is placed on the subject's philtrum. A sliding visual target is slowly moved by experimenter (1-2 cm/s) towards the subject's eyes along the visual midline. The subject reports when the visual target is too near to focus on without double vision (diplopia) [1].

VR-Verge - a custom-designed VR test of vergence insufficiency. During this task the participant viewed a visual target that slowly approached the eyes along the visual midline. The subject was instructed to indicate with a button-press when the target was too close to keep visually fused and was perceived to split into two objects.

C. Data Analysis

Testing for criterion-measure validity was performed with Pearson or Spearman correlations depending on the normality of the data. The novel VR assessment outcomes were compared to the standard, validated criterion measures or gold-standard when available, e.g. SOT. To establish construct validity, independent means t-tests were performed comparing groups with and without a history of mTBI.

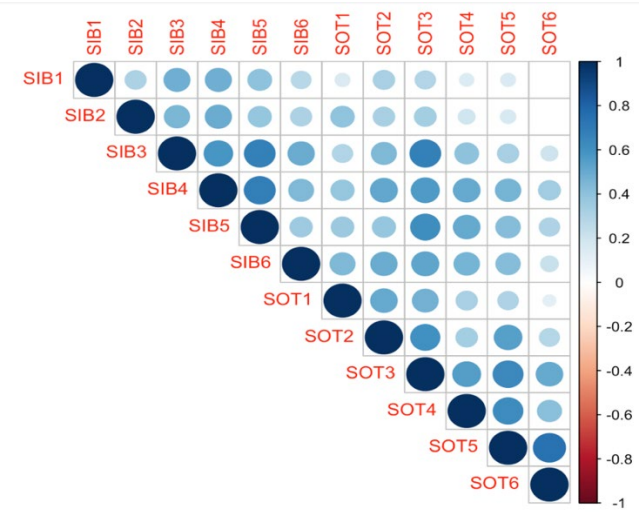

Fig. 1 Correlation matrix comparing the balance assessment conditions from the SOT and VR-SIB.

III. Results

A. Balance assessments

The balance scores on comparable conditions of the VR-SIB showed significant correlations with the gold-standard SOT with r=0.300-0.672 ($p < 0.01$) providing criterion measure

validation (Fig. 1). However, no between group differences were found (p>0.10, n.s.).

B. VOR assessments

The VR-DVAT and standard DVAT were significantly correlated in the horizontal direction (r=0.570, p=0.014) and trended toward significance in the vertical direction (r=0.481, p=0.09, n.s.), however this was only observed for group with a history of concussion (Fig. 2). There were no between group differences.

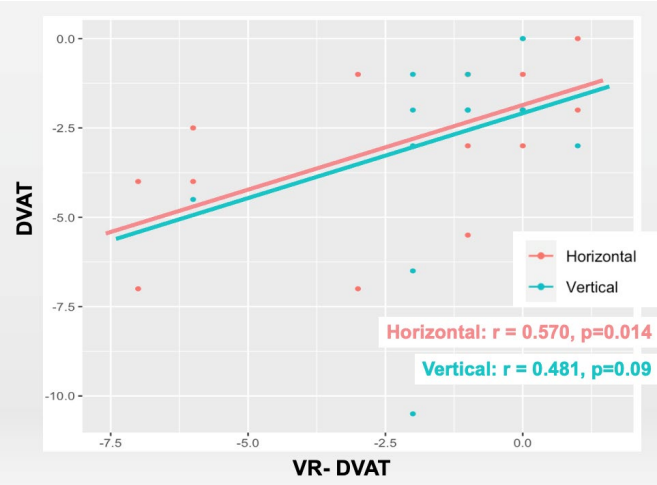

Fig. 2 DVAT correlations for criterion-measure validation.

C. Oculomotor Convergence Assessments

The VR-Verge showed a highly significant correlation (ρ = 0.454, p< 0.001) with the criterion-measure manual NPC (Fig. 3). However, no between group differences were found (p>0.10, n.s.).

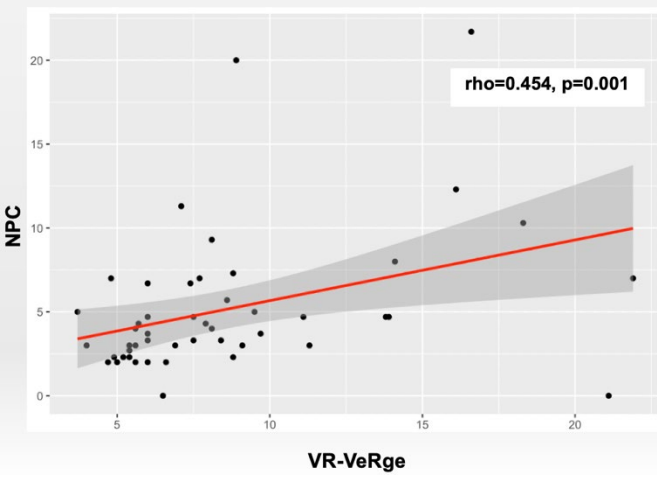

Fig. 3 Convergence assessment correlations for criterion-measure validation.

IV. Discussion

This intermediate analysis of an ongoing validation study suggests a novel custom-designed software solution integrated with a VR HMD can provide objective measures of balance, vestibular, and oculomotor function, which are significantly correlated with the validated outcome measure that are currenlty used for clinical evaluation. Preliminary findings comparing VR-SIB with SOT, VR-DVAT with traditional DVAT, and VR-VeRge with NPC suggests each shows promising criterion-measure validity.

The findings from the VR-SIB relative to the SOT supports previous findings where we showed a high level of criterion-measure and construct validity when we tested healthy younger and older adults [12]. In that study, both our devices were able to accurately separate old from young with and AUC>0.80. In the current study, we tested a younger cohort with ages ranging from 18-50 yrs. And although we have tested 18 individuals with a history of mTBI, all were asymptomatic, and neither the criterion nor the novel measures have detected subacute deficits. The fact that the neither the gold-standard SOT, nor the VR-SIB could detect between-group differences suggests postural deficits, if any, are largely undetectable by any of the assessments we conducted. Despite the lack of sensitivity of both balance assessments, they still revealed strong construct validity, in that, as the conditions got significantly more challenging (e.g. form vs. foam or EO vs Spin) balance was significantly decreased (p<0.01) as has been shown in our previous studies [12]. Finally, because this is preliminary analysis and we are testing asymptomatic participants, we may require a larger sample size to detect subacute signs and may still be underpowered at this stage.

In conclusion, these early findings suggest criterion-validity of the novel portable VR-based assessments. After validation these assessments can provide an easy-to-use, objective means for quick clinical evaluation an individual's balance, vestibular, and/or oculomotor function. With additional testing of more impaired individuals, we may begin to evaluate the sensitivity of such VR-based assessments.

Acknowledgment

The authors would like to thank Gregory Teodoro for his work in the development of the virtual reality scenes.

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Acceptance and Usability of the c-VVAS: A new tool to evaluate Visual Vertigo

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Abstract — Visual vertigo (VV) is a common symptom in people with persistent postural-perceptual dizziness (PPPD). A few subjective scales have been validated for assessing the intensity of VV, yet they are limited by recall bias, as they require individuals to rate their symptoms from memory. The aim of this pilot study was to develop and test a computerized, video-based tool for the assessment of VV in people with PPPD. The Computerized Video-based Visual Vertigo Analogue Scale (c-VVAS) was developed by adapting five scenarios from the original paper-pencil version, VVAS (PP-VVAS), developed by Dannenbaum et al. (2011). In this pilot study, PPPD participants (n=8) and age- and sex-matched controls (n=8) rated their level of dizziness using the PP-VVAS and the c-VVAS. Participants also reported on their experiences using the c-VVAS using a questionnaire developed based on the Technology Acceptance Model (TAM) and open-ended questions. We conclude that the c-VVAS is highly accepted and can be used as a realistic and convenient clinical assessment tool.

Keywords—Persistent postural perceptual dizziness, visual vertigo, assessment, vestibular rehabilitation, non-immersive virtual reality

I. Background

A. Persistent Postural-Perceptual Dizziness (PPPD)

PPPD is a chronic vestibular disorder characterized by persistent non-spinning dizziness, visual/motion hyper-sensitivity, and perceived unsteadiness. Due to the variety of symptoms, PPPD has physical, psychological, and social consequences. Those with PPPD commonly experience exacerbation of symptoms in environments with complex and moving visual stimuli, such as shopping centers, grocery stores and busy intersections [1-3]. They may also have difficulty watching TV and movies. As there are no physical, laboratory, or imaging findings established, the diagnosis of PPPD is made purely from gathering a thorough clinical history. Currently, there are few validated tools to measure symptom severity or progression through treatment [4-7].

B. Assessment of Visual Vertigo

Clinicians presently assess the intensity of visual vertigo (VV), also called visually induced dizziness, as an outcome measure for rehabilitation interventions in people with PPPD. The Visual Vertigo Analogue Scale (VVAS) was developed to subjectively measure VV intensity and consists of nine visual analogue scales, each pertaining to a specific situation that provokes VV [4]. An advantage of using the VVAS is that it is simple and quick to administer [5]. One major drawback of the VVAS and the validated tools is the possibility of having recall bias, as it requires the individuals to rate their symptoms in a particular scenario from memory. Because people with PPPD tend to avoid provocative situations and activities, the scoring of the items may not reflect the present reality [8].

C. Virtual Reality in the Assessment of PPPD

Virtual reality (VR) is generally defined as a non-invasive simulation technology that allows a user to perceive and/or interact with a computer-generated environment [9]. The two modalities used with VR are immersive and non-immersive environments. Non-immersive VR involves little or no interaction but perception can still be manipulated through video display with a simple 2-dimensional interface [9]. It tends to induce less cybersickness, defined as "symptoms of discomfort and malaise produced by VR-exposure" [10]. Thus, non-immersive VR may be more accepted by the users with PPPD [11,12]. Another advantage of a non-immersive system is its relative low cost, leading to a greater utility in clinical settings. For the above reasons, this pilot study commenced with a non-immersive video display, mainly to minimize the risk of adverse events and to ensure that the symptoms

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experienced can be attributed to the specific scenarios presented to the PPPD population, and not being narrowly linked to the use of VR technology.

II. Methodology

A. Objective

The goal of this study was to evaluate participants' acceptance of the c-VVAS based on the Technology Acceptance Model (TAM), while the usability of the tool was assessed with open-ended questions.

B. Development of a computerized video-based assessment

Five items from the VVAS were adapted into video format of 30 seconds each to recreate daily situations that provoke vertigo symptom in people with PPPD: i) Walking through a supermarket aisle; ii) Being a passenger in a car; iii) watching traffic at a busy intersection; iv) Walking through a shopping mall; v) Going down an escalator. Details of this tool with the supplementary video files as well as the correlation of the paper-pencil and computerized versions of the VVAS have recently been published [13].

C. Assessments

Eight subjects diagnosed with PPPD along with eight age- and biological sex-matched healthy controls were recruited for this pilot study. Each subject participated in one 30 to 60-minutes in-person session at the research center of the JRH. After written consent was obtained, participants were asked to fill out the paper version of the VVAS (PP-VVAS) by marking a vertical line on a 10-cm line to indicate the intensity of VV they recall experiencing in each of the situations. Demographic information and information regarding onset of PPPD and interventions received for the PPPD group was also obtained.

The assessment using the c-VVAS was done in a quiet room with the lights off. The computer monitor, with a diagonal screen measure of 24 inches, was positioned at 30 inches from the subjects' eyes. Before starting, participants reported verbally their baseline level of dizziness on a scale of 10 (from none-0 to maximal-10). After each scenario, they filled out one visual analogue scale by marking a vertical line on a 10-cm line to indicate the intensity of vertigo they experienced *while* watching that specific scenario. Subjects were instructed to look at the crosshair icon displayed on screen and to press the spacebar to start the next scenario, once their dizziness returned to baseline level.

After the assessment using the c-VVAS, participants filled out a questionnaire with seven 5-point Likert scales, developed based on the TAM, to assess the following domains: (i) user's perceived usefulness of the tool; (ii) perceived ease of use; (iii) attitudes and intention to use (*see figure 1*) [14]. The acceptance rate was calculated by adding the score of each statement (strongly disagree = 0; strongly agree = 4) and transforming the total, which is on 28, into percentage.

Finally, participants commented on positive and negative aspects of the c-VVAS, ways to improve it, and whether they prefer the paper-pencil or the computerized version of the VVAS (Table 1). Sessions were recorded, and the subjects' answers were transcribed verbatim.

III. Results

Overall, all participants show high acceptance of this assessment tool based on new non-immersive VR, with a mean total score of acceptance of 91.74% across the two groups. The domain with the highest score was the perceived ease of use (EOU) for both the PPPD group (98.44%) and the control group (100.00%). The control subjects were more willing to use the c-VVAS (100.00%) in the future compared to the PPPD group (85.94%), whereas the PPPD subjects perceived a greater usefulness of the tool (90.63%) compared to the control group (81.25%) (Table 2).

Based on the participants' feedback regarding the c-VVAS, there was a consensus that the 5 scenarios were well chosen and depict appropriately the real-life situations. Another positive comment was the appropriate length of the videos. When asked about ways to improve the c-VVAS, a frequent suggestion was the addition of dynamic tasks, as participants were seated and stationary for this study. It was also stated that including head and body movements would evoke a more realistic experience. Lastly, 2 subjects recommended the use of VR-headset/ goggles and of a bigger computer screen, to make the experience more immersive (Table 3).

Technology Acceptance Questionnaire

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
1. The video-VVAS was easy to use.	1	2	3	4	5
2. The instructions for the video-VVAS were clear and comprehensible.	1	2	3	4	5
3. There are aspects to the video-VVAS that I did not like.	1	2	3	4	5
4. I am willing to be assessed with the video-VVAS again.	1	2	3	4	5
5. The scenarios represent something I encounter in my daily living.	1	2	3	4	5
6. I perceive the video-VVAS to be a useful assessment tool for my dizziness.	1	2	3	4	5
7. The dizziness that I felt watching the video clips was the same dizziness I experience in real life.	1	2	3	4	5

Fig. 1. Technology Acceptance Questionnaire

TABLE I. POST SESSION OPEN-ENDED QUESTIONS

Question 1a	What did you like about using the computer-based system?
Question 1b	Was there anything you didn't like?
Question 2	Is there anything you would improve about the system if possible?
Question 3	If you had the choice, would you prefer to use the paper-and-pencil version or the computerized version of the Visual Vertigo Analogue Scale (VVAS) to assess your PPPD?

TABLE II. PARTICIPANTS' PERCEPTION AND ACCEPTANCE OF THE C-VVAS

Category	Mean Score of PPPD (%) (N=8)	Mean Score of Control (%) (N=8)	Mean Score of Both Groups (%) (N=16)
Perceived EOU (statement 1,2)	98.44	100.00	99.22
Attitude & Intention (statement 3,4)	85.94	100.00	92.97
Perceived usefulness (statement 5,6,7)	90.63	81.25	85.94
Total score[1]	91.52	91.96	91.74

[1]Note that the total score represents a weighted average, with the domain of perceived usefulness being the most important as it includes 3 statements out of 7

TABLE III. THEMES IDENTIFIED FROM THE PARTICIPANTS' INTERVIEW ABOUT THE USABILITY OF THE C-VVAS

Themes	Quotes
1. Scenarios depict real life situations	P1: "*the videos that were shown were something that you do in normal days*" P4: "*toutes les situations sont très appropriées à la vie de tous les jours*" [Eng. Translation: "*All the situations are very appropriate to everyday life*".]
2. Appropriate length of videos	P4: "*Ça provoque le vertige, mais ça se résorbe rapidement. Donc j'aime le 30 secondes*." [Eng. Translation: "*This triggers the dizziness, but it is resolved rapidly. Therefore, I like the 30 seconds*"] P7: "*Une chance que c'était pas long. Si c'était une heure, je risquerais de vomir*." [Eng. Translation: "*Luckily it wasn't long. If it was one hour, I might have thrown up*."]
3. Should incorporate natural movements	P4: "*Ça provoque le vertige, mais ça se résorbe rapidement. Donc j'aime le 30 secondes*." [Eng. Translation: "*This triggers the dizziness, but it is resolved rapidly. Therefore, I like the 30 seconds*"] P7: "*Une chance que c'était pas long. Si c'était une heure, je risquerais de vomir*." [Eng. Translation: "*Luckily it wasn't long. If it was one hour, I might have thrown up*."]
4. Need more immersiveness	P1: "*I'm sure if you were to use 3D glasses, or what you call them, probably it would be a different story."* C8: "*It might be more immersive if it was a bigger screen*."

IV. DISCUSSION AND CONCLUSIONS

The c-VVAS was highly accepted by all participants, similar to the findings of other studies on the use of VR for rehabilitation in various populations [15-17]. Participants in both groups strongly agreed that it was easy to use the tool (98.44% and 100%, respectively), suggesting its potential to be implemented in clinical settings. The PPPD group demonstrated a weaker intention to re-use the c-VVAS in the future (85.93%) compared to the control group (100%). This difference seems to stem from the fact that the tool does trigger/increase symptoms in people with PPPD but not in the controls and that symptoms of VV can be quite uncomfortable. However, the PPPD group perceived the c-VVAS to be more useful (90.63%) compared to the control group's rating (81.25%), which makes sense as the tool was created for the PPPD population, and it has more meaning for them. All participants chose the c-VVAS over the PP-VVAS as the former provides a more immersive and "live" experience where they could better envision themselves in the presented situation, which suggests potential prevention of recall bias that is associated with the PP-VVAS. Indeed, some PPPD patients were hesitant when filling out the PP-VVAS as they had been avoiding the places that provoke their VV. Such avoidant behaviors are common in people with VV [8].

When asked about potential ways to improve the assessment tool, participants mentioned the use of dynamic tasks (e.g., walking, turning, avoiding obstacles, etc.) to make the experience more realistic. However, this would necessitate the use of immersive VR (with the VR-headset), which may increase sensory conflicts and therefore cybersickness, unless the simulation is very sophisticated and provides synchronized visual-vestibular cues [10,18]. An immersive environment may simply be too provocative for those with a high baseline of VV. Moreover, the equipment required for immersive VR is much more expensive and thus unlikely to be practical clinically. Another reason supporting the current design of the tool and the test condition is that adding head turns may end up assessing the postural aspect of the PPPD as opposed to the visual/ perceptual aspect.

We are currently extending the study to recruit participants with PPPD from multiple sites to examine the psychometric properties and validity of the C-VVAS tool.

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Attractive and *Repulsive* vibrotactile biofeedback during balance-cognitive multitasking

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***Abstract*— Directional vibrotactile biofeedback for balance control can be encoded in form of a *Repulsive* (instructing to move in the opposite direction of vibrations) or *Attractive* (instructing to move in the direction of vibrations) signals. However, which of these encodings is less cognitively demanding, remains unresolved. We compared in 32 healthy young adults the effect of *Attractive* and *Repulsive* vibrotactile biofeedback not only on balance control, but also on cognitive load during balance-cognitive multitasking with different difficulty/complexity (simple: choice reaction time task, CRT; difficult: two-back task, 2back). Trunk motion reduced ($p \leq 0.001$) and percentage of time spent within the deadzone (Time-in-DZ; feedback inactive) increased ($p \leq 0.001$) due to feedback in both *Attractive* and *Repulsive* group (n per group: 15; 8 females, 7 males). Though, Time-in-DZ reduced in the 2back task compared to the CRT. Further, the cognitive load measured with the linear integrated speed accuracy tradeoff increased in the *Attractive* group ($p_{adjusted} \leq 0.01$) and in the 2back task ($p_{adjusted} \leq 0.001$), which together with the still improved balance control indicates a prioritization of posture (posture-first principle). As interference between balance control with vibrotactile feedback was lower in the *Repulsive* encoding, we would suggest that *Repulsive* encoding is a better choice for use in daily life.**

Keywords—multitasking, balance control, vibrotactile biofeedback

I. Introduction

Among different biofeedback modalities to reduce trunk motion and thus improve balance control, vibrotactile feedback is a good choice for everyday use, since it does not interfere with other tasks such as hearing, seeing and eating [1], [2] In addition to various ways for feedback location [3], there are also different ways to encode directional vibrotactile feedback. In many previous studies, users were instructed to move in the opposite direction of vibrations (*Repulsive* feedback encoding) when they exceeded a predefined body sway threshold [1], [4]–[6]. *Repulsive* encoding serves as an avoidance signal, indicating that the individuals have deviated from a stable postural position and need to move in the opposite direction [7]–[9]. On the other hand, *Attractive* encoding implies that the users need to move in the direction of vibrations (approach signal) for an increased postural stability [7]–[9]. Studies comparing these two instructed encodings suggest that both are effective to reduce body sway and increase the percentage of time spent within the deadzone (stable area: feedback inactive). Though, the *Repulsive* encoding resulted to be subjectively more intuitive with respect to the perceived familiarity and learning effort [8], [9]. However, it is still unrevealed if this is also reflected in the objectively measured cognitive load, which can be assessed by performing multiple tasks simultaneously (multitasking), e.g. balance and cognitive task. Previous studies have shown that while during balance-cognitive multitasking vibrotactile biofeedback improves balance control (reduces trunk motion, increases time within the deadzone), it negatively affects cognitive task performance (i.e. response time) [10]–[12]. However, these studies used only a *Repulsive* encoding. While some studies found the *Repulsive* encoding to be subjectively more intuitive [8], [9], some others found individuals to involuntarily move in the direction of vibration, when vibrotactile feedback is uncoupled to human body sway and uninstructed [13], [14]. Consequently, it remains still unclear to what extent the two feedback encodings (*Repulsive* vs. *Attractive*) impose different cognitive loads.

In this study, we aimed to investigate the influence of *Attractive* and *Repulsive* vibrotactile biofeedback on both cognitive load and balance control during multitasking with different levels of difficulty. A secondary goal was to investigate to what extent the effect on balance control differs in anterior-posterior (AP) and medio-lateral (ML) direction [8], as usually a greater sway reduction is observed along the axis in which a greater baseline sway is observed. We expected both *Attractive* and *Repulsive* encoding to reduce trunk tilt and increase the time spent in the deadzone during quiet standing. Moreover, we expected a corrected response time based on the linear integrated speed accuracy trade-off to increase with feedback at least for the *Repulsive* encoding as well as with increasing cognitive task difficulty.

II. Methods

A. Participants

Sample size was calculated based on previous studies [8], [9] that found an increased subjectively perceived familiarity and effort of learning for the *Attractive* encoding only (n per group: 16). Further, we considered the study of Haggerty et al. [10] that

observed an increase in response time to a choice reaction time task due to vibrotactile biofeedback during balance-cognitive multitasking. Since we expected a smaller effect in younger adults [11], [15] compared to older adults, as assessed by Haggerty et al. [10], we recruited 32 healthy young adults. Individuals were included to participate in our study if they did not report any neurological, musculoskeletal, vestibular, or other diseases that could influence their independent standing and hearing abilities. The study was conducted in accordance with the ethical code of conduct of the Helsinki Declaration and approved by the ethical committee of the Technical University of Munich (2019-248_1-S-SR). All participants gave written informed consent. Participants were assigned by covariate adaptive randomization to one of the two equal-sized groups, balanced by gender (n=16, 8 females). Due to technical problems in two participants, for analysis later on 15 individuals were included (7 males, 8 females). Individuals did not differ between groups in neither of their baseline measurements, such as age, anthropometry, vibrotactile threshold, body sway threshold, and balance control parameters during baseline sway.

B. Instrumentation

To provide vibrotactile biofeedback, we used a haptic vest similar to the one used in our previous work [9]. It consists of two vibrotactile motors in the front and to at the back (10mm vibration motor 310-122; Precision Microdrives Inc.). Feedback was given as soon as trunk tilt angle exceeded a threshold based on individual baseline trunk motion. Trunk angle was assessed by an inertial measurement unit (IMU) (MTW Awinda by Xsens). Further, to assess not only trunk motion but also the underlying control effort based the centre of pressure, a force plate (AMTI, six-axis) was used. In this work we focus, however, on the trunk sway. Sampling frequency was set to 100 Hz for both IMU and force plate. Finally, for the auditory cognitive task, we used a 360° speaker (Jabra Speak 510) and push buttons connected via an Arduino to the computer for participant's response.

C. Experimental Procedure

For initial preparation, we followed the procedure as described in Tannert et al. [9]. This included the assessment of the just noticeable vibrotactile threshold by the methods of limits and the assessment of baseline sway during upright narrow (2.5cm inter-foot distance) normal bipedal stance with eyes closed. The vibrotactile intensity was defined as 130% and 120% of the mean vibrotactile threshold of the two back motor locations. The body sway threshold to trigger vibrotactile biofeedback was defined as 1.2 times the absolute mean tilt angle assessed during baseline sway measurements for AP and ML, respectively.

During the experimental conditions participants stood in an upright and relaxed narrow (2.5cm inter-foot distance) Semi-Tandem stance with eyes closed, their dominant foot (preferred foot to kick a ball) in front and their arms relaxed on their sides [9]. First, familiarization trials were performed to ensure how the vest works. Familiarization trials were repeated until the participant felt comfortable. Based on the group they were assigned to, individuals were either instructed to move in the direction of vibrations (*Attractive*), or to move in the opposite direction of vibrations (*Repulsive*). To investigate the effect of these vibrotactile feedback encodings on cognitive load, we provided two auditory balance-cognitive multitasking conditions with different levels of difficulty/complexity. In the simple multitask, which was a choice reaction time task (CRT) [15], [16], participants heard a set of random numbers from 1 to 9 and were asked to press the right push-button when they heard either 1,2 or 3 and press the left for any other number. For the second cognitive task, we used the more difficult and more complex digit 2-back working memory task (*2back*) [16]. In this task, the users had to press the right push button if the number they heard was similar to the numbers they heard two steps back. Otherwise, they had to press the left push button. The cognitive tasks were implemented in MATLAB using psychtoolbox [17]. Before starting the measurements, participants performed one familiarisation trial for each cognitive task. Each cognitive task was conducted during quiet standing with (F) and without (nF) feedback. Moreover, the single-task quiet standing was also conducted with feedback. These five conditions (each 5 trials x 35s + 30s between trials) were conducted in a block-randomised order.

D. Data Analysis

Data were postprocessed with MATLAB: cut off first and last 2.5 seconds and Butterworth low-pass filtered with a 5Hz cut-off frequency to filter the force plate data. To evaluate cognitive load based on the cognitive task performance, we extracted the linear integrated speed-accuracy score (LISAS) [15]. For the postural domain, we computed the following dependent variables as a measure of trunk motion and balance control performance with respect to the feedback, respectively:

- RMS L5 tilt angle (°) in AP (roll) and ML (pitch)
- Percentage of time spent in deadzone in AP (roll) and ML (pitch) based on the tilt angles (Time-in-DZ)

E. Statistical Analysis

We computed mixed model ANOVAs for cognitive load and balance control parameters with Group (*Attractive* vs. *Repulsive*) as between-subject factor and Task (*CRT* vs. *2back*) as well as Feedback (F vs. nF) and Direction (AP vs. ML) as within-subject factors. Further, for the feedback condition separate mixed model ANOVAs were computed to investigate the multitasking cost compared to the single task with feedback. In case of violation of sphericity, Greenhouse-Geisser (GG) correction was reported. When a main or interaction effect resulted to be significant ($p \leq 0.05$) pairwise comparisons (Bonferroni correction) were reported. Effect size (η_p^2) is interpreted as small for 0.01, medium for 0.06, and large for 0.14.

III. Results

A. Cognitive Task Performance

The mixed model ANOVA with Group as between-subject factor and Task and Feedback as within-subject factors resulted in a significant **main effect of Feedback** (sphericity assumed: $F(1,28)=7.04$, $p=0.01$, $\eta_p^2=0.20$), as well as a **Feedback by Group interaction** (sphericity assumed: $F(1,28)=4.03$, $p=0.05$, $\eta_p^2=0.13$). The main effect of Feedback showed that the corrected response time is overall increased with feedback (mean difference=0.14 s (8%), $p=0.05$). However, the Feedback

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by Group interaction indicates that this is only true for the *Attractive* group (mean difference=0.24 s (14%), $p_{adjusted} \leq 0.01$), while for the *Repulsive* group multitasking costs were lower and not significant (mean difference=0.03 s (2%), $p_{adjusted}=0.65$). Moreover, we found a significant **main effect of Task** (sphericity assumed: $F(1,28)=69.78$, $p \leq 0.001$, $\eta_p^2=0.71$) and **interaction of Feedback by Task** (sphericity assumed: $F(1,28)=10.01$, $p \leq 0.01$, $\eta_p^2=0.26$). This revealed the corrected response time to increase due task difficulty (mean difference=0.72 s (47%), $p_{adjusted} \leq 0.001$), and the task effect to be stronger during *feedback* condition (increase: mean difference=0.86 s (55.45%), $p_{adjusted} \leq 0.001$) compared to the *no feedback* condition (increase: mean difference=0.59 s (39%), $p_{adjusted} \leq 0.001$). And finally, feedback increased the corrected response time only during the *2back* task (mean difference=0.27 s (12.54%), $p_{adjusted} \leq 0.01$), but not during the *CRT* (mean difference=0.01 s (0.5%), $p_{adjusted}=0.82$) (Fig.).

B. Balance Control

Lower Back

The mixed model ANOVA for RMS L5 tilt angle during dual-tasking also revealed a significant **main effect of Feedback** (sphericity assumed: $F(1,28)=16.63$, $p \leq 0.001$, $\eta_p^2=0.37$) with an overall lower trunk variability with feedback (mean difference=0.158° (21%), $p_{adjusted} \leq 0.001$). Besides the main effect of Feedback, we also found a significant **main effect of Direction** (sphericity assumed: $F(1,28)=77.23$, $p \leq 0.001$, $\eta_p^2=0.73$) indicating a greater RMS L5 tilt angle in AP than in ML (mean difference=0.41° (89%), $p_{adjusted} \leq 0.001$). Further, the mixed model ANOVA for RMS L5 tilt angle during both single and multitasking during *feedback* condition revealed again a significant **main effect of Direction** (sphericity assumed: $F(1,28)=61.84$, $p \leq 0.001$, $\eta_p^2=0.69$), which again showed lower RMS L5 tilt angle in ML compared to AP (mean difference=0.36° (89%), $p \leq 0.001$).

Also for Time-in-DZ, we found a significant **main effect of Feedback** (sphericity assumed: $F(1,28)=22.37$, $p \leq 0.001$, $\eta_p^2=0.44$), **main effect of Task** (sphercity assumed: $F(1,28)=4.46$, $p=0.04$, $\eta_p^2=0.14$), and **main effect of Direction** (sphercity assumed: $F(1,28)=8.34$, $p \leq 0.01$, $\eta_p^2=0.23$). These showed percentage time spent in the deadzone to increase with feedback (mean difference=14.43% (24%), $p_{adjusted} \leq 0.001$), to reduce with greater difficulty and complexity of the cognitive task (mean difference=3.00% (4.36%), $p_{adjusted}=0.04$) and to increase in AP compared to ML (mean difference=8.50% (13.62%), $p_{adjusted} \leq 0.01$). For the comparison of simple and multitasking conditions during *feedback* conditions, we found only a significant **main effect of Direction** (sphericity assumed: $F(1,28)=21.90$, $p \leq 0.001$, $\eta_p^2=0.44$), in accordance to previous results.

IV. DISCUSSION

As expected, and in line with previous works by Haggerty et al. [10] and Lin et al. [11] we observed an overall increased response time with feedback. Though, in contrast to those works that only provided *Repulsive* feedback, in our study corrected response time and thus cognitive load only increased in the *Attractive* group. The difference to the previous works may be related to the different age groups investigated, as older adults show a greater effect of sensory stimualtions (i.e. vibrotactile) on cognitive task performance than young adults [11], [18]. Thus, the effect might have been not big enough to detect with fifteen healthy young adults per group. Our finding of the *Repulsive* encoding imposing lower multitasking costs is in line with the previous study of Tannert et al. [9] and Kinnaird et al. [8] who found subjective evaluation of the intuitiveness to be in favour of the *Repulsive* feedback.

Further, the increase of corrected response time with feedback occurred only in the more difficult and more complex cognitive task. As balance control also improved during multitasking, this indicates that individuals prioritized balance control and delayed the secondary task (posture-first principle based on the bottle-neck theory) [3]. As this was not observed during the simple choice reaction time task, this may indicate some interference to take place in the working memory, especially in storage and updating coordination. As also suggested by Kinnaird et al. [8] the *Attractive* feedback may rerpresent a cognitively incongruent stimulus, as it indicates the individual to move towards the stimulus. The stimulus, however, represents the boundaries of a stable zone, which could be likened to a "cache" that individuals would intuitively prefer to avoid. This, however, needs to be confirmed by a follow-up study investigating the cognitive incongrueny cost in *Attractive* and *Repulsive* feedback encoding. As practice previously has been shown to improve both cognitive and sensorimotor task performance [19], [20], multitask performance, especially in the cognitive task could be further improved with proper training.

In the domain of balance control, our results are consistent with previous studies [8], [9] that have shown a reduction in trunk motion and time spent in the deadzone (feedback inactive) with both vibrotactile biofeedback encodings. Furthermore, our results are also in line with the work of Haggerty et al. [10], which demonstrated similarly an improvement in balance control during choice reaction time multitasking. Though, balance control performance dropped with the more complex task, which suggests an interference in the working memory, that seem to involve also updating coordination based on sensory information, as stated above. Previous research has also demonstrated that individuals who stand in a stance with more body sway, such as the Tandem Romberg stance, show greater sway reduction and thus greater benefits for balance control with additional haptic feedback [21]. We believe that this may also apply to the direction with greater body sway, as Kinnaird et al. [8] and Lin et al. [11] have found more consistent beneficial effects of vibrotactile biofeedback on balance control in the anterior-posterior direction. As the body sway threshold was individualized based on the baseline body sway, the effect of feedback did not differ across directions. However, as expected, we observed a greater trunk motion in AP compared to ML.

Since all participants in our study were healthy young adults, future studies should investigate the effects of *Attractive* and *Repulsive* vibrotactile biofeedback in other target groups, such as in older adults who are generally expected to experience greater cognitive costs. Additionally, longer familiarization trials may be necessary to gain a deeper understanding of how vibrotactile biofeedback works to improve the overall multitasking performance. Finally, future studies should further

investigate concepts of cognitive "congruency/incongruency" in relation to *Attractive* and *Repulsive* feedback to better understand the underlying cognitive processes involved.

V. CONCLUSION

The *Repulsive* vibrotactile biofeedback encoding revealed to be less cognitively demanding than the *Attractive* encoding, as cognitive load increased only in the *Attractive* group due to vibrotactile biofeedback. Furthermore, the increased cognitive cost due to feedback in the more difficult and complex cognitive task, suggests an interference to take place in the working memory, especially in storage and updating coordination. However, the increased cognitive load did not negatively affect balance control performance, as individuals of both encoding groups reduced lower trunk motion and increase the percentage of time spent in the deadzone where feedback was inactive. This suggests a posture-first principle. As interference between balance control with vibrotactile feedback was lower in the *Repulsive* encoding, we would suggest that Repulsive encoding is a better choice for use in daily life.

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Differential responses of chronic pain phenotypes during virtual reality exposure: *a pilot study*

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***Abstract*—Chronic pain affects the majority of individuals with spinal cord injury (SCI) and interferes with function and quality of life. The objective of this study was to evaluate the responses between chronic pain and exposure to virtual reality (VR) in two phenotypes of pain. This study was conducted in 17 individuals with SCI who engaged with VR for a five-minute and ten-minute bout. Pain intensity ratings were assessed at baseline and after each bout of VR. Both pain phenotypes reduced with VR exposure, however differences between pain phenotypes were observed. A decrease in neuropathic pain was achieved within a five-minute bout, and this decrease was maintained at the end of the VR sessions, whereas no change in nociceptive pain level was observed once the VR exposure was completed. These findings suggest that different mechanisms of pain modulation are activated through VR exposure in each pain phenotype.**

Keywords—chronic pain, virtual reality, spinal cord injury

I. Introduction

Chronic pain affects 70% of individuals with spinal cord injury (SCI) and leads to declines in health and quality of life [1]. Pain is characterized by phenotypes, which are derived from different mechanisms contributing to pain perception. Virtual reality (VR) has been an effective pain intervention for individuals with SCI in previous studies [2], however, efficacy of VR has not been compared across different pain phenotypes, and the optimal dosage of immersive VR as a chronic pain intervention has not been established.

While several studies have identified virtual walking as an effective intervention to moderate neuropathic pain in SCI [3,4], other research has shown that VR did not alter pain [5]. In these studies, pain phenotype was not described. In another study, although there were no improvements in pain intensity, VR facilitated immersive sensations of walking in individuals with SCI [6].

Chronic neuropathic pain in SCI and acute nociceptive pain in healthy populations have responded favorably to VR, however, the effects of VR on chronic nociceptive pain in SCI have not been assessed. The objective of this research is to compare differential pain responses to VR in two pain phenotypes: chronic neuropathic and chronic nociceptive pain in SCI.

II. Methods

A prospective cohort study was conducted in 17 individuals with SCI between the ages of 27 and 65 years old. Participants engaged with an immersive VR environment using an Oculus Quest (Meta, Menlo Park, CA) for a five-minute and ten-minute bout while seated in their wheelchair with their back supported. Participants engaged with a virtual environment through an avatar that allowed them to navigate and interact with a virtual landscape by virtually walking (Fig. 1). Motor pathways of the participants were primed for this activity and participants were oriented to the virtual scene. Participants were instructed to perform coordinated gross movement of their arms with the arm movement represented by the VR and turn their head in each direction.

Fig. 1. Virtual walking scene from participant perspective.

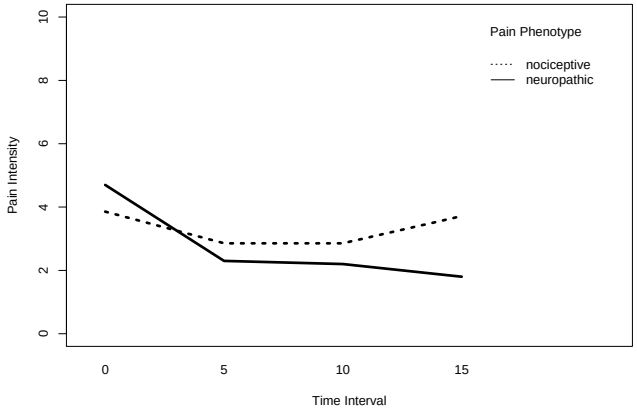

Fig. 2. Average neuropathic pain (solid line) and nociceptive pain (dashed line) intensity ratings across VR time intervals.

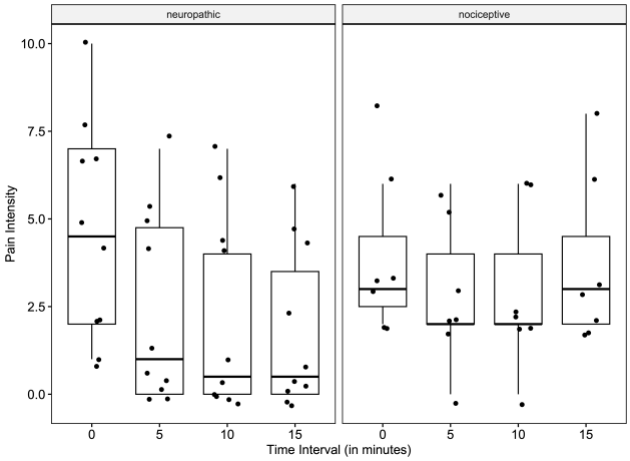

Fig. 3. Pairwise comparisons of pain intensity across VR time intervals by pain phenotype.

Baseline pain was assessed and categorized by phenotype using the International SCI Pain Basic Data Set Version 2.0 [3]. Pain ratings were reevaluated after 5, 10, and 15 minutes. Friedman analyses of variance and post-hoc Wilcoxon signed rank test with Bonferroni corrections were conducted to identify changes in pain intensity across VR exposure time in each pain phenotype. Effect size was calculated using Kendall's coefficient of concordance.

III. Results

Both phenotypes changed with exposure to VR (Fig. 2). Neuropathic pain significantly decreased with VR ($\chi^2(3)= 24.5$, $p < 0.001$) and a large effect size ($W= 0.82$) was observed. Pain intensity was decreased at five minutes ($p.adj= 0.05$), 10 minutes ($p.adj= 0.03$), and 15 minutes ($p.adj= 0.03$) from baseline (Fig. 2). No significant changes in neuropathic pain were detected between other time intervals. Nociceptive pain significantly decreased with VR ($\chi^2(3)= 8.05$, $p= 0.04$) and a moderate effect size ($W= 0.38$) was observed, however no significant changes were identified between time points in post-hoc analysis (Fig. 3).

IV. Discussion

Neuropathic and nociceptive pain were both reduced by VR, with greater benefit linked to exposure time reported for neuropathic pain. However, palliative benefits for nociceptive pain were tied to active VR exposure, as there was no modification in pain after completion of the VR session. These findings suggest that different mechanisms of pain modulation are facilitated by VR in each pain phenotype.

Neuropathic pain arises after SCI as a result of maladaptive changes associated with damaged connections between the brain and periphery. VR promotes neuroplastic alterations in the sensorimotor cortex, which may initiate the reversal of maladaptive changes [7]. With prolonged exposure, the neuroplastic changes that are induced by VR may improve ownership of motor representations in the cortex [7]. Because many individuals with SCI experience deafferentation of the lower extremities, activating these areas of the cortex provides stimulation that is not supplied otherwise. Our findings that immersive VR exposure reduces neuropathic pain are consistent with a previous study which evaluated the efficacy of virtual walking as a neuropathic pain intervention for individuals with SCI [5].

Analgesia from VR in acute pain has been attributed to increased functional connections between the primary somatosensory cortex (S1) and audiovisual cortices, which consequently reduces pain processing within S1 [8]. A similar distraction mechanism may be responsible for the decrease in chronic nociceptive pain in this study.

There are several limitations to this study. The study conducted was pilot research with a limited sample size. Because of the small smaple size, participants could not be effectively stratefied by level of injury, completeness of injury, or demographics. Therefore, our analyses may not have accounted for some significant charactersitics, and our results may not be generalizable to all individuals with SCI or to other populations of individuals who are manual wheelchair users.

Results of this pilot study may contribute to the advancement of clinical pain management. Our initial findings may promote the development of targeted VR interventions for specific pain phenotypes and assist in determining the appropriate dosage of VR to balance efficacy with potential adverse effects, such as motion sickness. As VR becomes a greater part of SCI and pain rehabilitation, dosage will also become pertinent for reimbursement of services and guiding the distribution of time allotted for interventions utilized.

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ISVR

International Society for Virtual Rehabilitation

Oral Session 6

Aging and Cognition

16:15 to 17:45

July 25th, 2023

Exercise Intensity in a Virtual Bicycling Environment: Comparing Findings between Young and Older Healthy Adults (VCYCLE-Competition)

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***Abstract* – The effects of aging on the response to competitive exercise may provide insight into exercise strategies for healthy adults across the lifespan. Fifty healthy adults (25 young, 25 older) bicycled in 3 fully-immersive virtual environments (VE). Two of the conditions used competitive stimuli of other bicycle riders in the VE to drive exercise intensity, differing only in the instructions provided to the participant. The 3rd condition used road markers that changed color as visual feedback to increase cycling cadence. Findings from the three 5-minute exercise bouts indicate that young adults bicycled at a faster raw cadence in the 2 competitive conditions compared to older adults. However, there were no significant differences in normalized cadence or any other measures of exercise intensity comparing young to older adults. For both young and older healthy adults, exercise intensity (heart rate and cycling cadence) was higher in both competitive conditions compared to feedback. These findings may partially be explained by the high levels of competitiveness in each population. Therefore, VEs incorporating competitive exercise may be useful for driving exercise intensity in healthy adults across the lifespan.**

Keywords—virtual reality, exercise, competition, visual feedback, exercise intensity, aging

I. Introduction

According to the guidelines for physical activity and exercise in the US, 150 minutes of moderate-high intensity of aerobic exercise are recommended per week for adults, with potential benefits related to quality of life and longevity. [1] Through the use of different stimuli in virtual reality (VR), including competition and visual feedback, high-intensity bicycling can be achieved. [2-4] However, differences in the response to competitive exercise in VR between young and older adults have not been explored in depth in the literature and may provide insight into customized exercise strategies based on age and competitiveness. Therefore, we seek to understand differences related to exercise intensity between young and older adults during a competitive bicycling task, hypothesizing that older adults will exercise at a lower intensity in the competitive conditions compared to their younger counterparts. This report describes the findings from 50 healthy adults across the lifespan during competitive VR bicycling.

II. METHODS

A. Participant Characterisitcs

A total of 50 healthy adults were included in this study (25 young and 25 older). Competitiveness was measured using the Multidimensional Competitive Orientation Inventory (MCOI). [5] Participants were classified as one of 4 different types of competitive profiles using scores from the MCOI: self-developmental competitive, hyper-competitive, anxiety-driven competition avoidance, lack of interest in competition. Physical activity was measured using the International Physical Activity Questionnaire (IPAQ). [6] Inclusion criteria were: 21-75 years old (21-44 for young adults, 45-75 years for older adults), ability to ride a stationary upright bicycle, ability to sign informed consent. Exclusion criteria were: a recent history of severe heart disease, severe lung disease, uncontrolled diabetes, traumatic brain injury or any other neurological disorder (failed PARQ+ Screening, Physical Activity Readiness for Everyone Scale), [7] inability to follow directions or sign a consent form, inadequate vision or hearing ability to see or hear a television, unstable medical condition or musculoskeletal disorder such as severe arthritis, recent knee surgery, hip surgery, or any other condition that the investigators determined would impair the ability to ride the bicycle, moderate depression (score of 10 or more on PHQ-9 screening tool, Patient Health Questionnaire). [8]

B. Experimental Conditions

There were 3 conditions: visual feedback, competition against others, competition against oneself. The 2 competitive bicycling condition differed only in the instructions given to the participants. For competition against others, participants were told that the virtual cyclists on the road were traveling at an arbitrary speed and instructed to pass as many other cyclists as possible within 5 minutes. For the 2nd competitive condition, participants were told that the virtual cyclists were modeled after their own performance and to pass as many cyclists as possible in 5 minutes. This 2nd condition was framed as self-competition as the participants were instructed to beat their own best times by passing as many cyclists as possible. The non-competitive condition used road markers that changed color based on how fast each participant pedaled (augmented visual feedback condition). Participants were instructed to pedal fast enough to keep the road markers blue. The goal of each task was to have participants sustain a cadence of at least 25% faster than their comfortable bicycling cadence.

C. Outcomes

Two primary measures of exercise intensity were collected. Raw heart rate (HR) data were collected using an optical heart rate sensor worn on the participant's forearm

(*Polar OH1)*. Raw cycling cadence (revolutions per minute, RPM) data were collected using a cadence sensor attached to one of the pedals of the stationary bicycle *(Wahoo)*. HR data were normalized based on age (Karvonen) [9] and then averaged across each 5-minute exercise bout. Mean age-adjusted HR and the change in age-adjusted HR from start to end of trial are reported. Cycling cadence was averaged over each of the 3 trials and reported both as a raw cadence (RPM) and as a percentage faster than each participant's comfortable cadence (%). Findings were compared across the 3 conditions within each group and comparing young to older adults.

D. Data Analysis

For healthy young and older adults, repeated measure ANOVAs (RMANOVA) were performed to detect differences in the 3 bicycling conditions within each group (alpha = 0.05). Mixed ANOVAs (2 groups x 3 conditions) were performed to detect differences between young and older adults across the 3 conditions (alpha = 0.05 for interaction effects, alpha = 0.05 for the between-group main effect). Appropriate post-hoc tests were performed if any differences were detected in the ANOVAs (alpha = 0.0167).

III. RESULTS

For a summary of participant characteristics (including age, physical activity levels, and competitiveness) for both young and older healthy adults, *see Table 1*. Data related to HR and bicycling cadence are shown in *Table 2* for older adults and in *Table 3* for young adults. For normally distributed data, the mean and standard deviation are shown.

TABLE 1. CHARACTERISTICS OF OLDER & YOUNG ADULTS

Item	Older Adults	Young Adults
N (Female, Male)	24 (11, 13)	25 (7, 18)
Age (years, range)	61.2 (45 – 74)	26.5 (22 - 34)
Physical Activity (MET-Minutes)	5841 (4013)	2943 (1810)
Self-Developmental	4.4 (1.2) N = 19 (79%)	4.6 (0.9) N = 19 (76%)
Hyper-Competitive	2.3 (1.0) N = 0 (0%)	2.6 (1.0) N = 0 (0%)
Anxiety-Driven	2.5 (0.8) N = 0 (0%)	2.6 (1.2) N = 3 (12%)
Lack of Interest in Competition	2.6 (1.1) N = 4 (17%)	2.5 (0.9) N = 1 (4%)

Table 1. Age, physical activity levels, and competitive profiles are shown for older and young adults.

TABLE 2. EXERCISE INTENSITY FOR OLDER ADULTS

Outcome	Feedback	Competition Other	Competition Self
Heart Rate (% Max)	72.8 (13.7)	**77.2 *** (14.4)	**78.7 *** (13.6)
Change in Heart Rate (% Max)	17.1 (9.5)	**25.2 *** (10.1)	**30.3 *** (16.1)
Cadence (rpm)	96.9 (12.3)	**105.0 *** (9.4)	**107.4 *** (10.8)
Normalized Cadence (% Faster)	44% (39 – 65)	**62% *** (11)	**66% *** (13)

Table 2. Cycling cadence & heart rate for older adults. An asterisk (*) indicates higher values in each competitive condition compared to feedback ($p < 0.0167$).

TABLE 3. EXERCISE INTENSITY FOR YOUNG ADULTS

Outcome	Feedback	Competition Other	Competition Self
Heart Rate (% Max)	68.6 (9.4)	**75.9 *** (9.0)	**77.5 *** (73 – 83)
Change in Heart Rate (% Max)	15.3 (10 – 18)	**28.4 *** (6.5)	**30.5 *** (7.9)
Cadence (rpm)	102.1 (9.6)	**116.5 *** (9.9)	**118.3 *** (7.8)
Normalized Cadence (% Faster)	44% (39 – 56)	**69% *** (14)	**72% *** (13)

Table 3. Cycling cadence & heart rate for young adults. An asterisk (*) indicates higher values in each competitive condition compared to feedback ($p < 0.0167$).

For non-normally distributed data, the median and interquartile range are provided.

A. Heart Rate

Both young and older adults exercised at a higher age-adjusted HR and had a higher change in age-adjusted HR from start-to-end of trial in the competitive conditions compared to visual feedback ($p < 0.001$). Within each sample, there were no differences between the competitive conditions ($p > 0.0167$). There were also no differences in exercise intensity in either competitive condition comparing young to older adults (for interaction effects, all $p > 0.0167$). There were no between-group differences comparing young to older adults ($p > 0.05$).

B. Cadence

Both young and older adults exercised at a higher cadence (raw and normalized) in the competitive conditions compared to visual feedback ($p < 0.001$). Within each sample, there were no differences between the 2 competitive conditions ($p > 0.0167$). Comparing young to older adults, young adults exercised at a higher raw cadence in both competitive conditions compared to older adults (for both interaction effects, $p < 0.001$). There were no interaction effects ($p > 0.0167$) or between-group differences for the normalized cadence ($p > 0.05$).

IV. Discussion and conclusion

Across all 3 conditions, both young and older healthy adults exercised at a moderate-vigorous intensity on average. In both groups, healthy adults exercised at a moderate exercise intensity in the feedback conditions. (64-76% of age-adjusted maximum HR). For competition, only young adults reached a vigorous exercise intensity (>77% of age-adjusted maximum HR) when competing against themselves. Older adults exercised at a vigorous intensity in both competitive conditions, despite the different instructions and framing of the 2 competitive conditions. [1]

In the 2 competitive conditions, young adults bicycled at a faster raw cadence compared to older adults. However, when normalizing for each participant's comfortable cadence, there were no differences in bicycling cadence. The differences in raw cadence in the absence of differences in normalized cadence, may be explained by the effects of aging on the musculoskeletal system. [10] Therefore setting a target bicycling cadence that is personalized for each participant may be important in designing future exercise studies.

There were no differences in HR between young and older adults during either of the competitive bicycling bouts, suggesting they exercised at similar levels of cardiovascular intensity. These similar findings in the two groups (HR, normalized cadence) may be partially explained by the similar competitive profiles in each sample, with most of the young and older adults having self-developmental competitive profiles and high levels of competitiveness in general as suggested by the low "lack-of-interest" scores on the MCOI.

In this sample, age did not impact exercise intensity during competitive VR bicycling. Future studies should study competitive VR bicycling to see if exercise intensity can be sustained over longer bouts in both young and older adults.

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Home Virtual Rehabilitation for Early Alzheimer's or Chemobrain: Two Case Studies

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***Abstract*—Cognitive deficits from Alzheimer's disease (AD) or those subsequent to chemotherapy are not well addressed in the Standard of Care. The novel *BrightGo* system, when used at home, may provide an alternative therapy to address these Healthcare gaps. BrightGo consists of a modified Head Mounted Display, a Galvanic Skin Response sensor, a laptop, a router and a library of custom therapeutic games. Case 1, a 77 years old female in the early phase of AD and Case 2, a 66 years old breast cancer survivor post chemotherapy, underwent BrightGo home training for 8 weeks and were followed for another 8 weeks. Both improved on several cognitive measures, something maintained at follow up. At 16 weeks Case 2 depression severity had reduced by twice the minimal clinical important difference vs. baseline.**

Keywords—BrightGo, Alzheimer's, Chemobrain, home, Beck Depression Inventory – R.

I. Introduction

United States Alzheimer's Dementia (AD) population is estimated to be 6.7 million [1]. Pharmacological approaches are largely ineffective to delay related cognitive decline. While travel to clinics is problematic for caregivers [2], computer games used at home have shown benefit [3, 4].

Another population with lasting cognitive impairments is cancer survivors who underwent chemotherapy. This is commonly referred to as "chemobrain," affecting executive functions, memory and ability to focus [5, 6]. Similar to AD, pharmaceutical treatment was found to be largely ineffective. However, non-pharmacologic cognitive rehabilitation therapies and mindfulness meditation, demonstrated benefits in memory, verbal function/language and attention [7]. Use of computer games as an alternative to treat chemobrain remains untested.

Bright Cloud International Corp. developed the BrightBrainer System for individuals with cognitive deficits. The system benefitted individuals in Outpatient [8], Medical Adult Day Care [9] and Skilled Nursing settings [10]. However, the BrightBrainer size and cost made it unsuitable for home use. Research presented here details the follow-on *BrightGo* therapy system designed for training at home [11]. We report on an individual in the early stage of AD and a cancer survivor with chemobrain, who self-trained at home.

Research reported here was supported by grants R43AG065035 and R43CA232936 from the National Institutes of Heath

II. Methods

A. *BrightGo Therapeutic System*

BrightGo has five hardware components: a) an Oculus Quest Head-Mounted Display (HMD); b) a custom blink detection unit; c) a custom galvanic skin response (GSR) unit to measure emotive state (Fig. 1); d) a caregiver laptop; and e) a Wi-Fi router to ensure uniform communication.

The blink detection unit consisted of a micro camera mounted inside the HMD, which was connected to an electronic enclosure mounted on top of the HMD. The blink detector electronic enclosure had a microprocessor which analyzed frames received from the camera inside of the HMD. It also had Wi-Fi communication means to transmit the sensor data to the Quest though the Wi-Fi router, a battery and status LEDs.

a) b)

Fig 1. Main components of the BrightGo prototype system: a) blink detection unit; b) galvanic skin response unit. © Bright Cloud International. Reprinted by Permission.

The custom GSR electronic enclosure had its own processor, battery, and status LEDs, as well as Wi-Fi transmitter. The small GSR enclosure was placed on the floor, and connected through flexible wires to two patch electrodes. These electrodes were placed on the skin on the lateral inner side of the participant's foot, a location recommended whenever electrodes cannot be placed in the hand [12].

The HMD was worn by the participants throughout their sessions while in a seated position. Using game controllers, participants were instructed how to start a session, and how to cast HMD graphics to the laptop. This allowed caregivers to see what the participant saw on the HMD screen, and be able to assist.

During regular home therapy sessions the Quest controller allowed participants to play custom BrightGo games. In the first session, participants were asked to reach horizontally and vertically, and to press the controller trigger button. Range values were then stored on a Microsoft Azure secure server.

B. Games to train memory, focusing and executive functions

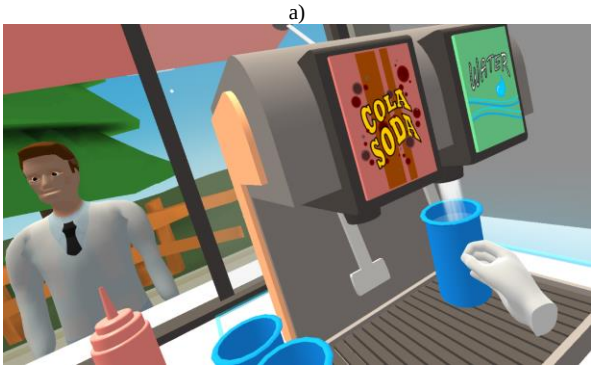
The above baselines were meant to adapt games to each participant. While motor impairments are not common in early stage AD or Chemobrain, this was done as a precaution.

Each session started with the relaxing scene shown in Fig. 2a, and soothing music. The scenery was the only bright region in a dim room, to help capture attention. During the relaxation baseline, participants were asked to stay still, and look forward at the image, while the HMD tracker measured head rotations. Additionally, BrightGo measured blink counts and skin electrical resistance (GSR), and the three variables weighted in determining an attention coefficient. Since GSR signal was hard to correlate, and the blink detector had occasional false positives, only head movements were used to determine if participants were cognitively engaged.

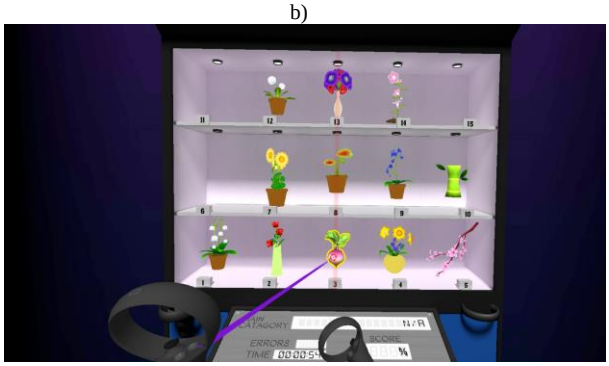
BrightGo software had an artificial intelligence (AI) component which adjusted game difficulty based on participant's past performance. When a participant had succeeded three times in a particular game, the AI increased game difficulty by one level. If a participant failed two times in a row, the AI lowered the difficulty by one level.

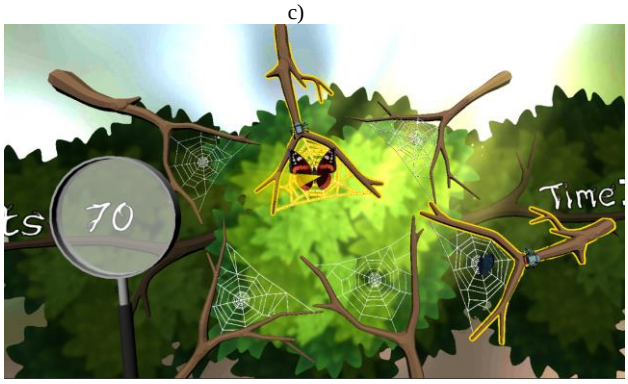
Sessions consisted of playing different games from among 12 available, based on specific cognitive deficits. Participants in the early phase of AD played games primarily training delayed memory (*Medicine Recall*, *Card Island*, *Xylophone*), pattern matching (*Catch 3D*), focusing (*Butterfly Rescue*, *Drums*, *Breakout 3D*), and reasoning (*Odd One Out*). Those with Chemobrain played games primarily training executive functions (*Numbers Avalanche*, *Towers of Hanoi*, *Food Truck*), memory (*Card Island*, *Medicine Recall*), pattern matching (*Catch 3D*), focusing (*Butterfly Rescue*, *Breakout 3D*, *Kites*), and reasoning (*Odd One Out*). The majority of games played were from the BrightBrainer Library [13-15], re-coded in C# and Unity for the Quest. Of the five new games developed for BrightGo, *Medicine Recall* and *Numbers Avalanche* have been previously described [11]. Below we detail *Food Truck*, *Odd One Out*, and *Butterfly Rescue*.


a)



b)


c)



d)

Fig. 2. BrightGo scenes a) Relaxing baseline; b) *Food Truck*; c) *Odd One Out*; d) *Butterfly Rescue*. © Bright Cloud International. Reprinted by permission.

Food Truck (Fig. 2b) trained primarily executive functions, namely food preparation to fill an order placed by

an intelligent agent. The game had 16 levels of difficulty, progressing from drinks and exact change, to drinks, a cheeseburger, a hotdog, and making change.

Odd One Out (Fig. 2c) is our version of a test of fluid intelligence [16]. Participants were presented with a set of 3-D objects in a display case. The object set category varied randomly between vegetables, fruits, flowers, cats, dogs and cars. When a given object was intersected by a ray coming from the controller avatar, it was highlighted and rotated in place for better viewing. Once selected by pressing the trigger, the computer uttered a noun associated with that object. Difficulty increased with number of objects, and closeness in shape and color, making finding the odd one harder.

Butterfly Rescue (Fig. 2d) trained focusing, and speed of reaction. Participants were tasked with rescuing butterflies trapped in spider webs, by using a magnifier avatar to burn the webs, before spiders reached the trapped butterflies. Difficulty increased with number of butterflies and the speed of spiders.

C. Cases

The two cases described here were part of experimental groups in randomized control pilot studies. While both RCTs targeted individuals living at home, one focused on early stages of AD being treated with a cholinesterase inhibitor, while the second RCT enrolled breast cancer survivors with chemobrain following completion of their course of chemotherapy. Baseline characteristics for the two cases are shown in Table I.

Case 1 was a 77-year-old female on Donepezil (10 mg) for early stage AD, and two blood pressure medications. While her depression was in the normal range (per Beck Depression Inventory II), her MoCA score was 17/30 indicating moderate cognitive impairment. She was living in the community, with her husband, who was also recruited to assist in the study.

Case 2 was a 66-year-old female breast cancer survivor with lasting impairments in focusing and memory following her chemotherapy which ended 11 months prior to enrollment. She was complaining of lower extremity neuropathy and severe joint pain. Her depression was in the mild range (Beck score of 17). While her MoCA score of 27 was at the lower normal range, Case 2 did complain of issues with focusing and memory. She was retired and lived in the community with her husband, also recruited to provide feedback on BrightGo use.

D. Data Collection Instruments

This feasibility study had an ABAA protocol, with data collected at baseline (A), during training sessions (B), 8 weeks post (A), and at 16 weeks follow up (A). Each clinical evaluation session consisted of standardized cognitive and emotive state measures, as listed in Table 2. Most outcome measures were same for both Case 1 and Case 2, however Quality of Life tests were specific for the condition. Categorical Verbal Fluency (Animals), Phonemic Verbal Fluency (COWAT) and Functional Activities Questionnaire (older adults) were administered only to Case 1, while the NAB Word Generation (measure of executive functioning) test was given only to Case 2.

Subsequent to approval from WCG Institutional Review Board, participants were screened with MoCA test and the Cybersickness Susceptibility Questionnaire [17]. The latter was needed due to wearing of an HMD for extended time.

Game Performance was automatically sampled at each session for session game average difficulty and average duration. A project portal graphing capability allowed researchers to remotely monitor individual performance.

Subjective evaluations were done at 4 weeks and 8 weeks of BrightGo training, using custom forms. These forms differed slightly based on diagnosis, and further differed from forms meant to be filled by the caregiver. Each answer was rated on a 5-point Likert scale (1 -least, 5 -most desirable).

E. Experimental Protocol

Each home received one BrightGo system, and participants were instructed how to use the system. Their spouses were told how to assist. The first session was observed on-site by the team and subsequent sessions were mostly done independently, or assisted remotely.

Both cases trained for 8 weeks, however frequency differed, with Case 1 doing 5 sessions/week, and Case 2 4 sessions every week. Sessions were set to increase in duration and number of different games played. At the completion of a game, its performance data parameters were uploaded on our cloud server, and researchers occasionally called the home when prescribed number of sessions in a week were not met.

III. OUTCOMES

Case 1 visual memory (BVMT-R) and total recall (HVLT-R) showed substantial improvements post, maintained at follow up. Verbal phonemic and categorical fluency improved minimally, but gains were lost at 16 weeks. All other cognitive measures showed decline. There was also gradual decline in the spouse quality of life, while Case 1 maintained good mood and wellbeing. Case 1 was able to use BrightGo and improved in game difficulty, from 2.5/16 to 13/16 over 8 weeks training.

Case 2 improved from baseline to follow up in all cognitive measures, except NAB Word Generation, where performance was normal at all three evaluations. There was

TABLE I. CASE DEMOGRAPHICS AND MEDICAL HISTORY AT ENROLLMENT. © BRIGHT CLOUD INTERNATIONAL. REPRINTED BY PERMISSION

Case	***Age***	***Gender***	***Race***	***Education*** (school years)	***Diagnosis***	***Medication***	***MoCA score***	**Beck Depression**	**Cognitive deficits**	**Computer User**	**Native Language**
1	79	F	Caucasian	15	Early phase of Alzheimer's	Donepezil 10 mg	17/30	0	Memory	yes	English
2	66	F	Caucasian	16	Chemobrain	Gabapentin 3x100 mg	27/30	17	Focusing Memory	yes	English

also an increased in Quality of Life (Psychological Wellbeing) for both participant and caregiver, maintained at follow up. Case 2 started borderline clinically depressed, something that worsened post intervention (Beck Depression Inventory -R). However, depression severity was reduced 35% at follow up, twice the 17.5% Minimal Clinically Important Difference [18]. Case 2 started at 3.3 average game difficulty and reached 12.5/16 average game difficulty of in her last session.

IV. DISCUSSION

BrightGo was able to be used independently by both participants, and be moved by the caregiver of Case 1 to a new home, without impacting the training regimen. Both participants benefitted cognitively in several measures and maintained them at follow up, although the caregiver of Case 1 saw a decrease in his quality of life. Case 2 depression severity reduced at follow up by 2x MCID.

While findings are encouraging, their generalizability is limited by the small sample of two individuals.

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TABLE II. BRIGHTGO COGNITIVE AND EMOTIVE OUTCOMES © BRIGHT CLOUD INTERNATIONAL CORP. REPRINTED BY PERMISSION.

Outcome	Case 1					Case 2				
	t0	t1	Δ(t1-t0)	t2	Δ(t2-t0)	t0	t1	Δ(t1-t0)	t2	Δ(t2-t0)
COGNITIVE OUTCOMES										
Brief Visual-Spatial Memory Test-Revised (Total Recall)	3	14	11	9	6	20	17	-3	31	11
Categorical Verbal Fluency (Animals)	7	9	2	7	0	-	-	-	-	-
Phonemic Verbal Fluency (FAS)	7	12	5	6	-1	-	-	-	-	-
Hopkins Verbal Learning Test –Revised (Trials 1-3)	10	17	7	18	8	23	27	4	33	10
NAB Attention (digits forward)	9	5	-4	7	-2	3	5	2	6	3
NAB Executive Functioning (word gen)	-	-	-	-	-	10	12	2	10	0
Trail Making Test-B (errors)♦	4	8	4	8	4	0	0	0	0	0
MOOD/PERSONALITY OUTCOMES										
Beck Depression Inventory -R♦	0	0	0	0	0	17	25	8	11	-6
Functional Activities Questionnaire (Older adults with dementia)	7	23	16	22	15	-	-	-	-	-
Quality of Life Patient*	52	52	0	52	0	35	56	21	47	12
Quality of Life Caregiver**	40	38	-2	37	-3	83	106	23	95	12

*For older adults with dementia for Case 1 and for cancer survivors for Case 2. **For family of older adults with dementia for Case 1, or caregiver of cancer survivors for Case 2 (Psychological wellbeing). ♦ Less is better

Development of Multimodal Motion-Assisted Memory Desensitization and Reconsolidation (3MDR) Therapy for Multi-platform Use

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***Abstract*— As researchers continue to create novel and innovative virtual reality (VR) based rehabilitation applications, there is a parallel need to make these developments accessible to clinicians with varying levels of available tools and skill sets. Here, we outline our work towards converting Multimodal Motion-Assisted Memory Desensitization (3MDR) therapy for posttraumatic stress disorder from exclusive VR technology to more accessible VR and augmented reality (AR) platforms. In this work, we highlight the technological considerations of developing an environment across multiple platforms and highlight user interface development (both for patient and therapist user experience). Our work has resulted in a single software capable of being deployed to multiple VR and AR platforms that are actively being used at multiple sites internationally. While continuous feedback from patients, clinicians, and researchers will be incorporated into the program, this work creates a software basis for expanding 3MDR therapy to a wider range of patients and therapists.**

Keywords—VR/AR, PTSD, talk therapy, 3MDR

I. BACKGROUND

Virtual reality as a tool for exposure-based therapy for posttraumatic stress disorder (PTSD) has been explored over the past 20 years. However, its widespread use outside of research environments is limited due to a lack of technology adherence in clinical practices. Here, we present our work, from a hardware and software perspective, in moving an evidence-based virtual reality (VR) therapy closer to real-world use. Multimodal Motion-Assisted Memory Desensitization (3MDR) is an exposure-based trauma therapy for PTSD that was developed in the Netherlands in 2011 and is currently being tested with military service members and veterans across the Netherlands, Canada, United States, and United Kingdom [1-5]. In its original version, large-scale VR systems were used to provide an immersive environment that provided exposure therapy and eye movement desensitization and reprocessing (EMDR) therapy during a physical activity (walking on a treadmill). These large-scale VR systems, the Computer Assisted Rehabilitation Environment (CAREN) or the Gait Real-time Analysis Interactive Lab (GRAIL) (Motek Medical B.V., Amsterdam, Netherlands), include a panoramic, projection-based screen to deliver the VR environment. A treadmill embedded in the platform allows users to walk while immersed in the VR environment. However, such large-scale VR environments are expensive and are only available in select locations around the world. These constraints limit the type and number of patients who can receive 3MDR therapy for PTSD.

Recent advances in VR and augmented reality (AR) have made these technologies more affordable and mobile, which is necessary for expanded accessibility. VR/AR development software has also expanded cross-platform capabilities and third-party technology integration, allowing for more clinical and research applications. However, translating a therapy from one platform and/or reality to another requires an informed development method, platform dependent and independent adaptability, and clinical testing/acceptance. In this work, we explore the redevelopment of 3MDR software to support: (1) panoramic 180-degree projection-based screens, (2) single screen, and (3) AR head-mounted display (AR-HMD). During this development, equivalency of the virtual environments across the CAREN system, screen-based system, and an AR-HMD was prioritized to maintain integrity of the

therapy itself. However, platform-dependent features were implemented to optimize visual immersion. Here we present a brief outline of the software development and the technical considerations when developing a PTSD treatment with more accessibility.

II. Methods

A. 3MDR Environment

The original 3MDR virtual environment was created in D-Flow, Motek's proprietary software for the CAREN platform and evaluated as a PTSD treatment in multiple studies [1-5]. However, to allow for a cross-platform development and custom work, the Unity game engine (Unity Technologies, San Francisco, CA, USA) was used to redevelop the virtual environment and integrate a host of external tools (e.g., heart rate monitoring, motion capture). Here, we developed the 3MDR environment with three scenes corresponding to the three phases of the therapy. Each scene contains a rolling texture that scrolls at the participant's self-selected walking speeds to allow for 'movement' through the environment. In the 'Warm-up' and 'Cool-down' scenes, the environments contain a clear blue horizon scrolling texture that the patient experiences, accompanied by self-selected, therapy-associated music (Figure 1a). The Corridor scene is the bulk of the therapeutic application (Figures 1a and 1b). This scene contains the same endlessly scrolling ground texture with a futuristic corridor. The corridor contains two sets of doors. The second corridor ends at one of seven self-selected, trauma-related pictures. Here, screen scrolling stops while the treadmill continues rolling, eliciting a feeling of still walking towards the picture/trauma. Talk therapy is administered while viewing the image. Key emotional phrases are identified and overlayed on the image, followed by an EMDR task.

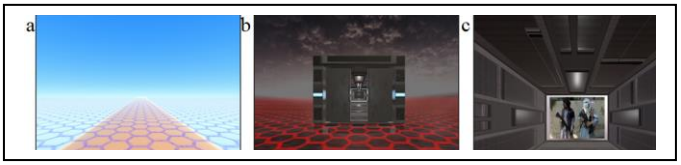

Fig. 1: Different stages within the 3MDR experience: a) Warm-up and Cool-down scenes, b) approaching corridor, and c) arriving at chosen image. Images courtesy of NHRC.

B. Patient and Therapist User Experience

Two optical flow modifiers were chosen to match the participant's self-selected walking speed to the visual flow. Both Warm-up and Cool-down clear scenes have a flow multiplier of 1.5 times the treadmill speed [6], while the Corridor scene has a flow multiplier of 1.6 times the self-selected treadmill walking speed [7]. This matches literature on projected VR environments. These values were maintained across the three hardware platforms.

The therapist user interface (UI) controls patient speed, patient emotional phrase input, and EMDR parameters. This UI mirrors the view of the participant in the virtual environment. Therapists are prompted after each corridor image to enter the patient's Subjective Units of Distress (SUDs) score. All information is saved into a JavaScript Object Notation (JSON) file specific to the patient identification and session numbers. All saved data can be reviewed after the session and loaded into the UI. The JSON file is read and displayed in a side panel. This readable text contains data on walking speed, distance, and transition times as well as the phrases and SUDs scores used and any notes the therapist wishes to save. These values are saved to the JSON with date and time information and can be viewed and appended later.

C. Polymorphic Design

The developed Unity program was used to deploy this application to three locations: the CAREN, a three-flat-screen system with a therapeutic-grade treadmill, and the HoloLens 2 (Microsoft, Redmond, WA, USA) (Figure 2) with consumer-grade treadmill. The CAREN has a three-projector, 180-degree curved screen. Scalable Display Manager software (Scalable Display Technologies, Cambridge, MA, USA) is used to smooth the image across the screen. The three-flat-screen system utilizes manual camera rotation to mimic the expansive view of the CAREN system but with no active image warping. The HoloLens 2 uses a VR projection inside of the AR device, so instead of creating AR objects, the visual field fills the entirety of the headset. The participant is still able to view the floor and the therapist beside them through the device, which is essential to maintaining walking ability while in an AR-HMD virtual environment. Each of these applications is developed from the same code, but specific deployments are based on the number of connected screens.

A universal launch program was developed to manage version control and the applications across multiple sites. Code is developed by designers at the Naval Health Research Center (NHRC) and stable versions are pushed to a repository controlled by the research partners around the world. Clinicians launch this program and can view whether new code is available for download before launching the program. This streamlines the process of pushing new code to all sites at the same time: bugs can be fixed and patient experience can be improved at all sites nearly simultaneously. This improves user experience and data fidelity and allows the project to scale more across this multi-site, international effort.

D. Photon-Unity Networking

The Photon Server™ system (Exit Games Inc. Portland, OR) is used to wirelessly link the therapist UI laptop and the HoloLens 2 platform. An independent instance of the Photon on-premises server is launched on the therapist laptop and provides the messaging service. Both the therapist and patient must be connected to the same Wi-Fi network; an independent router, without internet connection, is supplied for each therapist suite. Self-selected images are not passed via Photon Chat to the HoloLens. Instead, the images for each session are preloaded onto the HoloLens during setup by dragging the

folder into the Images folder on the HoloLens. Integer values are passed to associate the images, limiting network slowdown.

To minimize computational cost and time delays on the HoloLens, the Corridor scene is modified when used with the HoloLens. A pseudo-scene transition is used from repeating corridor scenes (the HoloLens Corridor scene is not reloaded). Instead, the scene fades to white and returns the participant to the beginning of the corridor. All variables are reset in the scene without the need to reload variables.

III. RESULTS

The developed software has been deployed to three different locations, each utilizing different platforms: 3MDR on the CAREN at NHRC in San Diego, California; 3MDR on the HoloLens at Walter Reed National Military Medical Center, Bethesda, Maryland; and 3MDR on multi-screen systems at multiple sites associated with the University of Alberta, Alberta, Canada. We are actively seeking feedback from patients and therapists at these sites in order to continuously improve the developed software and user experience.

Fig. 2: 3MDR software used a) on the CAREN, b) on a three-screen setup, and c) within the HoloLens 2. Images a) and c) courtesy of NHRC. Image b) courtesy of Chelsea Jones, University of Alberta (with Permission).

IV. DISCUSSION

3MDR was developed to treat combat-related PTSD. This treatment has shown efficacy in addressing treatment-resistant PTSD in the United States, Netherlands, United Kingdom, and Canada. The long-term goal of 3MDR is to expand beyond combat trauma and serve the needs of first responder personnel. To that end, research has been conducted at the University of Alberta gathering the impressions of first responders [8]. Subjective feedback from this population was used to modify the corridor design, removing traces of yellow reminiscent of hospital markings, and tweak the color of the floor away from blood-red imagery. Future work includes the ability to control treadmill speeds and play music from within the software.

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Can we capture posture with a mobile phone?

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Abstract - Postural changes throughout the lifespan are important indicators of overall health and well-being. Currently, the most accurate method for evaluating posture relies on the use of Vicon, a system that is not readily available in clinical settings. The aim of this pilot study was to explore the potential of 3D scans conducted using smartphone sensors as a means of assessing posture and to validate this method against the gold standard, Vicon. Our preliminary results demonstrate that a simple photogrammetric tool can assess posture and estimate age accurately. Thus, photogrammetric methods in telerehabilitation and interventions can aim at slowing and preventing age-related declines. Further research is needed to fully establish the efficacy of this approach.

***Keywords*— Photogrammetry, Posture Assessment, Postural Age, Telerehabilitation**

I. Introduction

Postural changes can provide insight into an individual's overall health status and well-being. For example, during the aging process, postural changes, and particularly the progression of a stooped position, impose a great burden on the wellbeing of older adults, ranging from harming physical appearance and reducing lung capacity[1] to increasing the risk of functional decline [2,3]. Postural changes are common among individuals who experience depression and anxiety [4], as well as those with musculoskeletal problems[3].

Current methodologies for posture evolution include observation or photogrammetry, both of which have significant limitations [5]. To date the Vicon (Vicon Motion Systems) is considered the gold standard for postural assessment [6]. It is expensive, however, and unavailable in many settings; Vicon is also mostly irrelevant in clinical settings. Current technological developments including the wide variety of phone applications create the potential to develop easily implementable applications for postural evaluation. Such resources may be deployed in virtual reality applications or by telerehabilitation to inform progression of treatments or serve as a marker for the aging process or of different pathologies. The aim of the current study is to assess the potential of 3D scans conducted by simple, smartphone sensors in posture and age assessment and to validate such measurements against the Vicon gold standard system.

Two hypotheses led us in our investigation: one, that aging can indeed be estimated based on postural measurements; and two, that simple sensors have now advanced enough to enable age estimation from the postural data acquired with them.

II. Methods

We conducted two preliminary experiments to test our hypotheses:

A. Experiment one – age estimation using a high-end optical sensors system

To affirm the assumption that age can be estimated based on postural data, we used the gold-standard VICON motion-capture system. Ten older (age > 65) and 16 younger (age < 65) adults participated in this stage. For each participant, 39 reflective markers were positioned on anatomical landmarks to yield respective coordinates in space. These coordinates then enabled the calculation of values of 16 postural-significant angles for each subject – for example, the angle between the left glenohumeral joint, vertebra C7, and the right glenohumeral joint. Principal component analysis (PCA) was used to separate the data, as shown in Figure 1:

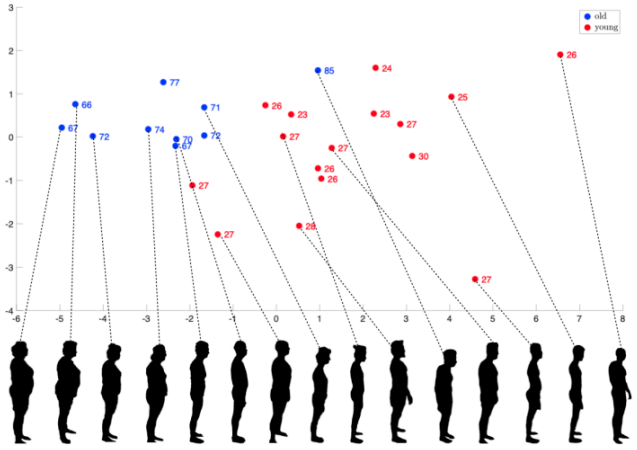

Fig. 1. Principal component analysis of postural data acquired by the VICON system. Blue – older participants (age > 65). Red – younger participants (age <= 30). Silhouettes of participants in sagittal view were added at the bottom of the figure.

B. *Experiment two – validation of a market-available smartphone application for posture assessment and age estimation*

After we established that posture can be reliably connected to chronological age when measured accurately, our second hypothesis was that similar estimations could be made with simpler data, not requiring the expensive Vicon apparatus.

We used the mobile application 3D Scanner App (Laan Labs) installed on an iPhone 12 Pro (Apple) to create 3D models of the upper body of 10 additional participants, 5 older (age > 65) and 5 younger (age < 65), as can be seen in Figure 2. The scanning process involved using the smartphone's front sensors in a spiral movement around the subject, with a diameter of approximately 70 centimeters.

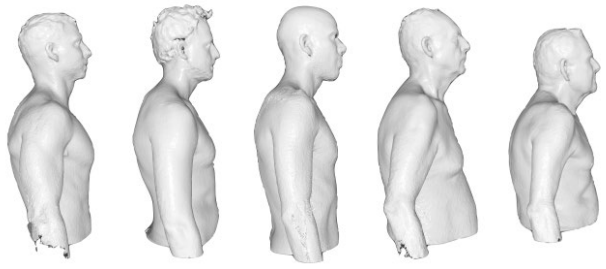

Fig. 2. Example 3D scans of some of the subjects participating in the second experiment.

The same set of 39 marker points used for Vicon was manually marked on the virtual models of the new subjects. Angles were again calculated and the new data acquired by the mobile app was used to test the Principle Component Analysis (PCA) trained in the first experiment. The results of this analysis can be seen in Figure 3.

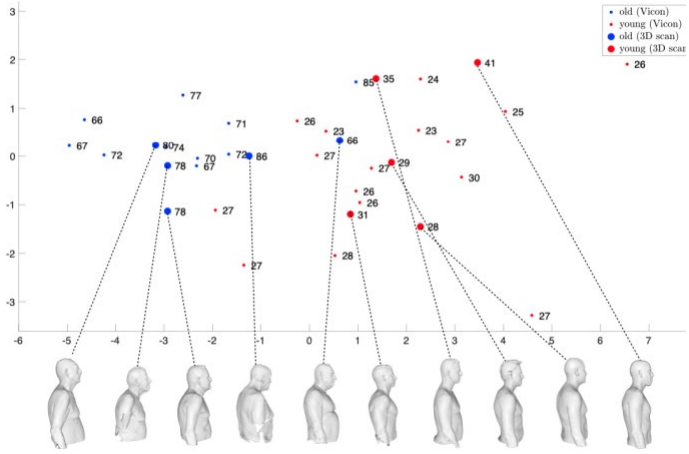

Fig. 3. Principal component analysis of the postural data acquired by the mobile application, after manual marking of anatomical points and extraction of postural angles.

III. Preliminary Results and Discussion

This preliminary investigation's aim was to assess the potential of photogrammetrical postural measurements in age assessment. As can be seen in Figures 1 and 3, the PCA successfully distributed participants into 2 main groups – older and younger adults – based on the postural variables acquired in both methods.

This serves as a proof of concept for the possibility of reliably using photogrammetry for the assessment of aging and for other possible uses. In the next stage, we aim to develop a methodology that does not require manual virtual labeling of anatomical points and can separate subjects based on age.

The development of a methodology for a low-cost, accurate assessment of posture is relevant for telerehabilitation in geriatrics and other medical fields. Such a tool could enable suiting personalized interventions for patients and assessing the success of interventions by their effects on posture. Future research in this direction is required.

IV. Conclusions

Our preliminary results validate a simple photogrammetrical tool against the current gold standard and show that age can be estimated from posture by simple means. Further studies could enable the use of photogrammetrical methods for both telerehabilitation and interventions aimed to slow and prevent accelerated aging.

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Supporting caregiver empathetic disposition through virtual experiences to enhance quality of life in people living with dementia

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***Abstract*— The care for people with dementia is frequently delegated to informal caregivers (e.g., relatives) with no useful knowledge to manage their care receiver. The situation's recurring nature puts them at risk for emotional distress. We present an online psychoeducational program that incorporates an immersive 360° video experience included in the ViveDe program. The main aim of the project is to reduce caregivers' perceived stress by acting on the cognitive components of empathy through the presence effect possible by ViveDe combined with a psychoeducational approach.**

Keywords—Dementia, Alzheimer, 360° video, immersive presence, psychoeducation, cognitive empathy

I. Introduction

Accompanying family members and informal caregivers after a diagnosis of dementia is a critical part of caregiving. Caregiving likely leads the patient and family to face many psychological and interpersonal changes. Among the most critical issues that can be observed in caregivers is that of not having a comprehensive understanding of dementia and how it manifests in everyday behaviors, and of not being able to understand what the patient's needs are and how best to care for them. In fact, memory loss, language difficulties, and spatial-temporal disorientation that are experienced by people with dementia make their emotional reactions, demands, and behaviors unusual and difficult to manage by those who find themselves alongside the patient. For this reason, several psychoeducational interventions have been developed and disseminated in the past decades with the aim of leading to caregivers of people with dementia toward a better understanding of disease symptoms and caregiving management techniques [1-2]. These approaches, while of high educational value, do not generally focus on the empathetic dimension of caregiving.

Empathy is a complex construct consisting of at least two components within the biopsychosocial dimension: a cognitive component (knowing or understanding what another person is feeling) [3] and an affective or emotional component (sharing or feeling another person's emotional state) [4]. These two constructs are associated with distinct neural systems: Cognitive empathy is related to higher-order functioning allocated to the medial and dorsolateral regions of the prefrontal cortex [5], while affective empathy is linked to activation of subcortical (e.g., amygdala, hypothalamus, and hippocampus) and cortical (e.g., anterior insula) structures [6].

Cognitive empathy, rather than affective empathy, seems to influence the quality of care provided to people with dementia [7]. Indeed, if the cognitive perspectives of the caregiver and the care recipient do not coincide, this discrepancy could result in ongoing and unjustified frustration of the caregiver, or in the misunderstanding from the care recipient in being supported predominantly (if not exclusively) in actions and situations that, from his or her own perspective, are not helpful in generating

quality of life. Therefore, perspective taking is of particular importance in dementia caregiving because the caregiver's goal is to provide proper care and to reduce stress and fatigue not only for the care recipient, but also for himself or herself [8]. It is likely that cognitively empathic caregivers achieve better illness trajectories, experience lower levels of anxiety, and are more satisfied in the caregiving process [9]. Establishing an empathic relationship in the caregiving of a person with dementia is expected to predict better quality of care as well as result in greater well-being for the caregiver, who over time comes to have lower levels of perceived stress, fewer symptoms of depression and more daily satisfaction [10].

II. AIMS AND SCOPE

With the aim of guiding caregivers towards a better understanding of the feelings experienced by people with dementia and of facilitating an empathic attunement with them, the educational-experiential proposal ViveDe (www.vivede.it) [11] was developed at the University of Bergamo. ViveDe uses virtual reality immersive technologies to enable the viewer to take on 'the point of view of a person living with dementia' and was originally developed with the aim of creating a Dementia-Friendly and more inclusive culture towards people with dementia. Since experiential learning through immersive technologies has proven to be an appropriate and effective method to elicit emphatic behavior [12], 360° videos explorable in VR were developed depicting everyday indoor and outdoor situations that enable users to experience the specific symptoms of dementia (e.g. disorientation, agnosia, apraxia and memory loss) and the challenges that a person with dementia faces daily. ViveDe videos were designed to be used with a commercial virtual reality device for smartphones (e.g., Headset V2) and optimized for lenses with FOV of 100°, presbyopia and myopia settings, and IPD and immersion settings. The audio is listenable with a set of headphones. The 360° videos (available here: https://www.youtube.com/playlist?list=PLHkLQH-uZrEirVL6-sX24K8pqiSyhgV-D) are fully explorable on the x/y axis from a first-person perspective (i.e., participants can perceive the entire scene as if they were in the shoes of a person with dementia and hear the person's voice as if it were their 'thoughts').

III. THE RESEARCH

Based on this background, we introduce a study that aims to use ViveDe combined with a psychoeducational intervention program specifically designed for Alzheimer's family caregiver participants (experimental group). The study will test the effectiveness of the psychoeducational intervention combined with the use of ViveDe by conducting 6 online meetings with small groups of caregivers, aimed at reducing their emotional burden and supporting their cognitive empathetic approach with the care receiver. This experimental intervention will be compared to a psychoeducational intervention program not involving the use of immersive technologies (control group). We will test the clinical and neurobiological effects of "taking the first-person perspective to dementia", as well as the role of presence generated from the immersive experience on caregiver empathetic disposition. For caregivers who are assigned to the experimental group, at each meeting the topic addressed in the psychoeducation program (e.g., the impact of the diagnosis, on caregiver how to deal with cognitive and behavioral symptoms, etc.) is subsequently experienced, in a guided manner, through ViveDe. We hypothesize that this approach will allow caregivers to immediately experience the learned theoretical knowledge and gain elements on which to develop an empathic approach in their own caregiving. We also speculate that the experiential learning possible through ViveDe may be an effective strategy to improve caregivers' understanding of dementia symptoms. Indeed, by using a fully explorable 360° immersive video, the sense of presence generated by ViveDe can guide caregivers into an experience that puts them in a position to be directly in touch with their care recipient's perspective and to experience what it is like to have dementia while understanding their needs.

The study, which will take place over the next 24 months and whose preliminary data on the first subjects are presented here, is funded by the Alzheimer's Association Clinician Scientist Fellowship program (AACSF-22-924470). Participants are recruited at the IRCCS Fatebenefratelli in Brescia, a national center for research and care for mental disorders and Alzheimer's disease and related dementias. It involves informal caregivers, self-defined as the person primarily responsible for a person with dementia for at least 4 hours a day over the last 2 years prior to enrolment. The care receiver should have a diagnosis of mild Alzheimer's disease (i.e., a score between 18 and 24 on the Mini-Mental State Examination). The study is designed as a two-arm randomized clinical trial: i) the control group (N=50) receives a psycho-educational intervention; ii) the experimental group (N=50) receives the combined intervention (psychoeducational and ViveDe). All interventions are provided as online video meetings. In the control group (psychoeducational intervention) an experienced psychologist-psychotherapist conducts a group session for maximum 10 caregivers at a time, which take place in 1-hour weekly sessions for 6 meetings. The meetings aim to support caregivers in managing activities of daily living and dealing with the emotional impact (e.g., anxiety, sense of guilty and anger). The topics treated include the overview and progression of Alzheimer's disease, recognition and management of cognitive symptoms, environmental adaptation, and stress management. The recurring theme during the meetings is how to have an empathic management of the person with dementia. In the experimental group (psychoeducational intervention and ViveDe), in addition to the psychoeducational intervention, we use the experiential approach possible with the 360° immersive videos provided in ViveDe project.

The sense of presence generated from the ViveDe experience have been tested in each meeting by an Italian adapted version of the Extended Reality Presence Scale (XRPS) [13] that caregivers are asked to compile just after the 360° video fruition. To test whether the immersive experience may have a greater impact on cognitive empathy and reduce emotional fatigue (e.g. anxiety, depression, quality of life), the outcomes of psycho-educational interventions are measured by means of validated psychological scales (e.g. Interpersonal Reactivity Index - IRI; Perceived Stress Scale - PSS; Short Sense of Competence Questionnaire - SSCQ; etc.) [14-16] in a comparison between pre-intervention (T0), post-intervention

(T1,±7 days from the end of intervention) and T2 (60 days ±7 days from the end of intervention). In addition, a sub-sample of 50 participants (randomly assigned to the two groups) will undergo task-based functional MRI to measure changes in neuronal activity of circuits underlying empathy.

IV. CONCLUSION

At the end of the intervention, we hypothesize that the ViveDe experience will be able to reduce caregivers' emotional impact and distress through a better understanding of a person with dementia perspective and, in turn, to elicit cognitive empathic behaviors (clinical outcomes) As the neurofunctional outcome (task fMRI data), we expect that the ViveDe intervention will elicit greater activation of in the circuits underlying cognitive empathy. and decreased activation of circuits associated with distress care

To date, only few studies have explored experiential technology use to support an improvement of caregiver's empathy and emotional management and properly controlled randomized clinical trials are still lacking. Moreover, to the best of our knowledge, this study will be among the first carrying out an evaluation of fMRI imaging outcomes of the cognitive empathic process possible through a 360° immersive experience. In conclusion, we prospect the benefits of this intervention will lead to the prevention of emotional and psychological burden in the caregiver. Moreover, the intervention could have an indirect but important effect also on patient's quality of life, e. g. through the reduction of unnecessary hospitalizations and more appropriate use of psychotropic drugs in managing symptoms in the caregiving of a person with dementia.

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