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Patient Engagement Advisory Committee
From: John Tawfik, DPT, GCS and Richard Engelmann, DPT
Accelerated Care Plus
4999 Aircenter Circle
Reno, NV 89502

Introduction

Virtual Reality (VR)/Augmented Reality (AR) is a simulation of a real world environment that is generated through computer software and is experienced by the user through a human-machine interface (Holden, 2005). The user has a sense of actual presence in, and control over, the simulated environment. 'Sense of presence' is a feeling of being in an environment even if one is not physically there, resulting in behavior that is congruent with how the patient would respond if truly in that environment (Seistrup, 2004). VR/AR using various interfaces are showing significant impact in the healthcare system. The field is highly interdisciplinary, bringing together signal processing, computer vision, computer graphics, user interfaces, human factors, wearable computing, mobile computing, computer networks, displays, sensors, to name just some of the most important influences. Positive research outcomes have been published using various VR/AR systems and technologies. VR technology has almost endless possible uses in medicine (Gupta et al., 2018); and the concepts and technologies have now been implemented into physical rehabilitation for *neurological, cardiopulmonary, fall prevention, orthopedics, and pain and wound management, cognition, continence and dysphagia interventions.*

Research indicates that patients enjoy performing virtual exercises and activities, therefore motivating them to exercise harder and longer. As a result, virtual rehabilitation treatment outcomes can equal or even exceed those achieved with traditional therapeutic exercise alone. Putting patients in a virtual reality (VR) environment can increase engagement and motivation to exercise through visual and auditory feedback. VR results in increased exercise intensity (e.g., longer duration, more repetitions) (Rand et al., 2014). Patient neuroplasticity is enhanced from repetition and the research shows that cortical reorganization occurs in response to task-oriented movements and activities (Holden, 2005). VR exercise variety has the ability to allow for the breakdown of complex movements/tasks into components to appropriately challenge the patient (Adamovich et al., 2009). Sufficient overload stimulation is required to improve performance of the sensorimotor system. Research also confirms that VR-acquired skills appear to transfer to real-life settings.

Some VR systems have preset and adjustable parameters to individualize the exercise to the patient's ability. The system's ability to customize the exercise allows patients to be progressively challenged while receiving frequent, positive feedback, setting them up for success. In addition, exercises can be performed in both individual and multiple participant formats. Objective data establishes baseline performance, supports individualized goal-setting, and can create a sense of competition within patients themselves and/or with others. The combination of telemedicine and virtual reality may more optimally serve and challenge elder adults both physically and cognitively over time in future lockdowns. There is a need to provide long-term remote training and feedback (Meulenberg et al., 2020).

Introduction References

Adamovich, S. V., Fluet, G. G., Tunik, E., & Merians, A. S. (2009). Sensorimotor Training in Virtual Reality: A Review. *NeuroRehabilitation, 25*(1), 29-44. https://doi.org/10.3233/nre-2009-0497

Gupta, A., Scott, K., & Dukewich, M. (2018). Innovative Technology Using Virtual Reality in the Treatment of Pain: Does It Reduce Pain via Distraction, or Is There More to It? American Academy of Pain Medicine, *19*(1), 151-159. https://doi.org/10.1093/pm/pnx109

Holden, M. (2005). Virtual Environments for Motor Rehabilitation: Review. *CyberPsychology and Behavior*, *8*(3), 187-211. https://doi.org/10.1089/cpb.2005.8.187

Meulenberg, C., de Bruin, E. D., & Marusic, U. (2022). A Perspective on Implementation of Technology-Driven Exergames for Adults as Telerehabilitation Services. *Frontiers in Psychology*, *13*, 840863. https://doi.org/10.3389/fpsyg.2022.840863

Rand, D., Givon, N., Weingarden, H., Nota, A., & Zeilig, G. (2014). Eliciting Upper Extremity Purposeful Movements Using Video Games: A Comparison with Traditional Therapy for Stroke Rehabilitation. *Neurorehabilitation and Neural Repair*, *28*(8), 733-739. https://doi.org/10.1177/1545968314521008

Sveistrup, H. (2004). Motor Rehabilitation Using Virtual Reality. *Journal of Neuroengineering and Rehabilitation, 1*(10), 1-8. https://doi.org/10.1186/1743-0003-1-10s

Virtual Reality in Neurological Rehabilitation

In addition to patient engagement, motivation, and increase repetitions, there are also physiological benefits and changes that are especially important to the neurological rehabilitation population. Video game playing has been shown to increase dopamine levels. Dopamine is theorized to play a role with learning and VR may stimulate increased production thereby helping with neuromuscular reeducation (Koepp et al., 1998). Research shows that for stroke survivors, VR may decrease contralesional sensorimotor activity and increase ipsilesional activity, thereby leading to improved movement and function (You et al., 2005). Evidence exists that VR exercises induce cortical and subcortical changes at a cellular and synaptic level resulting in new patterns of motor activity (Holden, 2005). VR has the potential to improve balance and gait in patients across 6 neurologic conditions (Parkinson disease, multiple sclerosis, acute and chronic post-stroke, traumatic brain injury, and cerebral palsy) and brings additional benefits when combined with conventional rehabilitation, based on a review of ninety-seven articles including sixty-eight that were published during or after 2013 (Cano Porras et al., 2018).

Stroke (CVA): In a systemic review with meta-analysis of thirty-eight articles, Karamians et al. investigated the effectiveness of VR for UE stroke rehab using outcomes such as the Wolf Motor Functioning Test, Fugl-Meyer, or Action Research Arm Test (Karamians et al., 2019). Overall, VR- or gaming-based upper extremity rehabilitation post-stroke appears to be more effective than conventional methods (Karamians et al., 2019). There are of course different types of strokes: ischemic, hemorrhagic, as well as the location within the brain or brainstem. Kiper et al. concludes that reinforced feedback in virtual environment (RFVE) treatment combined with conventional rehabilitation (CR) promotes better outcomes for upper limb than the same amount of CR, regardless of stroke etiology (Kiper et al., 2018).

An RCT compared standard therapy and standard therapy plus screen-based VR in the treatment of upper extremity post-stroke where the VR trained subjects had statistically significantly greater Functional Independence Scores (FIM) self-care scores (eating, grooming, bathing, dressing, and toileting) (Yavuzer et al., 2008). A systematic review and meta-analysis of RCTs found that individuals who sustained a stroke can achieve significant gains on Body Structure/Function and Activity level outcomes, including improvements in cognitive function, through VR training (Aminov et al., 2018). Another RCT was used to compare the effectiveness of VR combined with real instrument training and conventional occupational therapy in the rehabilitation of subjects post-stroke (Oh et al., 2019). VR group showed greater therapeutic effects in a time-dependent manner than the control group, especially on the motor power of wrist extension, spasticity of elbow flexion and wrist extension, and Box and Block tests (Oh et al., 2019). VR group, but not the control group, showed significant improvements from before to immediately after training, on lateral, palmar and tip pinch power, Box and Block and 9-Hole Peg Test (Oh et al., 2019). VR group experienced significantly greater improvements in tip pinch power immediately after training and in elbow flexions spasticity 4 weeks after completion of training (Oh et al., 2019). Conclusion: VR with real instrument training was effective at promoting recovery of patients' upper-extremity and cognitive function (Oh et al., 2019). RCT compared conventional therapy and conventional therapy plus screen-based VR designed to challenge balance, weight shifting, and stepping skills in lower extremity rehab in subjects more than one year post-stroke (Kim et al., 2009). Compared to controls, VR trained subjects had statistically significant greater Berg Balance Scale scores, gait speed, step and stride length, and Modified Motor Assessment scores (Kim et al., 2009). A systematic review and meta-analysis concluded that VR training for balance or gait is more effective than training without VR for improving balance and gait ability in patients with stroke (De Rooij et al., 2016). Combining traditional rehab and virtual reality with reinforced feedback (reinforced feedback virtual environment - RFVE) showed encouraging results regarding reduction of spasticity and improvement of gait function (Luque-Moreno et al., 2019). Early intervention seemed to be ideal in promoting increased change. Ankle spasticity frequently limits function in patients post-stroke (Luque-Moreno et al., 2019).

Cycling: During cycle training with individuals following stroke, the unaffected limb tends to compensate for the affected one, which resulted in suboptimal rehabilitation (Yin et al., 2016). To address this issue, Yin et al. developed a lower limb Virtual Reality-Cycling Training System (VRCTS), which senses the cycling force and speed in real-time, analyzes the acquired data to produce visual feedback to patients consisting of a controllable VR car. This was used to specifically to train the affected side (Yin et al., 2016). The patient can cycle faster and control the VR car's direction with skills, then patients can finish more rounds, and more scores (Yin et al., 2016). Also with the different speeds, the VR car can provide patients with motivation to cycle faster and have better clinical effects (Yin et al., 2016). The Virtual Reality-Cycling Training System in this study can improve the symmetry of the bilateral pedal force from the cycling detection significantly, and the performance is better than the control group. In addition, the distribution ARI of bilateral pedal force and force plate is improved significantly (Yin et al., 2016). The result also shows that the VRCTS treatment translated to increase weight-bearing symmetry in static balance effectively (Yin et al., 2016). Additional technologies commercially available also offer left vs right symmetry, as well as biofeedback to decrease tone, increase motor control, strength, power and alternating work/rest cycles.

Wheelchair mobility: A RCT compared standard therapy and standard therapy plus screen-based VR for improving wheelchair mobility in patients with unilateral neglect found significant differences (Webster et al., 2001). Compared to controls, VR trained subjects performed statistically significantly better on a real-life wheelchair obstacle course (Webster et al., 2001).

Parkinson's disease: A RCT consisting 12 weeks of VR rehabilitation resulted in a greater improvement in the balance and gait of individuals with PD when compared to conventional physical therapy (Feng et al., 2019). A systematic review consisting of sixteen articles involving 555 participants with PD, with the authors concluding that: VR rehabilitation training performed better than conventional or traditional rehabilitation training in three aspects: step and stride length, balance function, and mobility (Lei et al., 2019). VR improves a number of outcomes, and may be considered for routine use in rehabilitation for patients with Parkinson's disease (Triegaardt et al., 2019). Kinect-based training was safe and feasible, and promoted improvement in activities (balance, gait), body function (cardiopulmonary aptitude) and participation /quality of life (QoL) (Pompeu et al., 2014).

Spinal cord injury (SCI): A systematic review found that VR-based rehabilitation in subjects with Spinal Cord injury may lead to positive effects on aerobic function, balance, pain level, and motor function recovery besides improving psychological/motivational aspects (Lacerda de Araújo et al., 2019)

Multiple diagnoses: VR interventions for balance neuro rehabilitation can foster meaningful improvements across a variety of clinical populations (Goble, J et al., 2014). Recently, Hornby et al., released a Clinical Practice Guideline (CPG) including VR to improve locomotor function following Chronic Stroke, Incomplete Spinal Cord Injury, and Brain Injury (Hornby et al., 2020).

Virtual Reality in Stroke/Cerebrovascular Accident (CVA) References

Aminov, A., Rogers, J., Middleton, S., Caeyenberghts, K., & Wilson, P. (2018). What do Randomized Controlled Trials Say About Virtual Rehabilitation in Stroke? A Systematic Literature Review and Meta-Analysis of Upper-Limb and Cognitive Outcomes. *Journal of NeuroEngineering and Rehabilitation, 15*, Article 29. https://doi.org/10.1186/s12984-018-0370-2

Cano Porras, D., Siemonsma, P., Inzelberg, R., Zeilig, G., & Plotnik, M. (2018). Advantages of Virtual Reality in the Rehabilitation of Balance and Gait: Systematic Review. *Neurology, 90*(22), 1017-1025. https://doi.org/10.1212/WNL.0000000000005603

de Rooij, I. J., van de Port, I. G., & Meijer, J. G. (2016). Effect of Virtual Reality Training on Balance and Gait Training Ability in Patients with Stroke: Systematic Reviews and Meta-Analysis. *Physical Therapy, 96*(12), 1905-1918. https://doi.org/10.2522/ptj.20160054

Holden, M. (2005). Virtual Environments for Motor Rehabilitation: Review. *CyberPsychology and Behavior*, *8*(3), 187-211. https://doi.org/10.1089/cpb.2005.8.187

Hornby, G., Reisman, D., Ward, I., Scheets, P., Miller, A., Haddad, D., Fox, E., Fritz, N., Hawkins, K., Henderson, Cl, Hendron, K., Holleran, C., Lynskey, J., Walter, A., & Locomotor CPG Appraisal Team. (2020). Clinical Practice Guideline to Improve Locomotor Function Following Chronic Stroke, Incomplete Spinal Cord Injury, and Brain Injury. *Journal of Neurologic Physical Therapy, 44*(1), 49-100. https://doi.org/10.1097/npt.0000000000000303

Karamians, R., Proffitt, R., Kline, D., Gauthier, L.V. (2019, Dec 7). Effectiveness of Virtual Reality- and Gaming-Based Interventions for Upper Extremity Rehabilitation Post-Stroke: A Meta-Analysis. *Archives of Physical Medicine and Rehabilitation*. (Online ahead of print). https://doi.org/10.1016/j.apmr.2019.10.195

Kim, J., Jang, S., Kim, C., Jung, J., & You, J. (2009). Use of Virtual Reality to Enhance Balance and Ambulation in Chronic Stroke: A Double-Blind, Randomized Controlled Study. *American Journal of Physical Medicine and Rehabilitation, 88*(9), 693-701. https://doi.org/10.1097/phm.0b013e3181b33350

Kiper, P., Szczudlik, A., Agostini, M., Opara, J., Nowobilski, R., Ventura, L., Tonin, P., & Turolla, A. (2018). Virtual reality for upper limb rehabilitation in subacute and chronic stroke: A randomized controlled trial. Archives of Physical Medicine and Rehabilitation, 99, 834–842.e4. https://doi.org/10.1016/j.apmr.2018.01.023

Koepp, M. J., Gunn, R. N., Lawrence, A. D., Cunningham, V. J., Dagher, A., Jones, T., Brooks, d. J., Bench, C. J., Graspy, P. M. (1998). Evidence for Striatal Dopamine Release During a Video Game. *Nature*, *393(6682)*, 266-268. https://doi.org/10.1038/30498

Luque-Moreno, C., Cano-Bravo, F., Kiper, P., Solís-Marcos, I., Moral-Munoz, J., Agostini, M., Oliva-Pascual-Vaca, Á., & Turolla, A. (2019). Reinforced Feedback in Virtual Environment for Plantar Flexor Poststroke Spasticity Reduction and Gait Function Improvement. *BioMed Research International, 2019*, Article 6295263. https://doi.org/10.1155/2019/6295263

Oh, Y. B., Kim, G. W., Han, K. S., Won, Y., Park, S. H., Seo, J. H., & Ko, M. H. (2019). Efficacy of Virtual Reality Combined with Real Instrument Training for Patients with Stroke: A Randomized Controlled Trial. *Archives of Physical Medicine and Rehabilitation, 100*(8), 1400-1408. https://doi.org/10.1016/j.apmr.2019.03.013

Yavuzer, G., Senel, A., Atay, M. B., & Stam, H. J. (2008). "Playstation Eyetoy Games" Improve Upper Extremity-Related Motor Functioning in Subacute Stroke: A Randomized Controlled Clinical Trial. *European Journal of Physical and Rehabilitation Medicine, 44*(3), 237-244.

You, S. H., Jan, S. H., Kim, Y. H., Hallett, M., Ahn, S. H., Kwon, Y. H., Kim, J. H., & Lee, M. Y. (2005). Virtual Reality-Induced Cortical Reorganization and Associated Locomotor Recovery in Chronic Stroke. *Stroke, 36*(6), 1166-1171. https://doi.org/10.1161/01.str.0000162715.43417.91

Virtual Reality in Cycling References

Yin, C., Hsueh, Y. H., Yeh, C. Y., Lo, H. C., & Lan, Y. T. (2016). A Virtual Reality-Cycling Training System for Lower Limb Balance Improvement. *BioMed Research International, 2016*, 9276508. https://doi.org/10.1155/2016/9276508

Virtual Reality in Wheelchair References

Webster, J. S., McFarland, P. T., Rapport, L. J., Morrill, B., Roades, L. A., & Abadee, P. S. (2001). Computer-Assisted Training for Improving Wheelchair Mobility in Neglect Patients. *Archives of Physical Medicine and Rehabilitation, 82*(6), 769-775. https://doi.org/10.1053/apmr.2001.23201

Neurological

Goble, D. J., Cone, B. L., & Fling, B. W. (2014). Using the Wii Fit as a Tool for Balance Assessment and Neurorehabilitation: The First Half Decade of "Wii-Search". *Journal of Neuroengineering and Rehabilitation*, *11*, 12. Https://Doi.Org/10.1186/1743-0003-11-12

Virtual Reality in Parkinson's Disease (PD) References

Feng, H., Li, C., Wang, L., Ma, J., Li, G., Gan, L., Shang, X., & Wu, Z. (2019). Virtual Reality Rehabilitation Versus Conventional Physical Therapy for Improving Balance and Gait in Parkinson's Disease Patients: A Randomized Controlled Trial. *Medical Science Monitoring, 25*, 4186-4192. https://dx.doi.org/10.12659%2FMSM.916455

Lei, C. Sunzi, K., Dai, F., Liu, X., Wang, Y., Zhang, B., He, L., & Ju, M. (2019) Effects of Virtual Reality Rehabilitation Training on Balance in Patients with Parkinson's Disease: A Systematic Review. *PLoS ONE, 14*(11), e0224819. https://doi.org/10.1371/journal.pone.0224819

Pompeu, J. E., Arduini, L. A., Botelho, A. R., Fonesca, M. B., Pompeu, S. M., Torriani-Pasin, C. , & Deutsch, J. E. (2014). Feasibility, Safety and Outcomes of Playing Kinect Adventures!™ for People with Parkinson's Disease: A Pilot Study. *Physiotherapy, 100*(2), 162-168. https://doi.org/10.1016/j.physio.2013.10.003

Triegaardt, J., Han, T. S., Sada, C., Sharma, S., Sharma, P. (2019). The Role of Virtual Reality on Outcomes in Rehabilitation of Parkinson's Disease: Meta-Analysis and Systematic Review in 1031 Participants. *Neurological Science,* (Online ahead of print). https://doi.org/10.1007/s10072-019-04144-3

Virtual Reality in Spinal Cord Injury (SCI) References

Lacerda de Araújo, A., Neiva, J., Montiero, C., & Magalhães, F. (2019). Efficacy of Virtual Reality Rehabilitation After Spinal Cord Injury: A Systematic Review. *BioMed Research International, 2019*(7106951). https://doi.org/10.1155/2019/7106951

Virtual Reality Multiple Diagnoses Article References

Goble, D. J., Cone, B. L., & Fling, B. W. (2014). Using the Wii Fit as a Tool for Balance Assessment and Neurorehabilitation: The First Half Decade of "Wii-Search". *Journal of Neuroengineering and Rehabilitation*, *11*, 12. Https://Doi.Org/10.1186/1743-0003-11-12

Hornby, G., Reisman, D., Ward, I., Scheets, P., Miller, A., Haddad, D., Fox, E., Fritz, N., Hawkins, K., Henderson, Cl, Hendron, K., Holleran, C., Lynskey, J., Walter, A., & Locomotor CPG Appraisal Team. (2020). Clinical Practice Guideline to Improve Locomotor Function Following Chronic Stroke, Incomplete Spinal Cord Injury, and Brain Injury. *Journal of Neurologic Physical Therapy, 44*(1), 49-100. https://doi.org/10.1097/npt.0000000000000303

Virtual Reality in Cardiopulmonary Conditions

Reduction of exercise tolerance poses a huge health issue, often affecting patients with respiratory conditions, which is caused by skeletal muscle dysfunction and weakness and by lung function impairment (Condon et al., 2020). Virtual reality systems are emerging technologies that have drawn scientists' attention to its potential benefit for rehabilitation (Condon et al. 2020). The use of VRS as an intervention can provide options for rehabilitation, given their moderate effect for dyspnea and equivalent to weak effect for mean and maximum peak HR and SpO_2 (Condon et al., 2020). Moderate exercise using VR in COPD patients was shown to be safe, feasible, and enjoyed (Wardini et al., 2013). Pulmonary rehab program supplemented with VR training is a beneficial intervention to improve physical fitness in patients with COPD (Rutkowski et al., 2019). The 6-Minute Stationary Walk with VR (STVR-6) proved reproducible and valid to evaluate the functional capacity of subjects with COPD and may be an alternative to the 6MWT (Frade et al., 2019).

Virtual cardiac rehab (CR) improves mental and physical conditions of cardiac patients more effectively than conventional Cardiovascular Rehab programs (Penn et al., 2018). In subjects with coronary artery bypass grafts (CABG) the VR-trained subjects had superior clinical outcomes and achieved % target heart rate (THR), and Decreased sessions needed to attain THR and O_2 uptake goals (Chuang et al., 2006).

Virtual Reality in Cardiopulmonary References

Chuang, T. Y., Sung, W. H., Chang, H. A., & Wang, R. Y. (2006). Effect of a Virtual Reality-Enhanced Exercise Protocol After Coronary Artery Bypass Grafting. *Physical Therapy, 86*(10), 1369-1377. https://doi.org/10.2522/ptj.20050335

Condon, C., Lam, W. T., Mosley, C., & Gough, S. (2020). A Systematic Review and Meta-Analysis of the Effectiveness of Virtual Reality as an Exercise Intervention for Individuals with a Respiratory Condition. *Advances in Simulation (London, England)*, *5*(1), 33. Https://Doi.Org/10.1186/S41077-020-00151-Z

Frade, M., dos Reis, I., Basso-Vanelli, R., Brandão, & Jamami, M. (2019). Reproducibility and Validity of the 6-Minute Walk Test Associated with Virtual Reality in Subjects with COPD. *Respiratory Care, 64*(4), 425-433. https://doi.org/10.4187/respcare.06237

Penn, I. W., Chuang, E., Chuang, T. Y., & Yang, C. Y. (2018). Effects of Virtual-Reality Augmented Cardiopulmonary Rehabilitation Programs for Patients with Cardiovascular Diseases: A Systematic Review. *Neuropsychiatry, 8*(5), 1630-1636.

Rutkowski, S., Rutkowska, A., Kiper, P., Jastrzebski, D., Racheniuk, H., Turolla, A., Szczegielniak, J., & Casaburi, R. (2020). Virtual Reality Rehabilitation in Patients with Chronic Obstructive Pulmonary Disease: A Randomized Controlled Trial. *International Journal of Chronic Obstructive Pulmonary Disease, 15*, 117-124. https://doi.org/10.2147/COPD.S223592

Wardini, R., Dajczman, E., Yang, N., Baltzan, M., Préfontaine, D., Stathatos, M., Marciano, H., Watson, S., & Wolkove, N. (2013). Using a virtual game system to innovate pulmonary rehabilitation: safety, adherence and enjoyment in severe chronic obstructive pulmonary disease. *Canadian respiratory journal*, *20*(5), 357–361. https://doi.org/10.1155/2013/563861

Virtual Reality using Spirometry Biofeedback

In addition to breathing exercises such being formed virtually for relaxation, or deep breathing, breathing exercise can done with an airflow sensor to measure inspiratory and expiratory flow and volume data. This data can be incorporated into software, for interaction based on patient's performance. Breathing exercises using spirometry virtual reality biofeedback maybe incorporated into pulmonary rehabilitation for the following: dyspnea, abnormal breathing rhythm, pulmonary hyperventilation, diminished vital capacity, reduced airway clearance, muscle weakness, speech dysfunction, impaired phonation/voicing, dysphagia/swallowing difficulty, autonomic nervous system (ANS) dysregulation (e.g. pain, UI), decreased core stability, energy conservation training. Research shows: that there is a trend towards more minutes with spirometry VR biofeedback vs. control device (Bingham et al., 2012). Spirometry VR biofeedback group had significantly improved FVC, FEV1, and max voluntary ventilation values vs. control group (Joo et al., 2015). Spirometry VR biofeedback is reliable for pulmonary function assessment in individuals who are status-post stroke, and can be useful during rehabilitation to improve pulmonary function (Joo et al., 2018). Inspiratory muscle training with spirometry VR biofeedback is recommended over conventional training to improve diaphragm movement and pulmonary function in people with thoracic restriction (Jang et al., 2019). Future opportunities also exist in combining VR spirometry biofeedback with telemedicine for compliance and progression in those patients with respiratory impairment to reduce recidivism and health care costs.

Virtual Reality in Spirometry References

Bingham, P. M., Lahiri, T., & Ashikaga, A. (2012). Pilot Trial of Spirometer Games for Airway Clearance Practice in Cystic Fibrosis. *Respiratory Care, 57*(8), 1278-1284. https://doi.org/10.4187/respcare.01263

Chelabi, K., Balli, F., Bransi, M., Gervais, Y., Marthe, C., & Tse, S. M. (2021). Validation of a Portable Game Controller to Assess Peak Expiratory Flow Against Conventional Spirometry in Children: Cross-sectional Study. *JMIR Serious Games, 9*(1), e25052. https://dx.doi.org/10.2196%2F25052

Jang, M. S., Choung, S. D., Shim, J. H., & Hong, S. T. (2019). Effect of Virtual Reality Inspiratory Muscle Training on Diaphragm Movement and Respiratory Function in Female Patients with Thoracic Restriction. *Journal of Korean Society of Physical Medicine, 14*(1), 101-110. https://doi.org/10.13066/KSPM.2019.14.1.101

Joo, S., Shin, D., & Song, C. (2015). The Effects of Game-Based Breathing Exercise on Pulmonary Function in Stroke Patients: A Preliminary Study. *Medical Science Monitor, 21*, 1806-1811. https://doi.org/10.12659/msm.893420

Joo, S,. Lee, K.,& Song, C. (2018). A Comparative Study of Smartphone Game with Spirometry for Pulmonary Function Assessment in Stroke Patients. *Hindawi BioMed Research International, 2018*(2439312), 1-6. https://doi.org/10.1155/2018/2439312

Virtual Reality in Fall Prevention

Adults with sedentary lifestyles seem to face a higher risk of falling in their later years. Several causes, such as impairment of strength, coordination, and cognitive function, influence worsening health conditions, including balancing ability (Prasertsakul et al., 2018). A study found that VR based training can help reduce the risk of falls by improving static and dynamic balance (Kamińska et al, 2018). After 30 minutes of VR exercise 3 times per week, significant improvements were noted for the 6-Minute Walk Test (6MWT), Dynamic Gait Index (DGI), Tandem Stance Test (TST), and the Beck Depression Inventory (BDI) (Kamińska et al, 2018). Visibly better results were seen for individuals under and over 80 years old for the 6MWT, TST, and BDI (Kamińska et al, 2018). VR provides clinicians with a useful tool for improving dynamic balance and balance confidence in older adults (Rendon et al., 2012). The application of VR has a positive impact on the rehabilitation of the most predominant geriatric syndromes. The level of realism of the virtual stimuli seems to have a crucial role in the training of cognitive abilities (Bevilacqua et al., 2019). The systematic review by Bevilacqua et al (2019) also noted that future research needs to improve study design (i.e. include larger samples, longitudinal designs, long term follow-ups, and different outcome measures, including functional and quality of life indexes) to better evaluate the clinical impact of VR technology on healthy old subjects and in neurological patients (Bevilacqua et al., 2019). A review of the influence of VR on rehabilitation of balance in healthy elderly found that VR therapy was effective for the rehab of postural balance (Oliviera et al., 2017). Oliveira et al. noted that the realism of the virtual stimuli seemed to play an important role in the training of cognitive abilities (Oliviera et al, 2017). They introduced virtual reality as a technique presenting cognitive, motor and cardiorespiratory demands beneficial to the elderly and included 70 studies in the review (Oliviera et al, 2017). Further research using larger samples and similar methodologies would be beneficial in supporting the findings of this review (Oliviera et al, 2017). For older adults without neurological disorders, exergame-based training improved walking, and improvements were maintained at follow-up (Janhunen et al., 2021). Prasertsakul et al. proposed that VR-based training relies on the effect of motor learning in long-term training though different kinds of task training. In postural analysis, both VR and conventional exercise programs should be emphasized, to improve the balance ability in healthy adults (Prasertsakul et al., 2018). A study by Yom et al. demonstrated that virtual reality-based ankle exercise effectively improves the dynamic balance, muscle tone, and gait ability of stroke patients (Yom et al., 2015).

Virtual Reality in Fall Prevention References

Bevilacqua, R., Maranesi, Riccardi, G. R., Di Donna, V., Pelliccioni, P., Luzi, R., Lattanzio, F. & Pelliccioni, G. (2019). Non-Immersive Virtual Reality for Rehabilitation of the Older People: A Systematic Review into Efficacy and Effectiveness. *Journal of Clinical Medicine, 8*(11). https://doi.org/10.3390/jcm8111882

Janhunen, M., Karner, V., Katajapuu, N., Niiranen, O., Immonen, J., Karvanen, J., Heinonen, A., & Aartolahti, E. (2021). Effectiveness of Exergame Intervention on Walking in Older Adults: A Systematic Review and Meta-Analysis of Randomized Controlled Trials. Physical therapy, 101(9), pzab152. https://doi.org/10.1093/ptj/pzab152

Kamińska, M., Miller, A., Rotter, I., Szlyińska, A., & Grochans, E. (2018). The Effectiveness of Virtual Reality Training in Reducing the Risk of Falls Among Elderly. *Clinical Interventions on Aging - Auckland, 13*(2018), 1229-2338. https://dx.doi.org/10.2147%2FCIA.S183502

Oliveira, J., Guaratto, T., Bacha, J., Evangelista, R., Bocalini, D., Greve, J., & Alonso, A. (2017). Virtual Reality in the Rehabilitation of the Balance in the Elderly. *Manual Therapy, Posturology & Rehabilitation Journal, 15*(0)*,* 1-6. http://dx.doi.org/10.17784/mtprehabjournal.2017.15.481

Prasertsakul, T., Kaimuk, P., Chinjenpradit, W., Limroongreungrat, W., & Charoensuk, W. (2018). The Effect of Virtual Reality-Based Balance Training on Motor Learning and Postural Control in Healthy Adults: A Randomized Preliminary Study. *Biomedical Engineering Online*, *17*(1), 124. https://doi.org/10.1186/s12938-018-0550-0

Rendon, A., Lohman, E., Thorpe, D., Johnson, E., Medina, E., & Bradley, B. (2012). The Effect of Virtual Reality Gaming on Dynamic Balance in Older Adults. *Age and Ageing, 4*, 549-552. https://doi.org/10.1093/ageing/afs053

Yom, C., Cho, H. Y., & Lee, B. (2015). Effects of Virtual Reality-Based Ankle Exercise on the Dynamic Balance, Muscle Tone, and Gait of Stroke Patients. *Journal of Physical Therapy Science*, *27*(3), 845-849. Https://Doi.Org/10.1589/Jpts.27.845

Virtual Reality in Orthopedics

A systematic review and meta-analysis of research regarding the effectiveness of VR in orthopedic rehabilitation found: The evidence of VR effectiveness is promising in chronic neck pain and shoulder impingement syndrome (Gumaa & Youssef, 2019). VR and exercises have similar effects in RA, knee arthritis, ankle instability, and post-ACL reconstruction (Gumaa & Youssef, 2019). For fibromyalgia and back pain, as well as after knee arthroplasty, the evidence of VR effectiveness compared with exercise is absent or inconclusive (Gumaa & Youssef, 2019). VR-based games are potentially acceptable as motivational rehabilitation tool for patients following knee surgery; a program with varied levels of difficulty and consideration of the severity of the knee injury would best meet patients' needs (Lee, 2016).

Appropriate games on tablet devices may favor the management of low back pain, stimulating creative energy, which promotes distraction from pain and reduces its perception on indexes (Zavarize et al., 2016). Even after TKA, impaired proprioception are a risk factor for progression of gait limitations. A study by Puurnajaf et al., showed that training with a VR system improves motor skills (gait, postural control and direction shift) in TKR patients compared to traditional therapy (Pournajaf et al.,2017). The results obtained with the gait analysis and the TUG test are encouraging and suggest further instrumental investigations on the sit-to-stand and balance tasks (Pournajaf et al.,2017). A RCT on a larger sample is currently in progress in order to confirm these preliminary results (Pournajaf et al., 2017).

Virtual Reality in Orthopedics References

Gumaa, M., & Youssef, A. (2019). Is Virtual Reality Effective in Orthopedic Rehabilitation? A Systematic Review and Meta-Analysis. *Physical Therapy, 99*(10), 1304-1325. https://doi.org/10.1093/ptj/pzz093

Lee, M., Suh, D., Son, J., Kim, J., Eun, S., & Yoon, B. (2016). Patient Perspectives on Virtual Reality-Based Rehabilitation After Knee Surgery: Importance of Level of Difficulty. *Journal of Rehabilitation Research and Development, 53*(2), 239-252. http://dx/doi.org/10.1682/JRRD.2014.07.0164

Pournajaf, S., Goffredo, M., Criscuolo, S., Galli, M., Damiani, C., & Franceschini, M. (2017). Virtual Reality Rehabilitation in Patients with Total Knee Replacement: Preliminary Results. *Gait & Posture, 57,* 17-18. http://dx.doi.org/10.1016/j.gaitpost.2017.07.070

Zavarize, S., Pashoal, M., & Wechsler, S. (2016). Effects of Physiotherapy Associated to Virtual Games in Pain Perception and Heart Rate Variability in Cases of Low Back Pain. *Manual Therapy, Posturology & Rehabilitation Journal, 14, 1-7.* http://dx.doi.org/10.17784/mtprehabjournal.2016.14.354

Virtual Reality in Pain and Wound Management

Non-pharmacological adjuncts like VR have become an increasingly important option for effective pain management (Pourmand et al, 2018). The current epidemic of opioid misuse has increased a sense of urgency for identifying effective non-opioid analgesia (Pourmand et al., 2018). VR can distract patients from the actual therapy task thereby lessening exercise discomfort, fear, pain, and/or boredom. A systematic review of VR studies used to provide distraction for pain reduction included subjects with various causes of pain including burns, ischemic, thermal (experimental), post-surgical pain. The researchers concluded that VR distraction may be a useful tool for clinicians who work with a variety of pain problems (Malloy et al., 2010). Overall, head mounted display systems provided greater pain relief than screen display systems. Some studies demonstrated no difference in pain relief between the two systems (Malloy et al., 2010). VR is an effective pain reduction measure added to analgesics for burn patients undergoing dressing changes or physical therapy. It significantly reduced pain intensity; time spent thinking about pain, and unpleasantness, and was more fun compared with using analgesics alone (Luo et al., 2018). Strong evidence exists for the use of VR as an effective treatment in reducing acute pain. A Systematic review and analysis by Pourmand et al., included 28 articles reviewed here support the hypothesis that virtual reality can distract patients to reduce pain and anxiety (Pourmand et al., 2018). The evidence shows effective VR use for pain relief in both acute and chronic pain (Pourmand et al., 2018). Strong evidence exists for the use of VR as an effective treatment in reducing acute pain. Promising results have been achieved for chronic pain, but further research is needed for long-term chronic pain reduction (Mallari et al., 2019). VR may be particularly effective for phantom limb pain associated with distorted phantom limb movement and body representations (e.g., clamping, gnawing), compared with typical neuropathic sensations (e.g., shooting, burning, dysesthesia) (Osumi et al., 2019). Another small study reported positive findings for using VR with individuals having Complex Regional Pain Syndrome (CRPS) resulting in a 50% reduction in pre-treatment pain scores for 4 of 5 subjects, with the analgesic effect lasting beyond therapy for 2 people (Pollard et al. 2013). Authors reported No treatment related side effects for anyone (Pollard et al., 2013). The potential for increased compliance with fun activities as home gaming becomes more accessible, and VR benefits of learning and neuroplasticity (Pollard et al., 2013). Gupta et al report that In addition to distraction, there are novel mechanisms for VR treatment in pain, such as producing neurophysiologic changes related to conditioning and exposure therapies (Gupta et al., 2018). The ability to change behavior or provide new behavior strategies for patients suffering from chronic pain can provide lasting benefits even when the VR device is removed (Gupta et al., 2018). VR may have the ability to influence the opioid abuse crisis from multiple mechanisms (Gupta et al., 2018).

Virtual Reality in Pain and Wound Management References

Gupta, A., Scott, K., & Dukewich, M. (2018). Innovative Technology Using Virtual Reality in the Treatment of Pain: Does It Reduce Pain via Distraction, or Is There More to It?. *Pain medicine (Malden, Mass.)*, *19*(1), 151-159. https://doi.org/10.1093/pm/pnx109

Luo, H., Cao, C., Zhong, J., Chen, J., & Cen, Y. (2018). Adjunctive Virtual Reality for Procedural Pain Management of Burn Patients During Dressing Change or Physical Therapy: A Systematic Review and Meta-Analysis of Randomized Controlled Trials. *Wound Repair and Regeneration, 27*, 90-101. https://doi.org/10.1111/wrr.1

Mallari, B., Spaeth, E. K., Goh, H., Boyd, B. S. (2019). Virtual Reality as an Analgesic for Acute and Chronic Pain in Adults: A Systematic Review and Meta-Analysis. *Journal of Pain Research*, *12*, 2053-2085. https://doi.org/10.2147/jpr.s200498

Malloy, K., & Milling, L. (2010). The Effectiveness of Virtual Reality Distraction for Pain Reduction: A Systematic Review. *Clinical Psychology Review, 30(8)*, 1011-1018. https://doi.org/10.1016/j.cpr.2010.07.001

Osumi, M., Inomata, K., Inoue, Y., Otake, Y., Morioka, S., & Sumitani, M. (2019). Characteristics of Phantom Limb Pain Alleviated with Virtual Reality Rehabilitation. *Pain Medicine, 20*(5), 1038-1046. https://doi.org/10.1093/pm/pny269

Pollard, C. (2013). Physiotherapy Management of Complex Regional Pain Syndrome. *New Zealand Journal of Physiotherapy, 41*(20), 65-72.

Pourmand, A., Davis, S., Marchak, A., Whiteside, T., & Sikka, N. (2018). Virtual Reality as a Clinical Tool for Pain Management. *Current pain and headache reports*, *22*(8), 53. https://doi.org/10.1007/s11916-018-0708-2

Virtual Reality for Cognition

Long-term improvements in cognitive and psychological outcomes were achieved with computerized or virtual reality cognitive training for individuals with mild cognitive impairment or dementia (Coyle et al., 2015). Multiple studies have identified the value of using VR to assess cognitive function. A Virtual Shopping Test (VST) was created to analyze the ability of subjects to buy 4 items in a virtual shopping mall quickly and in a rational way. The VST was able to evaluate the ability of attention and everyday memory in patients with brain damage (Okahashi et al., 2013). Virtual Reality Day-Out Task (VR-DOT) is an effective tool for discriminating pre-dementia and mild Alzheimer's type dementia from healthy controls by detecting differences in terms of errors, omissions, and perseverations while measuring ADL function (Tarnanas et al., 2013).

Virtual Reality for Cognition References

Coyle, H., Traynor, V., Solowij, N. (2015). Computerized and Virtual Reality Cognitive Training for Individuals at High Risk of Cognitive Decline: Systematic Review of the Literature. *American Journal of Geriatric Psychiatry*, *23*(4), 335-359. https://doi.org/10.1016/j.jagp.2014.04.009

Okahashi, S., Seki, K., Nagano, A., Luo, Z., Kojima, M., & Futaki, T. (2013). A Virtual Shopping Test for Realistic Assessment of Cognitive Function. *Journal of Neuro Engineering and Rehabilitation, 10*(1), 59. https://dx.doi.org/10.1186%2F1743-0003-10-59

Tarnanas, I., Schlee, W., Tsolaki, M., Muir, R., Mosimann, U., & Nef, T. (2013). Ecological Validity of Virtual Reality Daily Living Activities Screening for Early Dementia: Longitudinal Study. *JMIR Serious Games, 1*(1), e1. https://doi.org/10.2196/games.2778

Urinary Continence

A study found that a treatment program combining pelvic floor muscle (PFM) exercises and virtual reality rehabilitation (VRR) is effective in reducing UI and improving QOL for older women with mixed urinary incontinence (MUI) (Elliott et al., 2015). Results: 91% compliance with class attendance; 92% compliance with home exercises (Elliott et al., 2015). Frequency and quantity of urine leakage, patient-reported symptoms and QOL significantly improved (mean improvement was 72.3%; more than half the group reported >75% improvement). 91% of participants were satisfied with the PFM/VRR training and would not seek additional treatment (Elliott et al., 2015).

Virtual Reality in Urinary Continence References

Elliott, V., de Bruin, E., & Dumoulin, C. (2015). Virtual Reality Rehabilitation as a Treatment Approach for Older Women with Mixed Urinary Incontinence: A Feasibility Study. *Neurourology and Urodynamics, 34*(3), 236-243. https://doi.org/10.1002/nau.22553

Virtual Reality for Dysphagia and Speech

Speech language pathologists (SLP) are currently using virtual Reality biofeedback to: promote improved swallow mechanics, normalize muscle function and tone, increase muscle strength and coordination, pain reduction, and a better quality of life. Biofeedback is used in neuromuscular training, and is promising for swallowing training (Li et al., 2016). The inclusion of visual biofeedback can allow for the incorporation of strength training principles of overload, specificity, and progressive resistance, the neuroplastic principles of intensity and salience, and the motor learning principles of an evolving challenge and feedback (Galek et al., 2021). The virtual Dysphagia Systems combines sEMG a non-invasive method of biofeedback with a virtual environment to engage patients in fun, interactive swallowing and speech exercises. Objective data highlights progress for patients and therapists to see while also guiding treatment plans. sEMG is a record of muscle activity, measured in microvolts, obtained through electrodes applied to the surface of the skin. Crary et al. (2004) studied dysphagia in patients following treatment for head/neck cancer completed a systematic therapy program supplemented with surface electromyographic (sEMG) biofeedback. A case study reported that surface electromyography with A "Bar Graph" visualization with robust visual and auditory stimuli, was employed to entice patient engagement and facilitate motivation (Bice & Galek, 2016). After five therapeutic sessions, the patient progressed from holding solids in her mouth with decreased swallow initiation to independently consuming a regular diet with full range of liquids with no oral retention and no verbal cues (Bice & Galek, 2016). In a subsequent RCT, authors report that It appears that sEMG visual and clinician verbal feedback increases the swallow effort ratio (SER), which may be a surrogate for intensity" (Galek et al., 2021). An increased SER may have a positive effect on swallow intervention as intensity is known to influence outcomes of exercise and elicit neuroplastic change (Galek et al., 2021). In another study, subjects with post-stroke dysphagia (n = 20) were individually matched to 2 separate groups, a game-based biofeedback group (n = 10) or a control group (n = 10), for age, gender, duration of dysphagia, and dysphagia grades (Li et al., 2016). Laryngeal elevation training combined with game-based biofeedback augments the change in hyoid bone displacement and FOIS scores, and increases the NG tube removal rate in patients with post-stroke dysphagia (Li et al., 2016). sEMG biofeedback further enhances effortful swallow performance and is considered an acceptable technique by patients (Archer et al., 2020). These findings support the potential application of sEMG biofeedback and the ES in dysphagia therapy in stroke, justifying further investigation of patient outcomes (Archer et al., 2020).

A review of virtual reality technologies in the field of communication identified that although use of VR in the field of speech-language pathology is in its infancy, "VR is an engaging means of delivering immersive and interactive training to build functional skills that can be generalized to the real world" (Bryant et al., 2019). One implication for rehab is that VR may be used to simulate natural environments to practice and develop communication skills (Bryant et al., 2019). A RCT found that although vocabulary related changes were seen in both groups, patients using the Rehabilitation Gaming System for chronic aphasia improved language and communication whereas the traditional therapy group did not. (Grechuta et al., 2019)

Virtual Reality for Dysphagia and Speech References

Archer, S. K., Smith, C. H., Newham, D. J. (2020). Surface Electromyographic Biofeedback and the Effortful Swallow Exercise for Stroke-Related Dysphagia and in Healthy Ageing. *Dysphagia, 36*, 281-292. https://doi.org/10.1007/s00455-020-10129-8

Bice, E. M., & Galek, K. E. (2016, March 31). The Use of Neuroplastic Principles Affects the Swallow Motor Plan of a Patient in Severe Cognitive Decline: A Case Study. *Perspectives of the ASHA Special Interest Groups, SIG 15*(1). https://doi.org/10.1044/persp1.SIG15.79

Byrant, L., Brunner, M., & Hemsley, B. (2018). A Review of Virtual Reality Technologies in the Field of Communication Disability: Implications for Practice and Research. *Disability and Rehabilitation: Assistive Technology, 15*(4), 1-8. https://doi.org/10.1080/17483107.2018.1549276

Crary, M. A., Carnaby Mann, G. D., Groher, M. E., & Helseth, E. (2004). Functional benefits of dysphagia therapy using adjunctive sEMG biofeedback. *Dysphagia*, *19*(3), 160–164. https://doi.org/10.1007/s00455-004-0003-8

Galek, K. E., & Bice, E. M. (2021). The Influence of Surface Electromyography Visual and Clinician Verbal Feedback on Swallow Effort Ratio at Different Bolus Volumes in a Healthy Population. *Folia phoniatrica et logopaedica : official organ of the International Association of Logopedics and Phoniatrics (IALP)*, *73*(6), 449-454. https://doi.org/10.1159/000511497

Galek, K., Bice, E. M., & Allen,K., (2021). A Novel Protocol Designed to Treat Spastic Dysarthria Secondary to Traumatic Brain Injury: A Case Study. *Perspectives of the ASHA Special Interest Groups, 6*(3), 542–552. https://doi.org/10.1044/2021_PERSP-20-00110

Grechuta, K., Rubio Ballester, B., Espín Munne, R., Usabiaga Bernal, T., Molina Hervás, B., Mohr, B., Pulvermüller, F., San Segundo, R., & Verschure, P. (2019). Augmented Dyadic Therapy Boosts Recovery of Language Function in Patients with Nonfluent Aphasia. *Stroke*, *50*(5), 1270-1274. https://doi.org/10.1161/STROKEAHA.118.023729

Li, C. M., Wang, T. G., Lee, H. Y., Wang, H. P., Hsieh, S. H., Chou, M., & Jason Chen, J. J. (2016). Swallowing Training Combined with Game-Based Biofeedback in Poststroke Dysphagia. *PM & R : The Journal of Injury, Function, and Rehabilitation*, *8*(8), 773-779. Https://Doi.Org/10.1016/J.Pmrj.2016.01.003

Conclusion

Today the field of VR/AR has moved beyond entertainment or fitness systems. It is now being designed specifically for the use of geriatric populations and physical rehabilitation. VR results in increased volume of exercise and a substantially greater number of therapeutic repetitions whereas traditional therapy may be limited by tasks found to be boring or arduous. VR devices have features that benefit lower functioning patients, those with cognitive deficits, difficulty standing, endurance and cardiopulmonary deficits, hemiparesis, dysphagia, visual, and other neurological disorders. VR technology designed specifically with patient population in mind has made significant impact than simply leveraging off-the-shelf gaming technology and adapting it for rehab/medical interventions. The body of research is quite extensive with various degrees of size and quality, but overwhelmingly positive in the outcomes when using AR/VR when compared to traditional interventions alone. This past decade, the field of AR/VR has moved from research to commercial implementation into physical therapy, occupational therapy, and Speech language pathology practice across all settings to improve patient engagement, motivation, and intensity of exercise to individualize patient treatment and improve functional outcomes.