deXtreme™ – a Novel Robotic Device for Upper Extremity Rehabilitation

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Introduction

Stroke, brain injury, and spinal cord injury continue to cause significant functional impairments affecting daily lives. In the United States, the annual incidence of traumatic brain injury is 2.5 million, stroke 800,000, and spinal cord injury 17,000. Many of these patients have residual weakness of their arm, affecting their ability to provide activities of daily living, such as washing their face, comb their hair, putting on a shirt or pants, and cooking.

Rehabilitation has been shown to improve function by strengthening a weak arm, improving the arm's coordination of movements, leading to restoration of function. The theory that rehabilitation improves strength and function by causing lasting changes in the brain is well validated (essentially, the concept of neuroplasticity). Neuroplasticity works on the principles that targeted, goal-directed, activities that appeal to the patient's interests and motivation, with certain intensity and repetitions, yield positive feedback and lead to lasting improvements in function.

Over the past 2-3 decades, there has been a significant rise in the use of upper extremity robotic devices for rehabilitation. These robotic devices target the neuroplasticity principles of repetition, intensity, patient engagement, attention, and feedback. These include end-effector robots (such as ArmeoSpring), exoskeleton robots (such as ArmeoPower), and hybrid robots (such as Harmony SHR). Advantages of using robotic devices for rehabilitation include: practice repetition, objective measurement and feedback, engagement & motivation & compliance, and customization.

Robotic assisted therapy for paretic upper limb to be safe and allows for increased number of repetitions and intensity of practice (Veerbeek 2016). However, the impact of robotic assisted therapy in the first weeks post-stroke remains unclear (Veerbeek 2016). Robotic assisted therapy in the outpatient setting (within 6 months of stroke onset) has shown to yield improvement in upper limb motor function, passive joint motions, and quality of life as compared to conventional therapy (Bhattacharjee 2024). A meta-analysis by De Laco et al found that upper limb robotic assisted rehabilitation provide a small significant improvement in upper limb muscle synergism, muscle power, motor performance, and basic activities of daily living; no changes in muscle tone or upper limb capacity, except with exoskeletons (De Laco 2024). A review by Yang et al also shows improved motor function (Fugl-Meyer score and modified Barthel index), and no significant difference in spasticity (modified Ashworth scale) (Yang 2023).

Background on deXtreme™ & Error Enhancement

One key theory of robotic assisted therapy is error enhancement practice to improve motor function and movement quality, called neuro-adaptive control (Patton 2004). When a patient moves the arm to follow a path on the computer screen, the robot enhances the movement error and can also disturb the movement. When the robot enhances the erroneous movement disturbs by applying external forces, the patient will intuitively and automatically try to correct this disturbance and, thus, forced to work on strengthening their control and coordination (Israely 2018). Many patients post-stroke may not recognize small errors, thus, amplifying the movement disturbances will make it easier for patients to notice and try to correct the movements (Coremans 2024).

The deXtreme by BioXtreme (https://bio-xtreme.com) is a robotic device designed to take advantage of this concept of error enhancing therapy. It is a unique robotic system which applies motor error enhancement forces in combined virtual environment to restore and rehabilitate motion and dexterity. Recent study by Coremans et al demonstrated “significant improvement in upper limb motor function, activity and self-perceived performance” (Coremans 2024). According to the results, participants on average performed 1043 reaching repetitions during the 5 hour training period. It is worth noting that none of the participants experienced any adverse effects in this study; only 2 had increased tension and pain, with pre-existing tension in the neck-shoulder before starting treatment.

Another study by Abdollahi et al demonstrated the effectiveness of robotic error enhancement in post-stroke rehabilitation. The study found that patients who received error-enhanced robotic therapy showed greater improvements in motor function compared to those who received robotic therapy without error enhancement. The researchers concluded that robotic error enhancement showed modest advantage of error augmentation in only a short period of time of 3 weeks (Abdollahi 2018).

deXtreme™ Utilization at Brooks Rehabilitation

The deXtreme arrived at Brooks Rehabilitation in early November 2023. The BioXtreme team and Brooks clinicians met on 11/6/23 and started the set up and training over the next two days. We initially set up the deXtreme in the Brooks NeuroRecovery Center (NRC, https://brooksrehab.org/services/neuro-recovery-center/). The rationale for this location is to help determine the targeted population for the deXtreme. After trialing for over a month in the NRC, we then relocated the deXtreme to the stroke floor of Brooks Rehabilitation Hospital for an additional 2 months of trial. Designed occupational therapists (OT) at Brooks Rehabilitation, who have additional expertise in rehabilitation technology, were identified to be therapy champions for use of the deXtreme. We had a total of 8 occupational therapists trialing the deXtreme for a total of about 3 months.

A patient and therapy questionnaire was used to gather feedback, both from patients and therapists. We trialed the deXtreme on patients in the acute phase of rehabilitation, as well as the chronic phases. Feedbacks from clinicians were that the set up of the deXtreme was relatively easy. The OT team reported that initial onsite basic training was helpful to ensure their comfort with the deXtreme. They reported that the deXtreme is most helpful for patients with strength of 3/5 or greater in the upper extremity.

Patient feedback was that, in general, it was easy to use. The deXtreme can accommodate patients sitting in wheelchairs or in regular chairs. Most patients have a weak handgrip, and holding on to the original handgrip was a little bit of a challenge for some patients. The BioXtreme team quickly made adjustments to the handgrip to accommodate for better contact with the deXtreme. Some therapists and patients reported feeling frustrated with the deXtreme's assisted movements, which were intentionally designed to target error enhancing practices. No adverse effects were seen with any patients treated during the 3-month trial.

deXtreme™ Further Discussions

As mentioned above, error enhancement is a novel rehabilitation approach that leverages the body's natural adaptive responses to correct motor errors. When a patient performs a task, such as reaching for an object, their movement often deviates from the intended path due to neurological damage. Traditional methods typically involve repetitive practice to gradually reduce these errors, a process that can be slow and frustrating for patients [Patton 2006]. Because of this error enhancement method, use of the deXtreme can cause some initial challenges with the intervention, but after error enhancement was better understood as an intervention feedback was positive.. However, the scientific evidence to support the effectiveness of error enhancement is quite strong. We encourage clinicians and patients to give adequate efforts to take advantage of this method of neurorecovery.

As the field of neurorehabilitation continues to evolve, error enhancement is likely to play an increasingly important role in the development of new therapeutic approaches. The integration of advanced technologies, such as artificial intelligence-driven movement prediction, robotic systems, and virtual reality, will further enhance the effectiveness of error enhancement techniques (Messaoui 2024). Future research is expected to focus on optimizing these technologies to create more personalized and adaptive rehabilitation protocols.

Challenges and Considerations

Despite the promising potential of error enhancement, there are several challenges and considerations that must be addressed. Bioxtreme does have the capabilities to personalize calibrations for each patient treated, but one of the main challenges is ensuring that the level of error enhancement is appropriately calibrated for each patient. Too much enhancement could lead to frustration or discouragement, while too little may not provide sufficient stimulus for neuroplasticity.

Another consideration is the need for robust clinical trials to validate the long-term effectiveness and safety of error enhancement techniques as a whole across diverse patient populations. While existing studies have shown positive outcomes, more research is needed to determine the optimal conditions for different types of neurological injuries and stages of recovery. This includes understanding the interplay between error enhancement and other therapeutic modalities, such as pharmacological treatments, physical therapy, and cognitive-behavioral interventions and where they all compliment one another throughout the course of a patients recovery

Conclusion

The role of error enhancement in neuromuscular re-education represents a significant advancement in rehabilitation technology. By intentionally enhancing motor errors, BioXtreme’s devices engage the body’s natural adaptive responses, leading to faster and more effective motor recovery. Moreover, this approach promotes long-term neuromuscular re-education and improved motor memory, providing patients with lasting benefits and greater independence in their daily lives.

BioXtreme's innovative use of error enhancement sets a new standard in neurological rehabilitation, offering hope and improved outcomes for millions of patients worldwide. As research and technology continue to advance, error enhancement is poised to become a cornerstone of rehabilitation practices, driving forward the future of neuromuscular re-education and empowering patients to reclaim their independence and quality of life.

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