Revolutionizing Physiotherapy with Haptic Simulation: A Pathway to Smarter Rehabilitation

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Abstract:

Background: Haptic technology has emerged as a crucial interface in various fields, enhancing user experience through tactile feedback. This study investigates the effectiveness of haptic feedback in improving task performance and user satisfaction in virtual environments.

Methodology: A literature search in PubMed and Google Scholar from 2014 to 2024 used keywords related to haptic simulation in physiotherapy. Inclusion criteria focused on English-language studies from the last decade involving randomized clinical trials or experimental designs using haptic interfaces, with full-text access. Exclusion criteria eliminated older studies, review articles, and those without free access. Out of 117 identified articles, 30 were shortlisted after abstract screening, and 12 were selected for final analysis.

Discussion: Haptic technologies in rehabilitation improve gait, strengthen patient ownership, and enhance recovery through virtual feedback and robotic systems. They also enhance movement, balance, and user experience in prosthetics, demonstrating significant therapeutic potential.

Conclusion: Haptic feedback enhances performance and user satisfaction in virtual environments, highlighting its potential in various applications. This suggests a need for further exploration of its use in education and professional settings. Future research should aim to optimize haptic feedback mechanisms to fully maximize user benefits.

Keywords: Haptic, Simulation, Scope, Physiotherapy, neurological, musculoskeletal

INTRODUCTION

The term "Haptic" originates from the Greek term "haptesthai," which signifies the sense of touch. Haptic technology, or haptics, encompasses tactile feedback mechanism that exploit the user's sense of touch through the application of forces, vibrations, and movements. The term 'haptics' pertains to the ability to perceive and manipulate objects using the sense of touch.[1]

Through haptic exploration, which involves active touch and tactile examination of an object, we can discern the overall geometric shape of a larger object. This perceptual process comprises six qualitative types of haptic exploration, each characterized by the activation of specific receptors and the integration of spatial and temporal information.[2]

Haptic devices possess the ability to detect the cumulative or reactive forces applied by the user, whereas touch or tactile sensors quantify the pressure or force exerted by the user onto the interface, highlighting a clear distinction between the two technologies.Haptic interfaces are classified into two main categories: force feedback and tactile feedback.[1]

The field of haptics is comprised of three distinct domains: human haptics, machine haptics, and computer haptics. Upon physical contact with an object, an operator's skin receives interaction forces, which are then conveyed to the brain via sensory systems, giving rise to haptic perception. This, in turn, prompts the brain to issue commands that stimulate muscle activity, culminating in hand or arm movements, thereby demonstrating the fundamental principle of the human haptic system. [3]

Notable instances of haptic technology encompass consumer peripherals integrated with advanced motors and sensory equipment, such as force feedback-enabled joysticks and steering wheels, enhancing the immersive experience. Advanced haptic technologies, such as PHANTOM devices, are engineered for specialised sectors, including industrial, medical, and scientific fields.[1]

Haptic technology has far-reaching applications in various fields, encompassing telemanipulators, exoskeletal devices, advanced prosthetic limbs, physical rehabilitation, intelligent assistance devices, and near-field robotics, all of which leverage haptic feedback to enhance their functionality and user experience.[3]

Typically, a haptics system includes:

1. Sensor(s)
2. Actuator (motor) control circuitry
3. One or more actuators that either vibrate or exert force.
4. Real-time algorithms (actuator control software, which we call a “player”) and a haptic effect library.
5. Application programming interface (API), and often a haptic effect authoring tool.
6. The Immersion API is used to program calls to the actuator into your product’s operating system (OS).[1]

The effectiveness and progress of haptic interfaces hinge on several key factors, including the type of feedback, the dexterity and manipulability of the end-effector, the fidelity of haptic stimulation, and the advancement of actuator technology.[3]

Phantom Device: This outfit is designed to learn the position of a stoner's fingertip and apply a precisely controlled force vector to it. The device's mileage extends to enabling stoner engagement with a wide range of virtual realities, furnishing a palpable experience. also, it's poised to play a pivotal part in the operation of remote manipulators.

Haptic Device: This manipulator is equipped with sensors, actuators, or a combination of both. Various haptic devices have been developed for specific purposes, with the most popular being tactile-based, pen-based, and 3-degree-of-freedom (DOF) force feedback devices.

Haptic Interface: This system comprises a haptic device and software-based computer control mechanisms. Through the haptic interface, users can not only input information to the computer but also receive feedback from the computer in the form of physical sensations on various parts of their body.

Haptic Rendering: Haptic rendering is the process of calculating the sense of touch, particularly force, by sampling position sensors in the haptic device to determine the user's position within the virtual environment. This system consists of three components: a collision detection algorithm, a collision response algorithm, and a control algorithm.[1]

Haptic feedback, also known as force feedback, enhances the fine-tuning of desired motor responses by providing tactile sensations that refine movement precision.[4]Haptic devices are widely used in virtual graphics environments to afford limited perception of mechanical properties such as force, vibration, and friction.[5]

Haptic feedback in physical therapy is more demanding since it needs to adapt to each patient’s functioning level and each therapy session. Furthermore, certain types of haptic feedback (such as vibrations) that adversely affect normal training can prove beneficial in physical therapy.[6]

Handheld devices such the Haptic Revolver (Whitmire et al., 2018) provide users with the experience of touch, shear forces and motion in the virtual environment by using an interchangeable actuated wheel underneath the fingertip that spins and moves up and down to render various haptic sensations.[7]

Rehabilitation robotics offers the possibility of new methods of physiotherapy in orthopaedics with patients with musculoskeletal injuries, such bone fractures.

Previous study suggests that a novel haptic-enhanced VR system featuring haptic simulation that was developed to facilitate the long-term poststroke recovery of upper- extremity motor function.[8]

And fewer studies shows that exercises based on motor skill learning involving haptic interaction is more effective than a simple sensorimotor control training in multiple sclerosis.[9]

So our objective of our study to evaluate the efficacy and scope of the haptics interface used in various conditions of Physiotherapy and also usability of the proposed system.

METHODOLOGY

SEARCH STRATEGY: The literature search is carried out from 2014 to 2024 in the following scientific databases: Pubmed, Google scholar

To carry out the searches in the scientific database, the keywords Haptic simulation, scope, Physiotherapy, neurological, musculoskeletal, conditions, physical therapy combining them using Boolean operators AND and OR in the different searches.

SELECTION CRITERIA: The following article inclusion criteria were established,

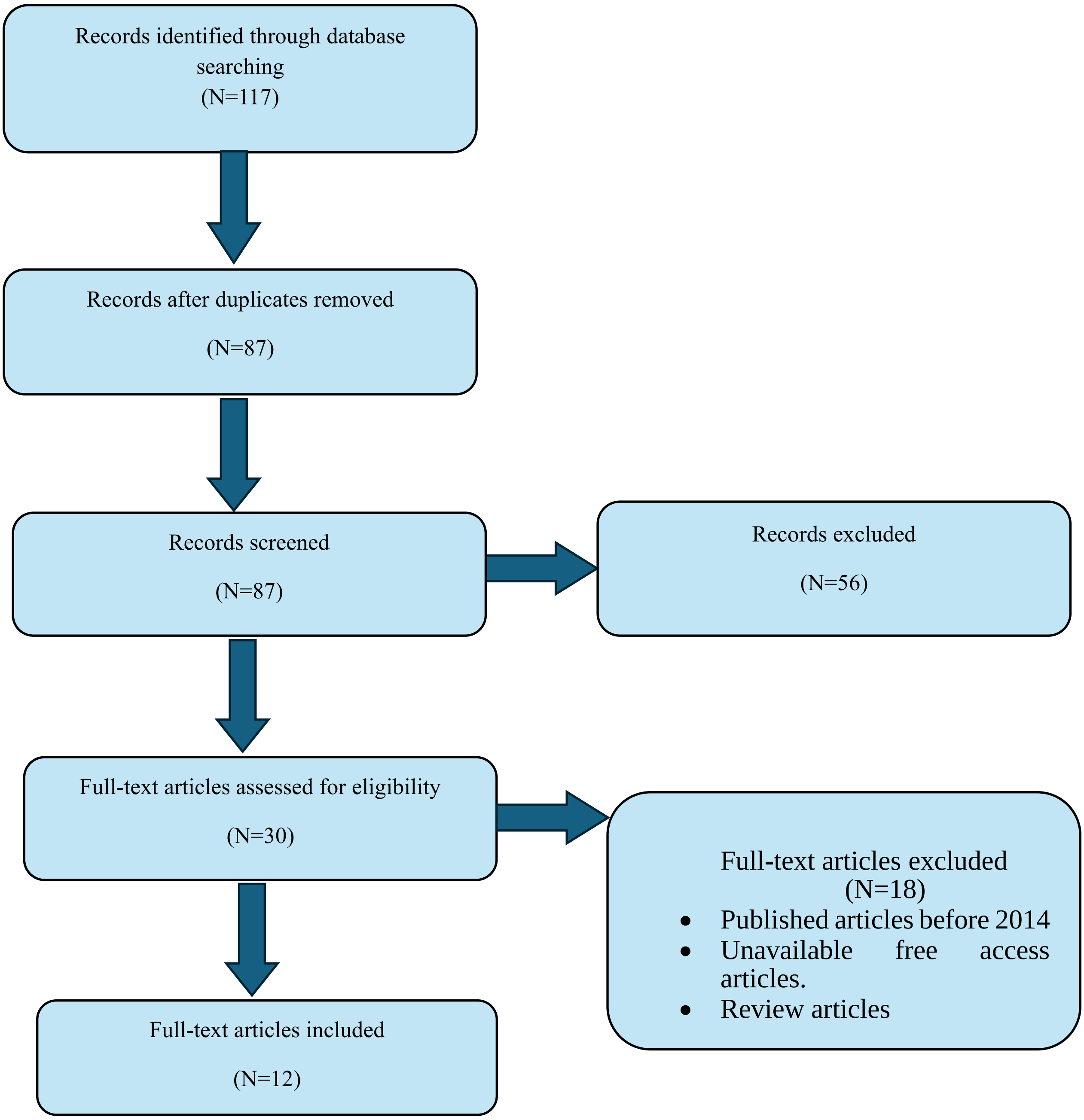
- Articles published in last 10 years (2014-2024)
- In English only
- Study design include Randomised clinical trail, experimental design, case study.
- Intervention carried out with haptic interface.
- Full text access articles were included.

The following are the exclusion criteria:

- Published articles before 2014
- Unavailable free access articles.
- Review articles

Study selection:

Identification- 117 articles
Evaluation by abstract reading- 30 articles
Revelant articles taken- 12 articles



CHARACTERISTICS OF THE INCLUDED STUDIES

SR. No.	Author/year	Sample size	Study location	Outcome measures	Intervention	Results
1.	Blouin,Lalumière, Gagnon et al. (2014)[10]	Eighteen long-term MWUs (16 men, 2 women) with	Montreal, Canada	PAR-Q (physical activity readiness questionnaire)	Pre-training, Training with haptic biofeedback:	M_{HB}, Mean power output increased with training blocks, 6

		spinalcord injury participated in this study. (Quasi-experimental study)		WUSPI(wheelchair user shoulder pain index) Scoring -3.9/1	(five 3 min block (rest 2 min b/w the blocks) 5 different biofeedback level were presented) visual feedback, Post training trail	subjects succeeded in changing their MEF pattern to follow the target pattern in both sides,4 in right side, 1 in left side.
2.	Afzal MR. Byun HY. Oh MK. et al (2015)[5]	A total of 16 subjects, 8 healthy and 8 recovering from stroke, participated in the present study. stroke patients ranged from 15–30, 2 have B/L hemiplegia, 3 right sided , 3 left side (Quasi-experimental study)	Rehabilitation Center of Gyeongsang Na- tional University Hospital (Jinju, Republic of Korea)	Mean Velocity Displacement (MVD), Planar Deviation (PD), Mediolateral Trajectory (MLT) and Anteroposterior Trajectory (APT)	Young healthy participants performed balance tasks after assumption of each of four distinct postures for 30 s (one foot on the ground; the Tandem Romberg stance; one foot on foam; and the Tandem Romberg stance on foam) with eyes closed. Patient eyes were not closed and assumption of the Romberg stance (only)	Kinesthetic haptic feedback signifi- cantly reduced (p-values <0.05) the MVD, PD, MLT, and APT parameters of body sway when any of the four pos- tures was assumed. All parameters showed that the body sway of stroke patients decreased when feedback was provided, and the MVD and PD

					was tested during a balance task 25 s in duration.	parameter exhibited significant values ($p < 0.05$ for both comparisons).
3.	Yeh SC. Lee SH. Chan R.C. et al (2017)[8]	Author recruited 16 participants with hemiparesis and motor impairment due to stroke. aged between 20 and 85 years. their proximal upper extremity on the more affected side was in Brunnstrom Stages II–VI. (Quasi-experimental study)	Taipei Veterans General Hospital, Taiwan,	Fugl-Meyer assessment (FMA), Wolf motor function test (WMFT), Test Evaluant les Membres superieurs des Personnes Agees (TEMPA), Box and Blocks test (BBT), handheld dynamometers (JAMAR)	Each VR training session involved practicing the two VR tasks, the pinch strengthening , and pinch-and-lift tasks. Each patient received 30 min VR training sessions 3 times per week for 8 weeks. (24 sessions)	Outcome measures, (FMA), (TEMPA), (WMFT), (BBT), and Jamar grip dynamometer, showed statistically significant progress from pretest to posttest and follow-up, indicating that the proposed system effectively promoted fine motor recovery of function.
4.	U. Sorrento, S. Archambault, Fung et al. (2018)[11]	A total of 13 healthy young adults (18–38 years old, 7 male and 6 female) (Quasi-experimental study)	Feil and Oberfeld CRIR Research Center of the Jewish Rehabilitation Hospital in Laval, Québec, Canada.	Instantaneous gait velocity, Stride length, Double limb support time	The paradigm was divided into three distinct gait epochs: pre-force, force, and post-force.	All 13 participants increased their instantaneous gait veloci-ties when walking with tension in the leash in the

					The pre-force epoch consisted of the participant walking with a slack leash (i.e. no tension) for 30 s. Participants walked with this force for 60 s. The force on the hand was then removed and participants continued to walk with a slack leash for another 30 s.	force epoch changes in 10 and 20 N paired samples T-test revealed significant changes in stride length between legs Indicating less time spent in double-limb support in either the 10 or 20 N conditions.
5.	Padilla-Castañeda, Sotgiu, Barsotti, Frisoli et al. (2018)[12]	Two healthy volunteers and ten patients (six males and four females) (Quasi-experimental)	USL 5 Rehabilitation Centre at Fornacette (Pisa), Italy	(i) the ranges of motion with extendable goniometers. (ii) the strength of the affected hand by the Jamar strength test. (iii) the pain sensation using the VAS pain test. (iv) Italian version of the DASH Questionnaire	30 minutes of exercising divided into three parts, with two pauses of 2 minutes for resting, for a total of 45 minutes per session (Bells(FE), balls(FE), Balloons(PS))	JAMAR score was found to be negatively correlated with mean executed ROM during games.vas (moderate negatively correlated) DASH score found positively correlated with FE

6.	Bortone I. , Leonardis D. , Mastronicola N. et al (2018)[13]	Twenty subjects were enrolled in the study and divided into three groups: i) CP/DD group, consisting of 8 motor-impaired children; age range: 7-14 yrs) affected with either CP (3 children) or DD (5 children), ii) TD group, consisting of 8 Typically Developing healthy children; 8 - 16 yrs) iii) AD group, consisting of 4 healthy ADults 24 - 32 yrs). (Quasi-experimental study)	Pisa, Italy	Kinesiological Assessment in real settings and with serious games (movement speed, movement accuracy)	Two motor tasks, the first involving grasp-to-reach and forearm pronation and supination, and the second involving linear path tracking on different directions with respect to the sagittal plane.	Obtained results reflected the different motor abilities of patients and participants, suggesting suitability of the proposed kinematic assessment as a motor function outcome.
7.	Vargas, Whitehouse, Huang, Zhu, Hu et al. (2019)[14]	seven neurologically intact subjects (6 Male, 1 Female, 20-35 years of age (within	Joint Department of Biomedical Engineering at University of North Carolina-	Single vs. Dual Stimulation. Comparison Variation in Stimulation Delay.	Multi-channel fully programmable stimulator was used to deliver the single and dual	The hand maps located on the left and right correspond to the evoked sensation during single

		subject design)	Chapel Hill and NC State University	Short-term Stability of Sensation.	electrical stimuli. A hand map MATLAB interface was used to record the location of sensation with a total of 108 hand regions. the subjects were asked to identify the locations of the sensation, and the sensation strength according to a three-point scale.	stimulation, while the center hand map shows the sensation during dual stimulations. The results indicated that the delay had minimal effect on the haptic perception for a given set of electrodes. with a moderate agreement in sensation magnitude and a substantial agreement in the sensation regions.
8.	Georgiou, Islam, Holland, Linden, Price, Mulholland, Perry et al. (2020)[15]	1 female participant (case study)	PJ Care residential care home in the United Kingdom	Temporal gait parameters: stride cycle time for both legs in the base line, with-cue and after-cue conditions	Prebaseline: subject asked to walk the length of 10-meter runway six time without wearing bracelet. Baseline: with bracelet switched off. With-cue: with bracelet switch on	Due to RHC, the time taken to complete a stride was reduced for both legs. This further supports the observations of the physiotherapists that RHC has changed gait pattern, and

					After-cue: subject walk rhythm to memory	she has been able to retain the changes from memory.
9.	Vargas, Shin, Huang et al. (2020)[16]	Ten neurologically intact subjects (seven males, three females, 20–35 years of age) (within subjects design)	University of North Carolina at Chapel Hill, US	Single vs. Dual Stimulation Comparison Variations in stimulation delay	The grid was placed parallel to the vector that connects the medial epicondyle of the humerus and the center of the axilla. Ordering of 2 objects.(18 trails) Ordering of 3 objects. (12 trails) Identification of random object (24 trails)	The majority of sensation regions remained unchanged during dual stimulation when compared with the single stimulations. Delay had minimal effect on the haptic perception for a given set of electrodes.
10.	Salaro C. Cattaneo D. Basteris A. et al (Feb 2020)[9]	41 patients were participated in this study.Patients randomly assigned to either robot-based haptic training or purely sensorimotor group (Randomised Controlled Trail)	Neurology Unit Dept Head and Neck Genova and Don Gnocchi foundation, Milan.	9HPT and Action Research Arm Test (ARAT) to assess arm/ hand dexterity and functio	Two groups were trained with two planar robotic manipulandums with haptic simulation and sensorimotor rehabilitation (every epoch – 24 movements (4 rep for each 6 possible direction ,1 session – 45 min , total –	9HPT, Overall effect was significant more in haptic group than the sensorimotor group. ARAT score was more significant in haptic group than sensorimotor (Effect of exercise is

					8sessions (2session per week in non – consecutive days	only significant in pyramidal grou
11.	K. Shell, E. Pena, J. Abbas et al (June 2022)[7] .	Seven right-handed adult study participants (five males, two females) (Within subjects design)	Florida international university (FIU)	SD profile, ACR model (calculate equivalent ACR)	Seven study participants received haptic feedback delivered via multi-channel transcutaneous electrical stimulation of the median nerve at the wrist to receive the haptic feedback. xTouch delivered different percept intensity profiles designed to emulate grasp forces during manipulation of objects of different sizes and compliance.	The results of a virtual object classification task showed that the participants were able to use the active haptic feedback to discriminate the size and compliance of six virtual objects with success rates significantly better than the chance of guessing it correctly
12.	Altukhaim, George, Nagaratnam, Kondo, Hayashi et al. (2024)	Twenty-three healthy participants (seven men and 16 women), of which 21 were right-handed	In Tokyo, Japan	Utilization of reaction time (RT) was measured in response to a sense of threat	Two sessions: 1.Training session: Inphase condition and anti phase condition.	The median RTs were consistently low under anti-phase condition in 20 out of 23 participants,

		(Experimental study)			2.Evaluation session: Inphase condition and anti phase condition	whereas the median RTs of three (participants 1, 7 and 18) were consistently high under in-phas condition

DISCUSSION

The use of haptic feedback is a promising approach in rehabilitation for a range of conditions that affect motor function, including stroke, multiple sclerosis, and other neuromotor impairments. The incorporation of haptic feedback into virtual reality, robotic-assisted therapy, and wearable devices has led to new and effective methods for improving motor learning, proprioception (body awareness), and the regaining of lost functions.

Studies indicate that kinesthetic haptic feedback enhances standing stability and locomotion, with improvements in balance and postural control, highlighting its potential for fall prevention and neuromuscular rehabilitation. Investigating how haptic forces affect walking adaptation reveals that haptic cues can modify walking patterns, offering a potential benefit for gait retraining in neurological conditions. This supports existing research that external sensory feedback can promote neuroplasticity and motor learning by reinforcing correct movement patterns.

The potential of haptic biofeedback in upper limb rehabilitation has been the subject of several studies, particularly in the context of stroke recovery and neurodegenerative diseases. The results of these studies indicate that the integration of haptic cues within virtual reality environments can lead to improvements in both grasping accuracy and overall hand function. Studies of robotic-assisted forearm rehabilitation in virtual reality have shown that incorporating haptics leads to better motor recovery, providing evidence for the effectiveness of multisensory rehabilitation approaches.

Compelling evidence from study table suggests that haptic-based interventions can be as effective, or even more effective, than traditional rehabilitation approaches. By providing accurate proprioceptive feedback, haptics can address sensory deficits and lead to greater functional improvements. Studies exploring the use of wearable haptics in immersive virtual reality rehabilitation programs for children with neuromotor impairments have revealed increased engagement and improvements in motor learning, suggesting that haptic technology holds significant potential for pediatric rehabilitation.

In addition to rehabilitation, haptic feedback is being investigated for its potential in perceptual training and enhancing the connection between cognitive processes and motor skills. Research highlights progress in artificial somatosensory feedback, which may lead to better prosthetic control, sensory re-education, and virtual interaction. A separate study explores how haptic rhythms might be used for movement coordination and timing rehabilitation, potentially helping patients with movement disorders.

One of the most significant advantages of haptic feedback is its capacity to improve the user's sense of embodiment and facilitate better integration of sensory information. Research has indicated that providing multiple forms of sensory feedback can strengthen the brain's internal representation of the body, which in turn leads to greater patient engagement and improved outcomes in rehabilitation programs. This finding holds particular significance for virtual rehabilitation approaches, where the combination of immersive virtual environments and haptic cues has the potential to optimize both motor learning processes and overall recovery.

Our review concluded that the integrated haptic feedback into rehabilitation has shown promising results for gait, upper limb, and neurological rehabilitation, as well as sensory re-education and virtual immersion. By enhancing proprioception, motor control, and patient engagement, haptic technology offers a powerful tool for modern rehabilitation. Continued research and development of wearable, non-invasive, and intelligent haptic systems will be crucial for advancing personalized and effective interventions.

Although research strongly supports the use of haptic feedback in rehabilitation, some obstacles must be overcome. To make haptic feedback a standard part of clinical practice, we need consistent treatment methods, more information about its long-term effects, and easier access to the necessary devices. Furthermore, tailoring the feedback to a patient's real-time physiological responses could lead to even better results. Future research should explore the synergistic potential of haptic feedback and other neuromodulation techniques, including brain-computer interfaces, functional electrical stimulation, and adaptive AI-driven haptic systems, to develop advanced and responsive rehabilitation platforms.

REFERENCES

1. Jyothi BD, Krishnaiah RV. Haptic technology-a sense of touch. International Journal of Science and Research. 2013 Sep;2(9):381-4.
2. Steven M.LaValle Virtual Reality book
3. Giri GS, Maddahi Y, Zareinia K. An application-based review of haptics technology. Robotics. 2021 Feb 5;10(1):29.
4. Goyal C, Vardhan V, Naqvi W, Arora S. Effect of virtual reality and haptic feedback on upper extremity function and functional independence in children with hemiplegic cerebral palsy: a research protocol. Pan African Medical Journal. 2022 Feb 22;41(1).
5. Afzal MR, Byun HY, Oh MK, Yoon J. Effects of kinesthetic haptic feedback on standing stability of young healthy subjects and stroke patients. Journal of neuroengineering and rehabilitation. 2015 Dec;12:1-1.
6. Burdea G. The role of haptics in physical rehabilitation. Haptic Rendering. 2008 May:517-29.
7. Shell AK, Pena AE, Abbas JJ, Jung R. Novel neurostimulation-based haptic feedback platform for grasp interactions with virtual objects. Frontiers in Virtual Reality. 2022 Jun 3;3:910379.
8. Yeh SC, Lee SH, Chan RC, Wu Y, Zheng LR, Flynn S. The Efficacy of a Haptic-Enhanced Virtual Reality System for Precision Grasp Acquisition in Stroke Rehabilitation. Journal of healthcare engineering. 2017;2017(1):9840273.
9. Solaro C, Cattaneo D, Basteris A, Carpinella I, De Luca A, Mueller M, Bertoni R, Ferrarin M, Sanguineti V. Haptic vs sensorimotor training in the treatment of upper limb dysfunction in multiple sclerosis: a multi-center, randomised controlled trial. Journal of the neurological sciences. 2020 May 15;412:116743.
10. Blouin M, Lalumière M, Gagnon DH, Chénier F, Aissaoui R. Characterization of the immediate effect of a training session on a manual wheelchair simulator with Haptic biofeedback: Towards more effective propulsion. IEEE Transactions on Neural Systems and Rehabilitation Engineering. 2014 Jul 2;23(1):104-15.

11. Sorrento GU, Archambault PS, Fung J. Adaptation and post-adaptation effects of haptic forces on locomotion in healthy young adults. Journal of neuroengineering and rehabilitation. 2018 Dec;15:1-1
12. Padilla-Castañeda MA, Sotgiu E, Barsotti M, Frisoli A, Orsini P, Martiradonna A, Laddaga C, Bergamasco M. An Orthopaedic Robotic-Assisted Rehabilitation Method of the Forearm in Virtual Reality Physiotherapy. Journal of healthcare engineering. 2018;2018(1):7438609.
13. Bortone I, Leonardis D, Mastronicola N, Crecchi A, Bonfiglio L, Procopio C, Solazzi M, Frisoli A. Wearable haptics and immersive virtual reality rehabilitation training in children with neuromotor impairments. IEEE Transactions on Neural Systems and Rehabilitation Engineering. 2018 Jun 13;26(7):1469-78.
14. Vargas L, Whitehouse G, Huang H, Zhu Y, Hu X. Evoked haptic sensation in the hand with concurrent non-invasive nerve stimulation. IEEE Transactions on Biomedical Engineering. 2019 Jan 27;66(10):2761-7.
15. Georgiou T, Islam R, Holland S, Van Der Linden J, Price B, Mulholland P, Perry A. Rhythmic haptic cueing using wearable devices as physiotherapy for huntington disease: Case study. JMIR Rehabilitation and Assistive Technologies. 2020 Sep 14;7(2):e18589.
16. Vargas L, Shin H, Huang HH, Zhu Y, Hu X. Object stiffness recognition using haptic feedback delivered through transcutaneous proximal nerve stimulation. Journal of neural engineering. 2019Dec 5;17(1):016002.
17. Altukhaim S, George D, Nagaratnam K, Kondo T, Hayashi Y. Enhancement of sense of ownership using virtual and haptic feedback. Scientific Reports. 2024 Mar 1;14(1):5140.