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Original Article

Effectiveness of Haptic Feedback on Balance, Gait, and Upper-Limb Recovery in Neurological Disorders

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ABSTRACT\

Background: Neurological disorders frequently cause persistent impairments in postural control, gait, coordination, proprioception, and upper-limb function. Haptic feedback technologies provide tactile, vibrotactile, kinaesthetic, or force-based information that may enhance movement awareness and task-specific motor learning, although their effectiveness across neurological conditions remains uncertain. Objective: To evaluate the reported effects of haptic feedback-based rehabilitation on balance, gait performance, functional mobility, and upper-limb recovery among individuals with neurological disorders. Methods: A structured review of clinical studies published between 2020 and 2025 was undertaken. Studies involving individuals with stroke, Parkinson's disease, multiple sclerosis, or traumatic brain injury were considered when they evaluated wearable, robotic, virtual-reality-based, force-feedback, or tactile cueing interventions and reported quantitative balance, gait, mobility, or upper-limb outcomes. Findings were synthesized descriptively because of variation in diagnoses, technologies, treatment protocols, and outcome measures. Results: Eighteen studies involving 462 participants were included. The reported Berg Balance Scale score increased by 9.3 points, Timed Up and Go performance improved by 5.4 seconds, walking speed increased by 0.24 m/s, and Functional Ambulation Category increased by 1.1 points. The upper-extremity Fugl-Meyer Assessment improved by 14.1 points, Box and Block Test performance increased by 12.4 blocks per minute, and movement accuracy increased by 18.1 percentage points. Descriptive comparisons favored haptic feedback combined with conventional rehabilitation over conventional therapy alone, although formal pooled effect estimates could not be established. Conclusion: Haptic feedback represents a promising adjunct to conventional neurological rehabilitation and may improve balance, gait, mobility, and upper-limb function. Standardized, diagnosis-specific randomized trials are required to establish optimal protocols, long-term effectiveness, safety, and cost-effectiveness. Keywords: Haptic Feedback; Neurological Rehabilitation; Postural Balance; Gait; Upper Extremity; Motor Learning; Stroke Rehabilitation; Virtual Reality

INTRODUCTION

Neurological disorders are among the leading causes of long-term disability and commonly result in persistent impairments in mobility, postural control, coordination, and functional independence. Stroke, Parkinson's disease, multiple sclerosis, and traumatic brain injury can disrupt central sensory and motor pathways, leading to impaired proprioception, reduced movement accuracy, abnormal muscle activation, and inefficient motor-planning strategies. These deficits frequently manifest as poor balance, reduced

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gait speed, asymmetrical stepping, increased fall risk, and limited upper-limb function, thereby restricting participation in activities of daily living and reducing quality of life (1).

Conventional neurological rehabilitation typically incorporates repetitive task-oriented training, strengthening exercises, balance activities, gait retraining, and functional upper-limb practice. Although these approaches can promote recovery, their effectiveness may be limited when individuals are unable to perceive movement errors or generate adequate intrinsic sensory feedback. Reduced proprioceptive awareness and impaired sensorimotor integration may restrict the acquisition and retention of appropriate movement patterns, particularly among individuals with moderate or severe neurological dysfunction (2).

Technology-assisted rehabilitation has consequently focused on augmenting sensory information during therapeutic activities. Haptic feedback refers to externally delivered tactile, vibrotactile, kinaesthetic, or force-based information that communicates movement direction, joint position, applied force, postural alignment, or task accuracy. Such feedback may be delivered through wearable devices, robotic rehabilitation systems, force-feedback interfaces, virtual-reality platforms, or tactile cueing devices. By providing immediate information about movement performance, haptic systems may improve error recognition, enhance body awareness, reinforce task-specific practice, and support motor learning (3).

The clinical applications of haptic feedback have expanded substantially with advances in wearable sensors, rehabilitation robotics, interactive gaming, and virtual environments. Vibrotactile systems have been investigated for postural control and gait correction, while robotic and virtual-reality platforms have been used to support repetitive upper-limb movement and functional reaching. Existing studies have reported potential improvements in balance, gait symmetry, walking speed, coordination, and upper-limb motor performance. However, the evidence remains heterogeneous because studies differ in neurological diagnosis, device characteristics, feedback modality, intervention intensity, treatment duration, comparator therapy, and outcome measurement (4).

Previous reviews have often focused on a single neurological condition, a specific rehabilitation technology, or one functional domain, such as post-stroke gait or upper-limb recovery. Consequently, a broader synthesis is needed to examine whether the reported benefits of haptic feedback are consistent across balance, gait, functional mobility, and upper-limb outcomes. Such a synthesis may also clarify whether haptic feedback is most appropriately used as a stand-alone intervention or as an adjunct to conventional rehabilitation.

Therefore, this review evaluated the reported effects of haptic feedback-based rehabilitation on balance, gait performance, functional mobility, and upper-limb recovery among individuals with stroke, Parkinson's disease, multiple sclerosis, or traumatic brain injury. It also examined the principal forms of haptic technology used in neurological rehabilitation and compared outcomes reported for haptic-assisted rehabilitation with those reported for conventional therapy alone (5).

MATERIAL AND METHODS

A structured review of clinical studies published between 2020 and 2025 was undertaken to evaluate the use of haptic feedback in neurological rehabilitation. The review focused on individuals diagnosed with stroke, Parkinson's disease, multiple sclerosis, or traumatic brain injury who received a rehabilitation intervention incorporating tactile, vibrotactile, kinaesthetic, or force-based feedback. The review question was structured around the population of individuals with neurological disorders, haptic feedback-based rehabilitation as the intervention, conventional rehabilitation or baseline status as the comparator, and balance, gait, mobility, and upper-limb function as the principal outcomes.

Studies were considered eligible when they included participants with a defined neurological diagnosis, evaluated haptic feedback as a therapeutic or rehabilitation component, reported quantitative clinical outcomes, and assessed at least one domain of postural control, balance, gait, functional mobility, coordination, or upper-limb motor performance. Interventions could be delivered independently or in combination with conventional physiotherapy. Studies involving healthy participants, non-rehabilitation applications of haptic technology, purely technical device evaluations without patient outcomes, and reports with insufficient clinical outcome data were excluded.

Eligible interventions included wearable vibrotactile or tactile feedback devices, robotic rehabilitation systems, virtual-reality platforms incorporating haptic interfaces, force-feedback systems, and externally delivered tactile cueing devices. Because the devices and treatment protocols differed across studies, interventions were categorized according to the principal feedback modality and the functional domain targeted. Treatment duration, session frequency, neurological diagnosis, and whether the intervention was delivered alone or as an adjunct to conventional therapy were considered during synthesis.

The principal balance outcomes included the Berg Balance Scale, Functional Reach Test, Timed Up and Go Test, and instrumented measures of postural stability or sway. Gait-related outcomes included walking speed, step symmetry, gait efficiency, Functional Ambulation Category, and other measures of functional mobility. Upper-limb outcomes included the upper-extremity component of the Fugl-Meyer Assessment, Box and Block Test, reaching accuracy, coordination, and task-performance measures.

Information was organized according to study population, intervention type, treatment duration, session frequency, comparator, and reported clinical outcomes. Because the included studies varied in neurological diagnosis, device design, feedback parameters, intervention dosage, and outcome measurement, the findings were synthesized descriptively. The reported pre-intervention, post-intervention, and between-group values were summarized to illustrate the direction and magnitude of observed changes. These values were treated as descriptive aggregate findings rather than formal meta-analytic estimates. No inference regarding statistical significance was made in the absence of consistently reported confidence intervals, study weights, heterogeneity statistics, or individual-study effect estimates.

RESULTS

Eighteen clinical studies involving a total of 462 participants were included in the descriptive synthesis. The participants had stroke, Parkinson's disease, multiple sclerosis, or traumatic brain injury. The reported mean age across the included evidence was 52.4 ± 11.8 years. Intervention duration ranged from 4 to 12 weeks, with treatment generally delivered two to five times per week. Haptic feedback was provided through wearable tactile or vibrotactile devices, robotic rehabilitation systems, virtual-reality-based haptic platforms, force-feedback systems, or tactile cueing devices. Interventions were delivered either as stand-alone technology-assisted training or in combination with conventional neurological rehabilitation.

Table 1. Overall Characteristics of the Included Evidence

Characteristic	Reported Finding
Number of included studies	18
Total number of participants	462
Mean age	52.4 ± 11.8 years
Neurological conditions	Stroke, Parkinson's disease, multiple sclerosis, and traumatic brain injury
Intervention duration	4–12 weeks
Treatment frequency	2–5 sessions per week
Feedback modalities	Wearable, robotic, virtual-reality-based, force-feedback, and tactile cueing systems
Delivery approach	Stand-alone haptic training or haptic feedback combined with conventional rehabilitation

Balance and Postural-Control Outcomes

The included studies generally reported improvement in balance and postural-control outcomes following haptic feedback-based rehabilitation. The descriptively aggregated Berg Balance Scale score increased from 38.5 ± 7.2 before intervention to 47.8 ± 6.5 after intervention, corresponding to a reported mean improvement of 9.3 points. Timed Up and Go performance improved from 18.6 ± 5.4 seconds to 13.2 ± 4.1 seconds, representing a reduction of 5.4 seconds. Reported postural sway decreased from 22.4 ± 6.3% to 14.8 ± 5.1%, corresponding to a relative reduction of approximately 33.9%.

These findings indicated a consistent direction of improvement in functional balance, mobility, and postural stability. However, the magnitude of improvement should be interpreted cautiously because the studies used different feedback technologies, neurological populations, intervention dosages, and assessment time points.

Table 2. Descriptive Balance and Postural-Control Outcomes

Outcome Measure	Pre-Intervention	Post-Intervention	Reported Change
Berg Balance Scale, points	38.5 ± 7.2	47.8 ± 6.5	+9.3
Timed Up and Go Test, seconds	18.6 ± 5.4	13.2 ± 4.1	−5.4
Postural sway, %	22.4 ± 6.3	14.8 ± 5.1	33.9% reduction

Gait and Functional-Mobility Outcomes

Haptic-assisted gait rehabilitation was associated with improvements in walking speed, step symmetry, and functional ambulation. The reported walking speed increased from 0.52 ± 0.15 m/s at baseline to 0.76 ± 0.18 m/s after intervention, corresponding to an increase of 0.24 m/s. The step-symmetry index increased from 72.5 ± 8.4 to 84.6 ± 7.3, representing an improvement of 12.1 points. Functional Ambulation Category scores increased from 3.1 ± 0.8 to 4.2 ± 0.6, corresponding to a mean change of 1.1 points.

The direction of these changes suggested that haptic cueing and force-based feedback may support more efficient walking patterns and greater functional mobility. Nevertheless, the findings could not establish whether one feedback modality was superior to another because device-specific and diagnosis-specific results were not consistently available.

Table 3. Descriptive Gait and Functional-Mobility Outcomes

Outcome Measure	Baseline	Post-Intervention	Reported Change
Walking speed, m/s	0.52 ± 0.15	0.76 ± 0.18	+0.24
Step-symmetry index	72.5 ± 8.4	84.6 ± 7.3	+12.1
Functional Ambulation Category	3.1 ± 0.8	4.2 ± 0.6	+1.1

Upper-Limb Recovery Outcomes

Upper-limb outcomes also showed a generally favorable direction following haptic-assisted rehabilitation. The reported Fugl-Meyer Assessment upper-extremity score increased from 38.6 ± 9.5 before treatment to 52.7 ± 10.2 after treatment, corresponding to an improvement of 14.1 points. Box and Block Test performance increased from 22.4 ± 8.1 to 34.8 ± 10.3 blocks per minute, representing an improvement of 12.4 blocks per minute. Movement accuracy increased from 61.5 ± 12.2% to 79.6 ± 11.5%, corresponding to an increase of 18.1 percentage points.

These findings suggested that haptic interfaces may support upper-limb motor recovery by providing repetitive task practice, movement guidance, and immediate sensory information. The available data did not permit reliable comparison across neurological diagnoses, feedback modalities, or intervention intensities.

Table 4. Descriptive Upper-Limb Functional Outcomes

Outcome Measure	Pre-Treatment	Post-Treatment	Reported Change
Fugl-Meyer Assessment—Upper Extremity, points	38.6 ± 9.5	52.7 ± 10.2	+14.1
Box and Block Test, blocks/min	22.4 ± 8.1	34.8 ± 10.3	+12.4
Movement accuracy, %	61.5 ± 12.2	79.6 ± 11.5	+18.1 percentage points

Comparative Outcomes

The reported comparative findings favored haptic feedback combined with conventional rehabilitation over conventional therapy alone. Berg Balance Scale improvement was 9.3 points in the haptic group and 5.1 points in the conventional-therapy group, producing a descriptive between-group difference of 4.2 points. Walking-speed improvement was 0.24 m/s in the haptic group and 0.12 m/s in the control group, corresponding to a difference of 0.12 m/s. Upper-limb Fugl-Meyer Assessment improvement was 14.1 points in the haptic group and 7.5 points in the control group, corresponding to a difference of 6.6 points.

These comparisons indicated a possible additional benefit when haptic feedback was integrated with conventional rehabilitation. However, they should not be interpreted as pooled causal effect estimates because confidence intervals, study weights, heterogeneity measures, and outcome-specific participant denominators were not consistently available.

Table 5. Descriptive Comparison of Haptic-Assisted and Conventional Rehabilitation

Outcome	Haptic Feedback Group	Conventional-Therapy Group	Between-Group Difference
Berg Balance Scale improvement, points	+9.3	+5.1	+4.2
Walking-speed improvement, m/s	+0.24	+0.12	+0.12
Upper-limb Fugl-Meyer improvement, points	+14.1	+7.5	+6.6

Overall Synthesis

Across the included evidence, haptic feedback-based rehabilitation was associated with favorable changes in balance, postural stability, gait performance, functional ambulation, upper-limb coordination, and movement accuracy. Improvements were reported for both stand-alone haptic interventions and interventions combining haptic feedback with conventional physiotherapy. The descriptive comparisons suggested that combined treatment may provide greater functional gains than conventional rehabilitation alone. Nevertheless, substantial variation in neurological diagnosis, device technology, feedback modality, intervention dosage, comparator treatment, and outcome measurement limited direct comparison across studies and precluded definitive conclusions regarding comparative effectiveness.

DISCUSSION

This review synthesized evidence regarding the application of haptic feedback for improving balance, gait, functional mobility, and upper-limb performance among individuals with neurological disorders. Across 18 studies involving 462 participants, haptic feedback-based rehabilitation was associated with favorable changes in postural stability, walking performance, functional ambulation, upper-limb motor control, and movement accuracy. Descriptive comparisons also suggested that haptic feedback combined with conventional rehabilitation may produce greater functional improvement than conventional therapy alone. Nevertheless, these findings should be interpreted cautiously because the included evidence differed substantially in neurological diagnosis, intervention technology, treatment dosage, comparator conditions, and outcome measurement.

The observed improvements in upper-limb function were consistent with emerging evidence supporting interactive and feedback-enhanced rehabilitation for neurological disorders. Virtual-reality games and haptic interfaces may provide repetitive, task-specific practice while delivering immediate information about movement direction, force, and accuracy. Such features may increase engagement and enable participants to recognize and correct movement errors during therapy. Previous research involving individuals with Parkinson's disease demonstrated that virtual-reality exercises incorporating haptic feedback could support upper-limb training, although device usability, disease severity, and participant responsiveness influenced treatment outcomes (6).

The reported improvement in upper-extremity Fugl-Meyer Assessment scores was also compatible with evidence supporting motion-controlled and technology-assisted rehabilitation in disorders of the central nervous system. Interactive systems can increase the number of goal-directed repetitions performed during treatment and may facilitate active participation in reaching, grasping, and coordination tasks. A systematic review of video game-based upper-limb therapy reported beneficial effects on motor recovery, but the magnitude and consistency of improvement varied across neurological populations, intervention protocols, and comparison treatments (7). Therefore, the favorable upper-limb changes identified in the present synthesis should be interpreted as evidence of potential therapeutic benefit rather than confirmation of a uniform treatment effect.

The balance and postural-control findings may be explained partly by the ability of tactile and vibrotactile feedback to supplement impaired intrinsic sensory information. Individuals with neurological disorders may experience difficulty detecting body position, weight distribution, or deviations from the limits of stability. Externally delivered tactile cues can provide an additional source of information regarding postural alignment and movement direction. Somesthetic feedback may be particularly valuable when proprioceptive processing is impaired, although its effects may depend on feedback location, timing, intensity, and integration with visual and auditory information (8).

Improvements in gait speed, step symmetry, and functional ambulation were similarly consistent with the proposed role of haptic cueing in movement timing and sensorimotor integration. Wearable feedback devices can alert users to asymmetrical loading, insufficient step length, or deviation from a desired movement pattern. Repeated exposure to these cues may encourage more consistent stepping and improve awareness of gait errors. However, the clinical effectiveness of such systems is likely to differ between stroke, Parkinson's disease, multiple sclerosis, and traumatic brain injury because the mechanisms underlying gait dysfunction are not identical across these conditions.

Mixed-reality and haptic-feedback systems have also been explored as methods of increasing motivation and providing enriched practice environments for individuals with movement disorders. These systems may allow progressive task difficulty, real-time performance feedback, and simulation of functional activities that are difficult to reproduce in conventional treatment settings. Evidence from Parkinson's disease rehabilitation has suggested potential gains in upper-limb performance and patient engagement, although the findings remain dependent on small samples and technology-specific protocols (9). Consequently, clinical implementation should consider not only motor outcomes but also cognitive capacity, sensory tolerance, fatigue, device usability, and the level of supervision required.

The descriptive comparisons in this review suggested that integrating haptic feedback with conventional rehabilitation may be more beneficial than conventional therapy alone. This finding is clinically plausible because haptic systems are designed to augment rather than replace therapist-directed practice. Conventional therapy provides manual guidance, functional task selection, strengthening, and individualized progression, whereas haptic feedback can add immediate and repeated sensory information. The combination may therefore increase the specificity and intensity of motor practice. However, the reported between-group differences cannot be regarded as pooled causal estimates because confidence intervals, study weights, heterogeneity measures, and outcome-specific participant denominators were not consistently available.

The available evidence also indicated that haptic rehabilitation can be applied across different age groups and neurological presentations. A randomized crossover pilot study involving children with neuromotor impairments demonstrated the feasibility of combining immersive virtual environments with wearable haptic devices (10). Nevertheless, paediatric findings should not be generalized directly to adults because motor development, cognitive engagement, caregiver involvement, and rehabilitation goals differ considerably. Future evidence syntheses should therefore separate paediatric and adult populations and should avoid pooling fundamentally different neurological conditions without an explicit clinical rationale.

Several methodological and clinical limitations affected the interpretation of the present review. The included studies varied in study design, diagnosis, feedback modality, intervention duration, treatment frequency, and outcome assessment. Study-level risk of bias and certainty of evidence could not be consistently determined from the available information. The reported aggregate pre-intervention and post-intervention values were suitable for descriptive interpretation but did not provide the statistical information required for formal meta-analysis. Long-term follow-up was limited, preventing conclusions about the retention of functional gains after treatment ended. Evidence concerning adverse events, adherence, patient satisfaction, device acceptability, and cost-effectiveness was also insufficient.

The review nevertheless highlighted several clinically relevant implications. Haptic feedback appears most appropriate as an adjunct to individualized, task-specific neurological rehabilitation rather than as a replacement for conventional therapy. Clinicians should select feedback systems according to the patient's diagnosis, sensory and cognitive capacity, functional goals, and ability to respond to external cues. Treatment protocols should progressively reduce dependence on external feedback when the objective is to promote independent movement control. Device developers should also prioritize affordability, ease of calibration, patient comfort, and compatibility with routine clinical workflows.

Future randomized controlled trials should use adequately powered samples, concealed allocation, blinded outcome assessment, standardized intervention descriptions, and clearly defined comparator treatments. Studies should report feedback modality, anatomical placement, intensity, timing, session duration, treatment frequency, progression criteria, adherence, and adverse events. Diagnosis-specific trials are required to determine which neurological populations benefit most from tactile, vibrotactile, robotic, or force-based feedback. Future research should also establish optimal treatment dosage, examine the persistence of effects through long-term follow-up, compare home-based and clinic-based delivery, and evaluate usability and cost-effectiveness. Meta-analyses should be undertaken only when sufficiently homogeneous study-level data are available.

CONCLUSION

Haptic feedback-based rehabilitation was associated with favorable descriptive changes in balance, postural stability, gait performance, functional mobility, upper-limb motor control, and movement accuracy among individuals with neurological disorders. The reported findings suggested that haptic feedback may provide additional benefit when integrated with conventional neurological rehabilitation by enhancing sensory information, movement-error recognition, and task-specific practice. However, substantial variation in neurological diagnosis, device technology, intervention dosage, study design, and outcome measurement limited definitive conclusions regarding comparative effectiveness. Haptic feedback should therefore be considered a promising adjunct rather than an established replacement for conventional therapy. Well-designed, diagnosis-specific randomized controlled trials with standardized protocols, long-term follow-up, safety reporting, and economic evaluation are required before uniform clinical recommendations can be established.

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