REVIEW ARTICLE

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# Evaluation of Rehabilitation Interventions for Fine Motor Skill Acquisition among Patients with Parkinson's Disease: A Systematic Review with Meta-Analysis

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## ABSTRACT

***Background:*** Fine motor impairments in Parkinson's disease (PD) often make everyday tasks difficult. While pharmacologic treatment helps reduce general motor symptoms, targeted rehabilitation strategies are essential for improving upper-limb dexterity and functional independence.

***Objective:*** This systematic review and meta-analysis aim to evaluate the effectiveness of rehabilitation interventions designed to enhance fine motor skills in people with PD (PwPD), addressing gaps in the literature by focusing exclusively on upper-limb outcomes.

***Methods:*** Following PRISMA 2020 guidelines, a comprehensive search across five databases identified 55 eligible studies, including randomized controlled trials (RCTs) and non-randomized studies. Data extraction followed the PICOS framework. Risk of bias was assessed using RoB 2.0 and ROBINS-I tools, and the Physiotherapy Evidence Database (PEDro) scale. Meta-analyses were conducted using a random-effects model, and heterogeneity was explored through subgroup analysis.

***Results:*** Interventions included aerobic training, dexterity-based exercises, virtual reality, telerehabilitation, and LSVT-BIG. While individual studies showed positive trends, pooled meta-analyses of aerobic exercise, telerehabilitation, and dexterity training revealed non-significant effects due to substantial heterogeneity ($I^2 > 75\%$). Studies lacked long-term follow-up, and variability in protocols and outcome measures limited the ability to draw definitive conclusions.

***Conclusion:*** Rehabilitation approaches hold potential to enhance fine motor skills in PwPD, particularly through task-specific training and technology-assisted methods. However, the current evidence base is hindered by methodological inconsistencies and limited statistical significance. High-quality, longitudinal trials with standardized outcome measures are needed. The promising but underexplored use of weighted gloves for tremor control warrants future investigation.

***Keywords:*** Parkinson's disease, fine motor skills, upper limb rehabilitation, dexterity, telerehabilitation, systematic review, meta-analysis.

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## INTRODUCTION

Parkinson's disease (PD) is one of the most prevalent neurodegenerative disorders, affecting an estimated 6.2 million people worldwide—a number projected to double by 2040 due to global population aging [1]. The prevalence of PD rises sharply with age, affecting about 1% of individuals over 60 years, with men being more frequently affected than women. In comparison, a hereditary component is observed in 5–10% of cases [2].

The clinical presentation of PD is characterized by both motor and non-motor symptoms, among which upper-extremity (UE) dysfunction is particularly disabling. Motor symptoms such as tremors, bradykinesia, rigidity, and postural instability often emerge early in the disease. Tremors in the hands, present in up to 70% of patients in the early stages, are especially debilitating, interfering with basic activities such as writing, eating, dressing, and other daily functions [3]. In addition to tremors, PD impairs fine motor control, dexterity, and the ability to perform sequential movements—significantly reducing independence and quality of life [4].

While pharmacological and surgical treatments can help manage PD symptoms, they cannot stop disease progression or fully restore function, particularly for fine motor control [5, 6]. Rehabilitation, therefore, plays a critical role in improving functional outcomes. However, unlike lower-limb rehabilitation—which focuses largely on gait and mobility—UE rehabilitation is uniquely challenging because impairments are heterogeneous and complex [7, 8]. Fine motor control in the upper limb involves multiple dimensions of movement, requiring tailored therapeutic approaches that address both motor and cognitive aspects [9].

Traditional physiotherapy strategies, such as stretching, resistance training, aerobic exercise, and balance work, have shown benefits in improving motor performance and slowing functional decline [10,11]. Yet these methods often lack specificity for UE fine-motor rehabilitation. Recent advances in rehabilitation—including virtual reality (VR), robot-assisted therapy, and telerehabilitation—have opened new possibilities. VR-based training offers immersive and task-specific practice that enhances motor and cognitive engagement [12]. Robot-assisted therapy can provide high-intensity, repetitive, and precise training tailored to individual needs [13, 14]. Telerehabilitation expands access to therapy, enabling home-based interventions with personalized feedback, continuous monitoring, and improved adherence [15, 16].

Despite growing interest in these innovative approaches, existing systematic reviews predominantly focus on gait, balance, or general motor rehabilitation, with limited emphasis on fine motor skills in PD. Furthermore, there is a lack of comprehensive synthesis that compares the effectiveness, feasibility, and long-term impact of both conventional and technology-driven interventions [17].

Therefore, this systematic review and meta-analysis aim to critically evaluate rehabilitation interventions for fine motor skill acquisition in people with Parkinson's disease. By synthesizing evidence across traditional, advanced, and technology-assisted approaches, this review seeks to inform clinical practice, optimize rehabilitation protocols, and identify priorities for future research—ultimately contributing to better functional outcomes and improved quality of life for individuals living with PD.

## MATERIALS AND METHODS

### *Design*

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) standards were followed in this systematic review [19]. The goal was to assess the efficacy of rehabilitation programs designed to help Parkinson's disease (PD) patients with their fine motor abilities. The study used a quantitative methodology with a retrospective, secondary, and observational design. The study is registered with PROSPERO (ID: CRD42024565704).

### *Selection Criteria*

The PICOS framework was used to define the inclusion criteria. Regardless of the disease's stage or duration, studies involving people (≥18 years old) with a Parkinson's disease diagnosis were included. Physiotherapy, occupational therapy, neurorehabilitation, motor training, hand exercises, and assistive devices were among the interventions considered to improve fine motor skills. A placebo, usual care, no therapy, and alternative interventions, including deep brain stimulation or medication, were used as comparators. Fine motor skills were evaluated using objective metrics, such as timed finger tapping, the Purdue Pegboard Test, the Nine-Hole Peg Test, or accelerometer-based measures (e.g., peak amplitude, peak acceleration). Among the study designs that qualified were pre-post intervention studies, non-randomized controlled trials, and randomized controlled trials (RCTs). Qualitative research, reviews, case reports, procedures, conference abstracts, and commentaries were excluded, and only English-language publications were included.

### *Search Strategy*

A thorough search strategy was used to identify relevant research across multiple databases, including Web of Science, PubMed, Embase, CINAHL, and Scopus. Medical Subject Headings (MeSH) and free-text terms related to Parkinson's disease, fine motor skills, rehabilitation, and specific therapies were incorporated into the search terms. Terms like "Parkinson's disease," "physiotherapy," "fine motor skills," "hand function," "motor control," and "rehabilitation" were combined using Boolean operators ('AND,' OR').

The Rayyan web tool (Qatar Computing Research Institute, Doha, Qatar) was used in three stages of the research selection process [20]. It allows users to upload recognized information from all sources and facilitates the de-duplication, screening, and evaluation of articles by reviewers. Initially, three independent reviewers reviewed

abstracts and titles to exclude research that didn't meet the inclusion criteria. After that, full-text publications of potentially eligible research were obtained and evaluated in accordance with established standards. A fourth reviewer was consulted to settle any disagreements among the reviewers. A PRISMA flowchart showing the number of studies screened, excluded, and included was used to document the procedure.

To guarantee consistency, a standardized form was used for data extraction. Details of the study (author, year, design, and sample size), participant information (age, gender, disease stage, and duration), intervention details (type, frequency, duration, and intensity), comparator group information, outcomes evaluated (fine motor skills and secondary outcomes like quality of life and daily living activities), follow-up times, and important findings regarding motor skill improvements were all included in the extracted research.

*Quality of studies and risk of bias*

Two reviewers independently evaluated the quality of the included studies using the Risk of Bias in Non-Randomized Studies of Interventions (ROBINS-I) [21] for non-RCTs and the Cochrane Risk of Bias Tool and Physiotherapy Evidence Database (PEDro) Scale for RCTs [22, 23]. A third reviewer was consulted, or a consensus was reached to settle any disputes.

*Statistical Analysis*

Both narrative and quantitative methods were used in the data synthesis. When there was substantial variation among studies in interventions, results, or design, a narrative synthesis was used to synthesize the data. When necessary, a random-effects model was used to pool data for a meta-analysis. For continuous outcomes, standardized mean differences (SMDs) with 95% CIs were computed, and the I2 statistic was used to measure heterogeneity. Sensitivity analyses were conducted to assess the robustness of the findings by excluding studies at high risk of bias. In contrast, subgroup analyses were conducted based on variables such as intervention type and disease stage.

## RESULTS

*Search results*

The preliminary search encompassed five electronic databases (PubMed, Scopus, Web of Science, CINAHL, Embase). As a result, 12410 articles were retrieved from these databases. Following the removal of 2,081 duplicate articles, 11,196 articles were included for title screening; of these, 11,073 were excluded, resulting in a total of 123 articles for abstract screening. 38 articles were excluded because of an incorrect study design, 10 for an incorrect outcome measure, and 7 for an incorrect intervention. Further full-text analysis was performed on 68 articles, and of these, 55 were included in this review (Figure 1).

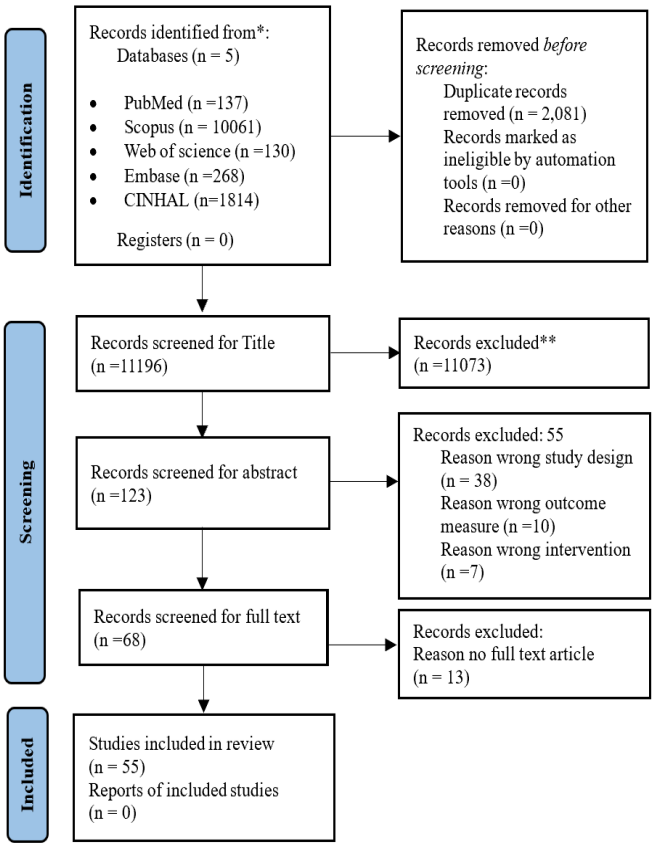


**Figure 1: PRISMA flow chart**

*Study Characteristics*

The studies were performed between 2000 and 2024 in these continents: Australia, Asia (China, India, Iran, Israel, Pakistan, Qatar, South Korea, Taiwan, Thailand, Turkey), Europe (Belgium, Germany, Ireland, Italy, Poland, Portugal, Slovenia, Spain, Switzerland, UK), North America (USA, Canada), South America (Brazil). The study included 1978 participants, with a mean age of 67.13 (±7.1). The sample consisted of 1084 men, 688 women, and 206 participants from eight studies where sex was unspecified.

*Outcome Measures*

- Primary Outcomes

Studies assessing upper limb dysfunction in Parkinson's disease primarily evaluated motor function, dexterity, and quality of life. Common measures included hand function tests such as the Nine-Hole Peg Test (9HPT) [14,16, 24–27]. Purdue Pegboard Test (PPT) [28–30] Jebsen Taylor Hand Function Test (JTHFT) [16, 26, 27, 31–33] the Box and Block Test (BBT) [27, 29, 31, 34, 35]which assesses manual dexterity, fine motor skills, and bimanual coordination. Motor performance was frequently measured using the Unified Parkinson's Disease Rating Scale (UPDRS) Part III [11, 27, 31, 36–42]often measured at multiple time points. Additional kinematic parameters like movement time (MT) [43–47] peak velocity (PV) [44–48] deceleration time [47]acceleration phase percentage (PTA) [44, 45] and movement smoothness (e.g., number of movement units) [45,49] are recorded to assess reach-and-grasp dynamics. Tremor severity was quantified using the Fahn-Tolosa-Marin Tremor Rating Scale (FTMTRS) [50], and

objective metrics like amplitude, frequency, and root mean square (RMS) displacement are measured using sensors or wearable devices [51–54]. Other outcomes include grip and pinch strength [16,55,56], handwriting performance [56–60]and functional independence in activities of daily living (ADL), assessed via the Functional Independence Measure (FIM) [61,62] and Parkinson's Disease Quality of Life Questionnaire (PDQ-39) [38,63]

- Secondary Outcomes

Secondary outcomes assessed psychological and cognitive functioning, treatment safety, and adherence. Psychological assessments include the Beck Depression Inventory (BDI) [24] and the State Trait Anxiety Inventory (STAI) [24]. Quality of life was measured using PDQ-39 [25,27,40,42,64–66], PDQ-8 [16], and the EuroQoL-5 Dimensions (EQ-5D) [11,24]. Cognitive assessments such as the Montreal Cognitive Assessment (MoCA) [50,62] was also employed. Treatment safety was monitored by tracking adverse events, and intervention compliance was assessed through exercise intensity and attendance records. Task performance metrics, such as success rates in grasping tasks [43,47], reaction [43,48] and movement times [43,49], and writing accuracy [57,60,67] or object placement further complements motor outcomes [31, 67]. Collectively, these outcomes provided a comprehensive understanding of the impact of interventions on motor function, dexterity, quality of life, and overall well-being in individuals with Parkinson's disease.

*Methodology Quality and Risk of Bias*

When we reviewed the 24 non-randomized control trials, we found both encouraging aspects and challenges. On the positive side, bias due to confounding was very low (4.17%), indicating that most studies were able to control for external influences. This adds confidence that the findings are not simply due to external factors. Bias in outcome measurement was also relatively low (29.17%), indicating that many studies used reliable methods to assess their results.

At the same time, some areas need attention. Some studies struggled with participant selection (75%) and classification of interventions (95.83%), which is not unusual in real-world clinical research where strict randomization can be difficult. Missing data were another challenge, affecting half of the studies, and selective reporting was observed across all studies. Rather than diminishing the value of the evidence, these points highlight where future research can be made stronger, through better reporting practices and more consistent methods.


**Figure 2a: Risk of bias graph: review authors' judgments about each risk of bias item presented as percentages across all included RTC studies.**

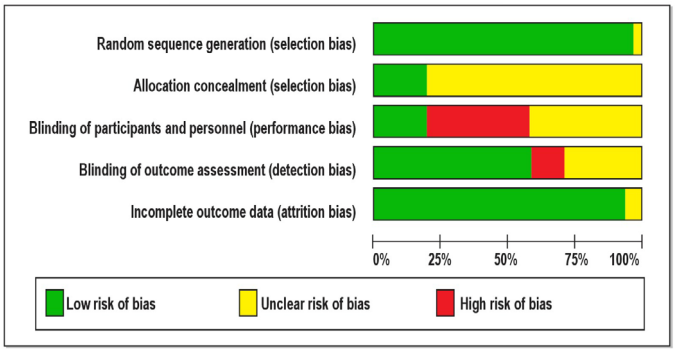


**Figure 2b: Risk of bias summary: review author's judgments about each risk of bias item for each included RTC studies.**

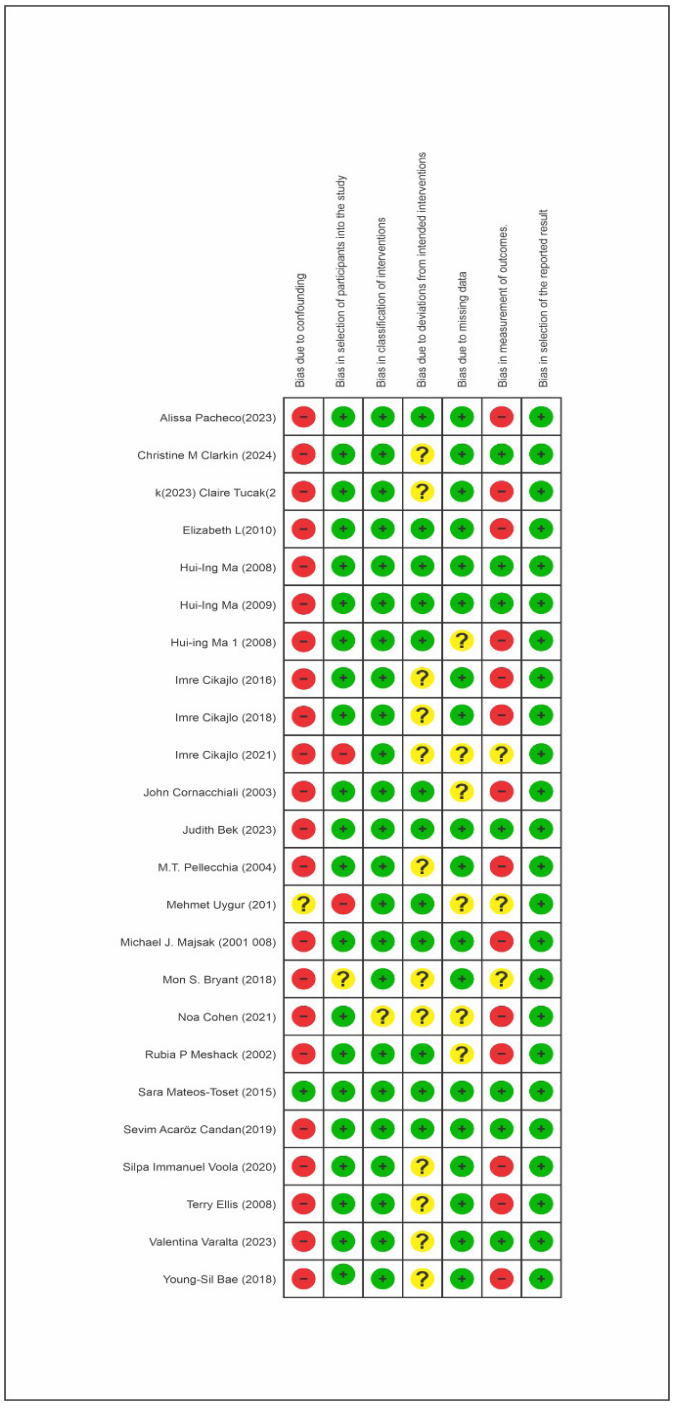


**Figure 3a: Risk of bias graph: review authors' judgments about each risk of bias item presented as percentages across all included n-RTC studies.**

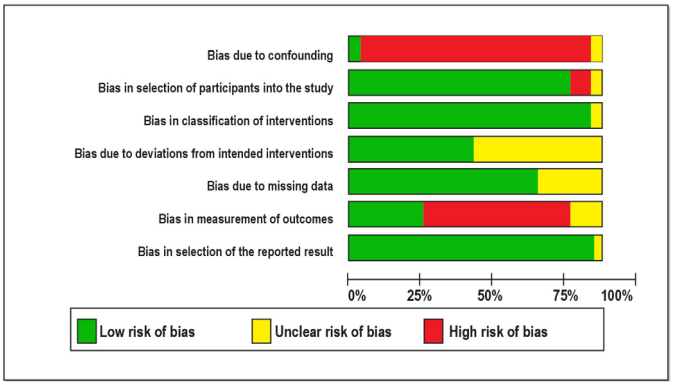


**Figure 3b: Risk of bias summary: review authors' judgments about each risk of bias item for each included n-RTC studies.**

*Interventions*

From these 55 studies, the various interventions were identified, summarized, and categorized into 6 themes (Table 1).

| Sr. No | Theme | Categories |
|---|---|---|
| 1 | **Motor-focused** | (a) Aerobic exercises<br>(b) Resistance exercises<br>(c) UL exercise<br>(d) Dexterity exercises<br>(e) Reach and Grasp<br>(f) LSVT-BIG<br>(g) Archery |
| 2 | **Sensory-based** | (a) Auditory stimuli<br>(b) Vibratory stimuli<br>(c) Weighted objects<br>(d) Glove |
| 3 | **Cognitive-based** | (a) Dual task<br>(b) Motor imagery<br>(c) Action observation |
| 4 | **Creative/Fine Motor** | (a) Handwriting exercises<br>(b) Clay art |
| 5 | **Technology-assisted** | (a) Telerehabilitation<br>(b) Robotic/VR/game-based exercises |
| 6 | **Multidisciplinary/Alternative** | (a) Miscellaneous |

1. Motor – Focused Interventions

   a. Aerobic exercises

   Aerobic and multimodal programs consistently improved motor skills, coordination, and daily activities. Cycling-based interventions (Jansen 2021; Uygur 2017) enhanced dexterity and motor control [36,55] while multi-component regimens (Swarnakar 2023; Nascimento 2014) improved UPDRS-III and ADL scores [11,68]. Flexibility and balance training offered short-term gains, but long-term benefits were achieved through varied exercise modalities (Schenkman 2012) [65]. An 8-week aerobic interval training program for 20 PD participants improved neurological symptoms,

executive function, and bimanual control (Marusiak, 2019) [68]. Overall, structured aerobic exercise effectively enhances motor and general health, with adherence being key to sustained outcomes.

b. Resistance exercises

Tremor-focused resistance studies showed mixed results. Eccentric resistance training (Kadkhodaie 2020) yielded the best outcome, reducing tremor amplitude by 63% [10]. Weighted utensils (Ma 2009) reduced movement efficiency without altering speed [45], and weighted items (Meshack 2002) had non-significant effects [54]. Evidence for hand resistance exercises remains inconclusive (Bryant 2018) [56].

c. Upper Limb exercises

A single RCT (Kadkhodaie 2020) with 21 participants used eccentric resistance training with weighted cuffs and balls (three sessions/week for six weeks). Results indicated reduced resting tremor and confirmed safety, though effects on postural tremor remain unclear [10].

d. Dexterity exercises

Dexterity-based interventions showed short-term improvements. HOMEDEXT (Vanbellingen, 2017) enhanced fine motor skills but lacked long-term effects [25]. One session of therapeutic putty (Mateos-Toset 2016) improved dexterity and grip strength, whereas ROM exercises did not [28]. Telerehabilitation (Voola 2020) enhanced dexterity and independence, with bimanual tasks outperforming Theraband use [63]. Dual-tasking studies (Proud 2010) revealed significant performance challenges [30]. No adverse events were reported, supporting safety. Overall, dexterity-focused programs improve hand use but require long-term follow-up to ensure sustained benefits.

e. Reach and Grasp

One study (Majsak 2008) with 16 participants (8 PD, 8 controls) examined reach–grasp under varied temporal and spatial conditions. PD participants exhibited longer movement times, smaller hand apertures, and slower grasp velocities [43].

f. LSVT – BIG

LSVT-BIG combined with occupational therapy improved hand function, ADLs, and quality of life (Choi 2022) [24]. Another RCT (Peterka 2020) reported better proprioception and QoL [64]. A small study with nine participants found improvements in motor function, gait speed, and QoL following externally cued LSVT-BIG (Clarkin 2024) [38].

g. Archery

A 12-week archery program (Chen 2023) (2 hours/week) improved gross and fine upper-limb function, fitness, and gait-balance versus controls [70].

2. Sensory-based

a. Auditory Stimuli

In a study of 20 PD participants (Ma 2008), marching music and weather-forecast audio were compared during spoon–bean tasks. Cognitive load from the forecast reduced velocity and increased movement units, while music had no effect [50].

b. Vibratory stimuli

Three studies demonstrated positive trends. Armshake® training (Varalta 2023) improved tremor and dexterity, sustained at follow-up [50]. Vibration therapy (Mosabbir 2020) significantly reduced tremor and rigidity [39]. A pilot study (Pacheco 2023) found no significant tremor changes across intensities, though participants reported comfort and subjective improvement [59].

c. Weighted objects

Weighted utensils (Ma 2009) and tools (Meshack 2002) showed inconsistent results, offering no significant tremor reduction [45,54].

d. Glove

An RCT (Jitkritsadakula 2017) with 30 PD individuals found that electrical muscle stimulation via Tremor's glove significantly reduced tremor during stimulation, though no lasting changes in UPDRS scores were noted [53].

3. Cognitive-based

a. Dual task

Dual-task interference in the dominant hand predicted 44% of ADL variance in PD (Acaröz Candan & Özcan 2019) [71]. A 12-week drum-based dual-task program (Park 2021) improved motor control, attention, and non-dominant hand function [72]. Another study (Williams 2013) linked upper limb freezing and dyscoordination to poorer coordination during specific conditions [73].

b. Motor Imagery

VR-based motor imagery (Kashif 2022) improved motor symptoms including tremor, rigidity, posture, and gait [37]. Mental imagery plus physiotherapy yielded better but non-significant gains in hand function versus physiotherapy alone (Mishra 2021) [74].

c. Action observation

Action observation therapy showed reduced amplitude and movement efficiency in PD versus controls (Bek 2023) (48). A 6-week home-based action observation + motor imagery program

(Bek 2021) improved dexterity and reaction time but not imagery ability [75]. No adverse events were reported, although the risk of bias was high.

4. Creative/Fine motor
   a. Handwriting exercises

      Four-week handwriting programs improved speed but not accuracy or motor symptoms (Vorasoot 2020) [57]. Longer training (24 weeks; Collet 2017) enhanced amplitude and reduced perceived handwriting difficulty [58]. Technology-assisted feedback training improved amplitude, with intelligent feedback being most effective (Nackaerts 2017) [60].

   b. Clay art

      A quasi-experimental study (Bae 2018) with 26 PD individuals each in experimental and control groups evaluated the effects of clay art therapy over 8 weeks, and the results showed improvement in hand dexterity, depressive symptoms, and quality of life [35].

5. Technology-assisted
   a. Telerehabilitation

      Telerehabilitation improved upper-limb motor and functional outcomes across studies: task-oriented circuit training (Eldemir 2023) [16], AI-based vCare system (Del Pino 2023) [15], hybrid clinic–home models (Isernia 2020) [76], short-term home programs (Voola 2020) [63], and Kinect exergaming (Cikajlo 2018) [27]. Collectively, these approaches enhanced dexterity, independence, and mental health.

   b. Robotic/VR/Game-based exercises

      Exoskeleton training (Raciti 2022) improved dexterity and reduced pain [14]. Both 2D and 3D exergaming enhanced fine motor skills (Cikajlo 2019) [34]. VR-based training improved speed and peak velocity but had limited real-world transfer (Ma 2011) [44]. Immersive VR reduced tremor severity by 35% in 78% of users (Cornacchioli 2023) [51]. Overall, VR and robotic systems support meaningful motor recovery and complement remote rehabilitation programs.

6. Alternate Therapy
   a. Miscellaneous

      A non-RCT (Cohen 2021) involving 158 PD participants tested an eight-week multidisciplinary intensive outpatient rehabilitation (MIOR) program that included physical, occupational, speech, and hydrotherapy, as well as boxing and dancing. Conducted thrice weekly (5-hour sessions), it improved independence, motor and cognitive function, balance, speech clarity, and quality of life [62].

*Meta Analysis*

a) Interpretation of Aerobic Exercises Forest Plot

The meta-analysis of five studies investigating the effects of aerobic exercise in Parkinson's disease showed a general trend toward a negative pooled effect size, suggesting that aerobic exercise might help reduce the measured outcomes. However, this finding was not statistically significant ($t(4) = -2.08$, $p = 0.106$). Four studies (Swarnkar, 2023; Nascimento, 2014; Ajimsha, 2014; Schenkman, 2012) reported negative effects, while one (Jansen, 2021) showed a minimal positive effect (0.02). The strongest negative outcome was observed in Ajimsha (2014) with an effect size of -1.42. However, most confidence intervals crossed zero, indicating a lack of individual study significance. Substantial heterogeneity ($Q(4) = 16.83$, $p = 0.002$) suggests that the differences between studies were greater than what could be expected by chance. Overall, while aerobic exercise may contribute to symptom improvement, the mixed results call for cautious interpretation and further well-controlled research (Table 2), (Figure 4).

**Table 2: Characteristics of the studies that have used Aerobic intervention for upper limb rehabilitation in patients with Parkinson's Disease**

| Sr. No. | Author (Year) Country | PEDro | Total Number of Participants Enrolled | Total Number of Participants in the Intervention Group | Total Number of Participants in the Control Group | Age (mean ± SD) | Gender Distribution (% male/female) | Description of the Intervention | Control Treatment | Primary Outcome(s) | Secondary Outcome(s) | Timing of Outcome Assessment | Primary Outcome Results | Secondary Outcome Results | Source of funding |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Schenkman, (2012), Colorado | 7/10 | 131 | G1: 39, G2: 41 | 41 | EG1: 63.4 ± 11.2, EG2: 64.5 ± 10, CG: 66.3 ± 10.1 | 66% male, 34% female | EG1: Supervised aerobic exercise (treadmill, bike, elliptical), EG2: Supervised flexibility, balance, and functional training | Home-based exercises using the Parkinson Foundation's "Fitness Counts" program with monthly supervision. Monthly supervised home exercises for 16 months. | Continuous Scale—Physical Functional Performance (CS-PFP) Test | UPDRS - ADL and motor subscales, PDQ-39 | Pre-post test | The EG2 demonstrated better physical function compared to the control and EG 1 groups, with no significant differences observed | UPDRS-ADL: The EG2 outperformed the control group. No significant group differences in UPDRS motor subscale or PDQ-39 quality of life scores | Not reported |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | Ajimsha, (2014), Qatar, India, Malaysia | 8/10 | 64 | 32 | 32 | EG: 61.4 ± 2.6, CG: 60.8 ± 2.1 | | Autogenic Training was conducted based on Schultz-style AT, modified to suit patients with Parkinson's. | The control group underwent 60-minute physiotherapy sessions, 5 times per week for 8 weeks | UPDRS | Not reported | Pre-post test | Patients in the AT group showed a 51.78% improvement in motor performance at Week 8 compared to the control group, with significant improvements in facial expression, rigidity, resting tremor, hand movements, and rapid alternating movements. | Not reported | Grant from the Mahatma-Gandhi University,Kottayam, India. |
| 3 | Nascimento, (2014), Brazil | 7/10 | 34 | 17 | 17 | EG: 67.8 ± 6.8, CG: 66.3 ± 8.1 | | Program focused on aerobic fitness, muscular resistance, balance, and motor coordination. | Standard medical care without exercise. | Pfeffer Instrumental Activities Questionnaire | Mini Mental State Examination | Pre-post test | Significant improvement in IADL and SD | MMSE scores were significant predictors of IADL performance | Not reported |
| 4 | Jansen, (2021), USA | 4/10 | 29 | 15 | 14 | EG: 63.50 ± 6.31, CG: 62.07 +_ 12.19 | 48% male, 52% female | CyclING on a stationary semi-recumbent cycle three times per week for eight weeks (24 sessions total). Pedaling rate was set 30% higher than their preferred cadence | Cycling at their self-selected cadence on the same model of the recumbent cycle. | Time and force characteristics during a bimanual dexterity task | MDS-UPDRS Motor III scores. Exercise compliance and intensity | Pre-post test | Significant improvement in th EG | Both groups showed improvement | Not reported |
| 5 | Swarnkar, (2023), India | 7/10 | 40 | 20 | 20 | EG: 57.5±12.1 CG: 52.3±12.5 | 72.5% male, 27.5% female | Strengthening: 2 days/week Aerobic: 3 days/week Agility: 2 days/week | Stretching exercises | UPDRS III | UPDRS I, UPDRS II, UPDRS VI, PDQL | The primary outcome was assessed at the 12-week mark. | EG showed a significant difference | EG showed significant improvements in UPDRS I, II, VI; PDQL results inconclusive. | Not reported |

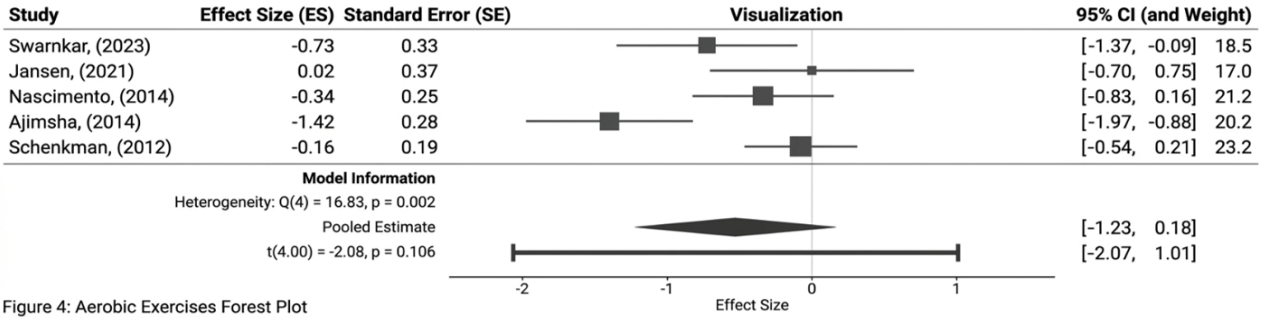


**Figure 4 - Aerobic Exercise Forest Plot**

b) Interpretation of the Telerehabilitation Forest Plot

The meta-analysis on telerehabilitation (TR) exercises aimed at improving upper limb function in Parkinson's disease produced mixed results. One study showed a strong positive effect, while others reported minimal or negative outcomes. When all data were pooled, the overall effect was not statistically significant (p = 0.743), indicating no consistent evidence that telerehabilitation improves upper limb function. Significant heterogeneity (p = 0.003) revealed considerable variation among the studies in terms of their design, sample size, and delivery methods. Despite its growing popularity and potential benefits, telerehabilitation's true effectiveness remains uncertain, and larger, more standardized trials are needed to clarify its role in Parkinson's rehabilitation (Table 3), (Figure 5).

**Table 3: Characteristics of the studies that have used Telerehabilitation intervention for upper limb rehabilitation in patients with Parkinson's Disease**

| Sr. No. | Author (Year) Country | PEDro | Total Number of Participants Enrolled | Total Number of Participants in the Intervention Group | Total Number of Participants in the Control Group | Age (mean ± SD) | Gender Distribution (% male/female) | Description of the Intervention | Control Treatment | Primary Outcome(s) | Secondary Outcome(s) | Timing of Outcome Assessment | Primary Outcome Results | Secondary Outcome Results | Source of funding |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Immaneul, (2020), India | | 10 | 5 | 5 | | 30% male, 70% female | Participants were taught six manual dexterity exercises via video calls over four weeks, including finger tapping, crossing circles, turning disks, nuts on bolts, and clay modeling exercises. | Therabands were used in a study to teach seven upper extremity strength training exercises, while a control group received 15 30-minute sessions over four weeks. | Purdue Pegboard Test, Chedoke Arm and Hand Activity Inventory, Parkinson's Disease Questionnaire-39 (PDQ-39) | None | Pre-post test | The control group improved in manual dexterity, but not as much as the experimental group. A significant difference was found in bi-manual tasks of the Purdue Pegboard test | None | Self-funded |
| 2 | Isernia, (2020), Italy | 8/10 | 31 | 11 | 20 | EG: 65.55 + 9.06, CG: 67.55 + 9.33 | 55% male, 45% female | ClinicHEAD offers personalized 12-hour sessions for balance, strength, endurance, executive functions, and memory improvement, while HomeHEAD offers 60 45-minute telerehabilitation sessions, with remote supervision and support from clinicians, aiming to improve individual functions through motor and cognitive tasks. | Patients in the UC group were advised to maintain their daily activities and avoid engaging in rehabilitation programs that differed from their usual routines. | SF-12 | Box and Block Test, assessing upper limb mobility | Pre-post test | Mental Health Score: Significant improvement | Improved dexterity in both hands | Not mentioned |
| 3 | Rocio del, (2023), Spain | 7/10 | 20 | 10 | 10 | EG: 64.5±7.9, CG: 69.1±3.5 | Not reported | vCare Telerehabilitation System | Standard clinical care provided at the clinic without access to telerehabilitation | EuroQoL-5 Dimensions, MoCA, UPDRS I-IV | Schwab and England Activities of Daily Living (ADL), Modified Hoehn and Yahr scale (H&Y) | Pre-post test | vCare group showed significant improvement in mobility and cognition | No significant difference | Not mentioned |
| 4 | Eldemir, (2023), Turkey | 7/10 | 30 | 15 | 15 | EG: 57.87 ± 9.79, CG: 61.40 ± 7.29 | 63% male, 37% female | Received task-oriented circuit training via telerehabilitation | Participated in a six-week home exercise program focusing on balance, gait, and mobility, supported by booklets and telephone support. | Nine Hole Peg Test (9-HPT), Jebsen Hand Function Test (JHFT), Grip Strengths, Pinch Strengths, UPDRS - III | UPDRS - II, PDQ - 8 | Pre-post test | TOCT-TR group showed significant motor improvements. | TOCT-TR group improved ADL, QoL. | Not mentioned |

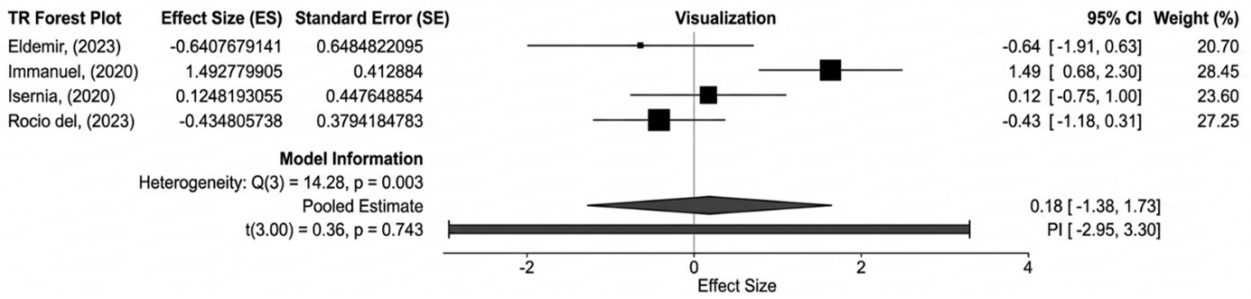


**Figure 5: Telerehabilitation (TR) Forest Plot**

c) Interpretation of Dexterity Exercises Forest Plot

The forest plot displays the results of a meta-analysis evaluating the effectiveness of hand dexterity exercises for upper limb rehabilitation in Parkinson's disease patients. Individual studies show a range of effect sizes, from a negative effect in L. Proud (2010) (-0.69) to strong positive effects in Wang (2020) (1.45) and Immanuel (2020) (1.39), indicating variability in study outcomes. The heterogeneity statistic is significant (Q (4) = 24.61, $p < 0.001$), suggesting substantial inconsistency across studies. The pooled effect size is not statistically significant (t(4) = 1.27, $p$ = 0.273), indicating that, overall, hand dexterity exercises did not produce a consistent, significant effect on upper limb function in Parkinson's patients across the analyzed studies. The large confidence intervals and heterogeneity highlight the need for further research with standardized protocols to clarify the intervention's effectiveness. (Table 4), (Figure 6).

**Table 4: Characteristics of the studies that have used Hand dexterity intervention for upper limb rehabilitation in patients with Parkinson's Disease**

| Sr. No. | Author (Year) Country | PEDro | Total Number of Participants Enrolled | Total Number of Participants in the Intervention Group | Total Number of Participants in the Control Group | Age (mean ± SD) | Gender Distribution (% male/female) | Description of the Intervention | Control Treatment | Primary Outcome(s) | Secondary Outcome(s) | Timing of Outcome Assessment | Primary Outcome Results | Secondary Outcome Results | Source of funding |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | L. Proud, (2010), Australia | | 44 | 22 | 22 | EG: 63.95 ± 9.78, CG: 63.64 ± 10.00 | 50% male, 50% female | Purdue Pegboard Test, with a dual-task condition where participants performed a verbal-cognitive task (serial 7 subtraction) alongside the dexterity test | No intervention for the control group, only baseline performance was recorded | Number of pegs placed in 30 seconds on the Purdue Pegboard test under both unitask and dual-task conditions | Performance on the serial 7 subtraction task | During experimental session, baseline unitask and subsequent dual-task conditions | Significant reduction in pegs placed for the PD group compared to controls | Greater dual-task interference in the PD group, with decreased subtraction performance | Not mentioned |
| 2 | Mateos - Toset, (2015), Slovenia | | 60 | 30 | 30 | EG: 72.60 ± 8.86, CG: 69.97 ± 9.59 | 60% male, 40% female | A single 15-minute hand-exercise session using therapeutic putty focused on hand strengthening and dexterity | 15 minutes of active upper limb range-of-motion exercises. | urdue Pegboard Test and the Chessington Occupational Therapy | Strength: Measured using hand grip and pinch strength (lateral, distal, tripod pinch) via dynamometer. | Pre and Post after 15 mins | Sigificant improvement in pieces placed | Hand grip and pinch strength increased | Not mentioned |
| 3 | Vanbellingen, (2017), Switzerland | 6/10 | 103 | 52 | 51 | EG: 67.15 ±7.94, CG: 68.16 ±7.38 | 61% male, 39% female | Participants were given a booklet containing instructions for six dexterity exercises, performed five days a week for four weeks, with follow-ups via phone after the first week. | Participants performed 7 strength exercises using elastic bands (upper limb focus). | Nine-Hole Peg Test (9-HPT) | Health-related Quality of Life (PDQ-39), Dexterity Questionnaire (DextQ-24), Coin Rotation Task (CRT), JAMAR Dynamometer, MDS-UPDRS II-III | Pre-post at 4 weeks and follow up at 12 weeks | HOMEDEXT group improved by 2.11 seconds, while Thera-band group showed no significant change | The HOMEDEXT group showed significant improvement in DextQ-24 and Quality of Life, while no significant differences were observed in other measures. The Coin Rotation Task, Hand Strength, and Motor Symptoms and ADL were not significantly different between the groups. | Not mentioned |
| 4 | Immaneul, (2020), India | | 10 | 5 | 5 | | 30% male, 70% female | Participants were taught six manual dexterity exercises via video calls over four weeks, including finger tapping, crossing circles, turning disks, nuts on bolts, and clay modeling exercises. | Therabands were used in a study to teach seven upper extremity strength training exercises, while a control group received 15 30-minute sessions over four weeks. | Purdue Pegboard Test, Chedoke Arm and Hand Activity Inventory, Parkinson's Disease Questionnaire-39 (PDQ-39) | None | Pre-post | The control group improved in manual dexterity, but not as much as the experimental group. A significant difference was found in bi-manual tasks of the Purdue Pegboard test | None | Self-funded |
| 5 | Wang, (2020), China | 6/10 | 46 | 23 | 23 | EG: 67.0 ± 5.6, CG: 67.1 ± 6.1 | 50% male, 50% female | Traditional Wuqinxi exercise based on five animals (tiger, bear, deer, monkey, bird) | Stretching exercises with slow, gentle joint movements | Purdue Pegboard Test | Parkinson's Disease Questionnaire (PDQ-39) | Pre - post test | The Wuqinxi group significantly improved PPT scores in dominant hand, both hands, and assembly task after 12 weeks, while the stretching group showed no significant improvement. | Both Wuqinxi and stretching groups significantly improved scores | National Key Research and Development Program of China |

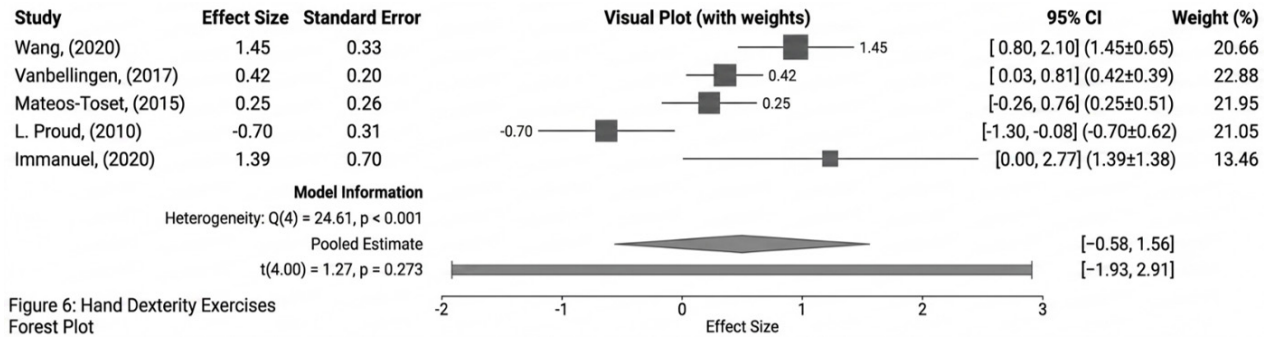


**Figure 6: Hand Dexterity Exercises Forest Plot**

## DISCUSSION

This systematic review shows that rehabilitation can improve upper-limb function and activities of daily living (ADLs) in people with Parkinson's disease (PD), but the evidence is uneven and context-dependent. Large, higher-quality bodies of evidence exist for lower-limb interventions (gait, balance, and resistance training), which reliably improve mobility, balance, and some ADL outcomes — probably because walking and safe community mobility are primary determinants of independence and fall risk, so they have been targeted more intensively by researchers and clinicians [77–80].

By contrast, upper-limb (UE) rehabilitation has a smaller, more heterogeneous evidence base. There are several reasons for this, which help explain the inconsistent findings in UE studies. First, the types of UE impairments in PD are themselves heterogeneous (bradykinesia, tremor, rigidity, impaired force/timing, dyscoordination, and sensory changes), so different patients present with very different problems to treat. Second, outcome measures

and tasks vary widely across studies (hand dexterity tests, kinematic measures, UPDRS subscores, functional ADL scales), so interventions that help one outcome may not show benefit on another [9, 81]. Together, these factors create biological and measurement heterogeneity that makes the pooled effects variable.

Exercise-based approaches (aerobic, strength, and task-specific practice) show promise for improving motor signs and hand function, and many trials report short-term gains; however, effects are often modest, sample sizes are small, and long-term maintenance is rarely assessed [48,55]. The Cochrane and meta-analytic literature supports broad benefits of structured exercise for PD motor outcomes (including gait, balance and quality of life), but the specific dose, content and durability of UE-targeted programs remain unclear [77, 80]. In short: exercise helps, but we need better-powered, longer follow-up trials targeted to the hand/arm.

Technology-assisted methods (robotics, virtual reality [VR], wearable devices, telerehabilitation) are promising for intensity, feedback and engagement, but the evidence is mixed [25, 28]. Systematic reviews find benefit in some robotic and VR programs (often when combined with conventional therapy), yet results are inconsistent for pure technology-only programs, and long-term superiority over hands-on therapy has not been established [78]. Part of the problem is variable device types, dosing, and outcome choices across studies.

Accessibility remains a key challenge [37]. Advanced systems are often costly and limited to specialized centres, while home-based telerehabilitation faces adherence and monitoring issues [16]. Tremor-focused rehabilitation, despite its clinical importance, is underexplored. Promising low-cost tools like weighted gloves or peripheral stimulation could stabilize movement, but stronger trials are needed to confirm their utility [53, 82].

In summary, while upper-limb rehabilitation shows meaningful benefits, its variability reflects the complexity of PD itself. Future studies should use standardized protocols, explore hybrid models combining technology with therapist guidance, and evaluate long-term and real-world effectiveness to enhance independence and quality of life.

## CONCLUSION

This review reinforces the role of rehabilitation in enhancing upper-limb function, independence, and overall quality of life in people with Parkinson's disease. Despite variability across studies, evidence consistently supports the value of targeted exercise, task-specific training, and technology-assisted programs in improving fine motor skills and daily function. With continued innovation and patient-centered approaches, rehabilitation can help individuals with Parkinson's not only regain control over movement but also maintain confidence and autonomy in their everyday lives.

### Limitations

The review included studies with small sample sizes, short durations, and varied methodologies, making direct comparisons challenging. Differences in disease stage, intervention protocols, and outcome measures may have influenced the findings.

### Clinical Recommendations

The review recommends task-specific and dexterity-based training for patients with Parkinson's disease, with a focus on long-term engagement and follow-up. Aerobic and multimodal exercises, such as cycling and flexibility-balance routines, can improve motor control and performance in daily activities. Technology-assisted methods, such as telerehabilitation and virtual reality, can enhance patient engagement and therapy intensity. LSVT-BIG and occupational therapy can improve hand function and quality of life. Sensory and vibratory interventions, such as vibratory therapy and weighted gloves, may support tremor reduction and motor improvements. Creative interventions, such as handwriting exercises and clay art therapy, can improve dexterity and mood. Clinicians should monitor heterogeneity and emphasize long-term outcomes.

### Future Scope

Future work should focus on larger, long-term trials using standardized outcome measures and hybrid models that combine technology with therapist guidance. Greater emphasis on accessible, cost-effective, and personalized interventions—such as weighted gloves or home-based programs—can further strengthen rehabilitation outcomes and long-term engagement.

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