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Effects of Exercise on Gait and Functional Performance in Individuals With Idiopathic Normal Pressure Hydrocephalus: A Scoping Review

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ABSTRACT

Background and Purpose: Exercise is recommended for individuals with idiopathic normal pressure hydrocephalus (iNPH), but its effects on gait and functional performance remain underexplored. This scoping review aimed to search (1) effects of exercise or physical therapy on gait and functional outcomes in individuals with iNPH, along with its underlying physiological and biomechanical mechanisms; (2) challenges to exercise implementation; and (3) replication potential of interventions.

Methods: Five databases (PubMed, Embase, Latin American and Caribbean Health Sciences Literature, Cumulative Index to Nursing and Allied Health Literature, and SpringerLink) were searched for full-text, peer-reviewed articles (2010-2023) on exercise or physical therapy for individuals with iNPH, with all types of study design. Two reviewers independently screened, extracted, and tabulated the search results. Research quality was assessed using the Joanna Briggs Institute critical appraisal checklist. The Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews and the Template for Intervention Description and Replication checklists were used as reporting guidelines.

Results: Six articles met the criteria, covering exercise interventions such as the Lee Silverman Voice Treatment-BIG exercise program, Dynamic Equilibrium Gait Training, High-Intensity Functional Exercise, Action Observation, and home-based physical exercise program (stretching exercises for back, gluteal, and trunk; strengthening exercise for shoulder, arm, and leg; and balance training). These exercises indicated positive effects on gait, sit-to-stand, mobility, balance, balance confidence, and disability, but did not significantly improve quality of life. All six articles provided sufficient details for replication; however, two were based on the same study project, leaving five unique studies included.

Conclusion: Exercise interventions, when carefully prescribed by physical therapists, represent a promising approach for improving gait and balance in individuals with iNPH. However, the current paucity of well-powered randomized controlled trials highlights the urgent need for further research to identify the most effective exercise protocol. Future studies should focus on specific exercise modalities and their long-term impact to improve management and rehabilitation of individuals with iNPH.

Key Words: exercise, functional performance, gait, normal pressure hydrocephalus

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The authors have no conflicts of interest to declare.

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CLINICAL IMPLICATIONS

- Exercise is recommended for individuals with idiopathic normal pressure hydrocephalus (iNPH), but effects on gait and functional performance may vary with the type and dose of intervention.
- The number and quality of studies was low. Three of four intervention approaches studied showed positive changes in gait and functional performance after exercise, in individuals with and without shunt surgery.
- Exercises to improve strength, balance and dynamic gait are recommended during and continuing after an episode of care.

INTRODUCTION

The global aging population is increasing rapidly, with 16% of the world's population projected to be 65 years or older by 2050.[1] Idiopathic normal pressure hydrocephalus (iNPH) is a condition that predominantly affects older adults and is associated with significant mobility and cognitive impairments. The incidence and prevalence of iNPH vary widely across study locations, ranging from approximately 1.2 per 1000 people aged over 70 years[2] to 1 in 27 in people aged 65 years and older.[3] Nevertheless, undiagnosed iNPH is remarkably high, resulting in delayed treatment and causing irreversible symptoms.[4]

The clinical manifestations of iNPH include gait disturbance, cognitive deficits, and urinary incontinence.[5] A common consensus defines iNPH as ventriculomegaly with the absence of prior conditions or diseases that disrupt cerebrospinal fluid (CSF) dynamics, resulting in a vicious cycle of neurological damage.[6] Among the three clinical manifestations, gait disturbances are the most prominent and severely impact mobility and functional independence.[6] Individuals with suspected iNPH often exhibit abnormal gait characteristics, including decreased stride length, gait speed, cadence, mid-swing foot elevation, and foot strike angle, along with increased double support duration and turning difficulties.[7,8] Impaired gait and mobility function further exacerbates mobility limitations, increasing the risk of falls and reducing overall quality of life.[9] These gait and functional limitations significantly hinder the ability to perform daily activities, emphasizing the need for targeted interventions to mitigate these deficits and improve overall functionality.

Exercise is widely recommended for individuals with neurological conditions[10,11] including in individuals with iNPH due to its potential to address physical and functional impairments. However, information regarding effectiveness of exercise for gait and functional abilities specific to individuals with iNPH is not clear. To the best of our knowledge, no study has systematically compiled the effect of exercise on gait and functional disabilities in individuals with iNPH. Therefore, this study aimed to search what is known from the literature on the impact of therapeutic exercise on gait and functional performance in individuals with iNPH. Furthermore, we also sought to collect and present information on implementation and replication of exercise studies in this population.

METHODS

Our scoping review followed a five-stage methodological framework which included (1) identifying the research question, (2) identifying relevant studies, (3) study selection, (4) charting the data, and (5) collating, summarizing, and reporting the results.[12] The Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist was used as a guide for reporting the results of this study.[13] In addition, the Template for Intervention Description and Replication (TIDieR) checklist was used to ensure that relevant and consistent intervention details were extracted.[14] A scoping review was considered appropriate in this study to overview the effect of exercise or physical therapy in individuals with iNPH.

Identifying the Research Questions

The primary research question guiding this scoping review was: "What types of exercise or physical therapy interventions have been implemented to target gait and functional performance in individuals with iNPH; what are the underlying physiological or biomechanical mechanisms related to the intervention effects, and challenges to their implementation?" Our secondary research question was: "Are the details of exercise interventions sufficiently described to enable replication in future studies?"

Data Sources and Search Strategy

Five electronic databases—PubMed, Embase, Latin American and Caribbean Health Sciences Literature (LILACS), Cumulative Index to Nursing and Allied Health Literature (CINAHL), and SpringerLink—were used to search relevant studies by two independent searchers (D. T. and N.Sa.). The results were then reviewed and finalized by the third member (N.Si.) (Supplementary file 1. http://links.lww.com/JGPT/A296). The search strategy used keywords such as: "idiopathic normal pressure hydrocephalus," "exercise," "physical therapy," "physiotherapy," "rehabilitation," "physical activity," "function," and "gait" and used "AND" as a conjunction for searching.

Study Selection

Data from the search process were imported to Endnote (Clarivate, USA), and duplicates were automatically removed. The remaining paper titles and abstracts were then screened according to the selection eligibility criteria which consisted of a fully published and peer-reviewed article (1) focused on the effect of exercise or physical therapy on gait and functional performance in individuals with iNPH; (2) published in an academic journal from 2010 to 2023; (3) written in English; and (4) encompass all types of study designs, including case studies, observational, cross-sectional, randomized control trials (RCTs), and prospective studies. Editorials, opinions, letters to the editor, and conference proceedings were excluded. Conflicts were resolved by discussion between reviewers (N.Si. and P.C.), and the decision was made by a third reviewer (S.B.).

Data Charting and Reporting Process

Three reviewers (S.B., N.Si., and P.C.) checked the accuracy of the gathered data and entered them into an Excel spreadsheet. A data charting form was created to extract study characteristics, including publication year, study design, participants, exercise details, and outcomes. Information relevant to the research questions, such as the types of interventions, mechanisms, and challenges to implementation affecting gait and functional performance as well as intervention details for replication, was extracted from each paper. Data were then integrated and addressed through discussion. Finally, a quality appraisal was performed by S.B. using the Joanna Briggs Institute (JBI) critical appraisal checklist according to the study design.[16]

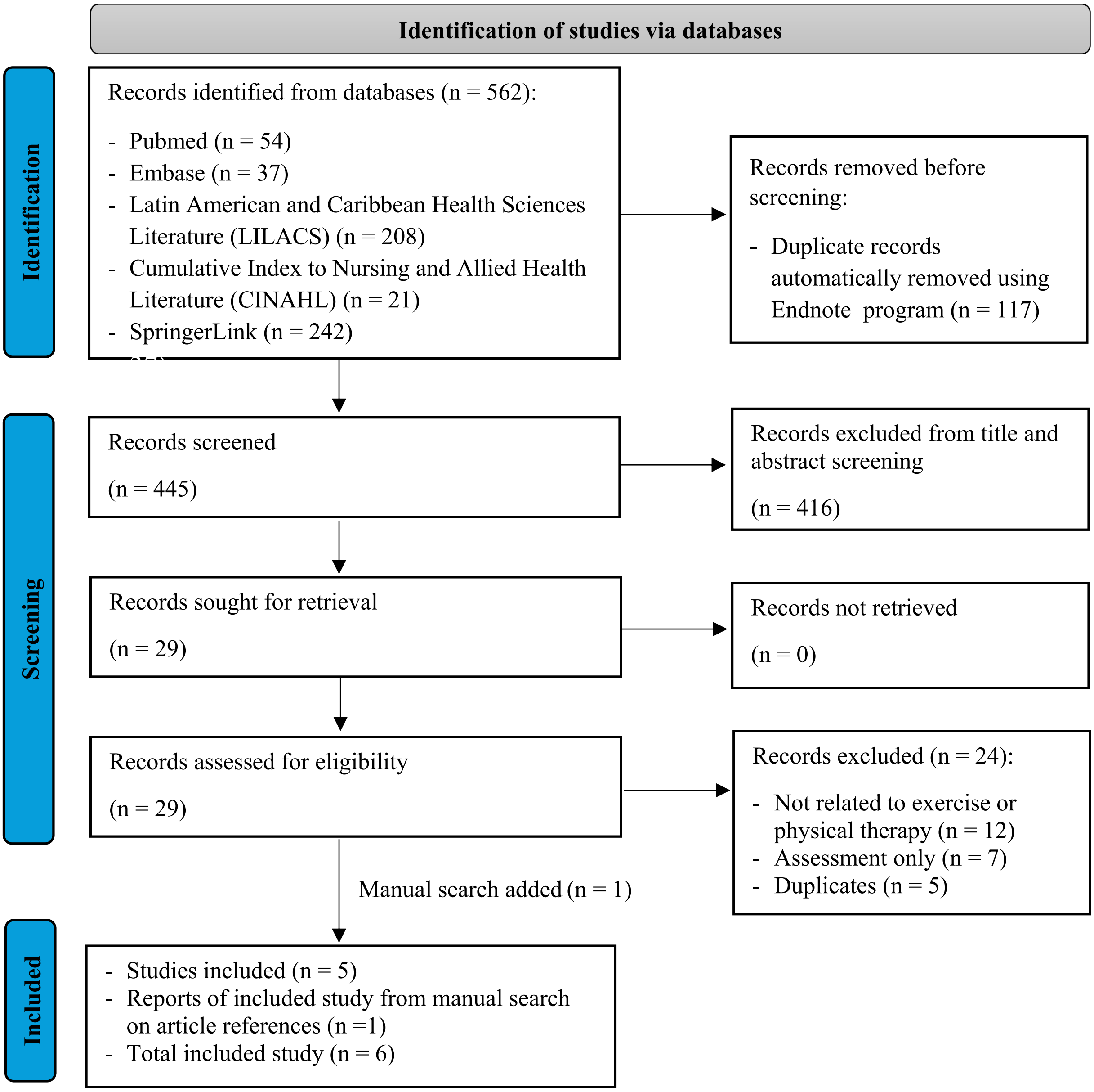

Figure 1. PRISMA 2020 flow diagram of the study selection.[15]

Table 1. Study Methods, Participant Characteristics, Outcomes, and Results and Conclusions of Included Studies

Study ID	Fillmore et al. (2020)[17]	Hnin et al. (2021)[18]	Modesto et al. (2019)[19]	Rydja et al. (2021)[21]	Rydja et al. (2022)[22]	Nikaido et al. (2023)[20]
Rationale and aims	To investigate the effect of the LSVT-BIG exercise program on balance, balance confidence, lower limb strength, mobility, and subjective reports of mobility in an individual with iNPH.	To investigate the feasibility of an acute effect of AO on gait and mobility in individuals with iNPH post-shunt surgery.	• To present a home-based physical exercise program for individuals with iNPH and to evaluate its adherence, acceptance, and applicability. • To compare the effect of a home-based physical exercise program between individuals with and without shunt surgery on gait, QoL, activities of daily living, static and dynamic balance, and its impact on the risk of falling.	To evaluate the effect of an added physical exercise program on outcomes and goal attainment for individuals with iNPH post-surgery compared to a control group.	• To evaluate short-distance walking, functional exercise capacity, functional strength, and activity and sleep variables before, 3 and 6 months after shunt surgery in individuals with iNPH. • To evaluate the effect of a physical exercise program on the same variables.	• To verify the effect of DEGT compared with SE and no postoperative rehabilitation in individuals with iNPH post-shunt surgery. • To compare fall incidence among individuals with iNPH who underwent DEGT SE, and no further rehabilitation.
Design/ Allocation	A case study	A single-group study	Non-RCT	RCT, 1:1 allocation using sequentially sealed envelopes	RCT, 1:1 allocation using sequentially sealed envelopes	Three-arm cluster RCT, 1:1:1 allocation through a computer-generated random sequence
Blinding	Not relevant	Not relevant	Not reported	Single-blinded (assessor)	Single-blinded (assessor)	Single-blinded (assessor)
Duration	4 weeks	1 session	10 weeks	12 weeks	12 weeks	6 weeks
Setting	Clinic, USA	Outpatient clinic at a hospital, Thailand	Participant's home and outpatient clinic at a hospital, Brazil	Two outpatient clinics at the hospitals, Sweden	Two outpatient clinics at the hospitals, Sweden	Outpatient clinic at a hospital, Japan
Participant numbers and demographics	**Diagnosis**: NPH **Number**: 1 with post-shunt surgery **Sex**: male **Age**: 62 years **MoCA**: 25 points **Disease duration**: 16 years **Time post-shunt surgery**: 1 month	**Diagnosis**: iNPH **Number**: 27 with post-shunt surgery **Sex**: 21 men and 6 women **Age**: 76.81 ± 5.53 years **MoCA**: 20.44 ± 4.07 points **Time post-shunt surgery**: 0.06-11.00 years	**Diagnosis:** iNPH or secondary NPH **Number**: 52, classified into shunted ($n = 26$) and non-shunted ($n = 26$) groups. **Sex**: 22 men and 30 women **Age**: Shunted (73.0 ± 13.5 years) and non-shunted (75.1 ± 7.7 years) **MMSE**: Shunted	**Diagnosis:** iNPH **Number**: 109 with post-shunt surgery, classified into exercise group ($n = 50$) and control group ($n = 59$) **Sex**: 65 men and 44 women **Age**: Exercise (72.1 ± 5.7 years) and control (75.0 ± 7.0 years) **MMSE**: Exercise	**Diagnosis:** iNPH **Number:** 109 with post-shunt surgery, classified into exercise group ($n = 50$) and control group ($n = 59$) **Sex:** 65 men and 44 women **Age**: 73.7 ± 6.6 years **MMSE**: 26.0 ± 3.0 points	**Diagnosis:** iNPH **Number**: 70, classified into the DEGT ($n = 23$), SE ($n = 23$), and control ($n = 24$) groups. **Sex**: 40 men and 30 women; DEGT (13 men), SE (15 men), and control (12 men). **Age**: DEGT (77.6 ± 5.1 years), SE (77.3 ± 4.1 years), and control

(*continues*)

Table 1. Study Methods, Participant Characteristics, Outcomes, and Results and Conclusions of Included Studies (*Continued*)

Study ID	Fillmore et al. (2020)[17]	Hnin et al. (2021)[18]	Modesto et al. (2019)[19]	Rydja et al. (2021)[21]	Rydja et al. (2022)[22]	Nikaido et al. (2023)[20]
			(22.0 ± 5.2 points) and non-shunted (17.0 ± 7.3 points)	(26.2 ± 3.1 points) and control (25.6 ± 3.0 points)		(76.8 ± 5.2 years) **MMSE**: DEGT (25.0 ± 4.5 points), SE (25.1 ± 3.1 points), and control (24.3 ± 3.8 points)
Inclusion criteria	• Had clinical symptoms which were excellent candidate for the LSVT-BIG exercise program. • Exhibit hypokinesia, postural control deficits and gait impairments • Had difficulties while turning, stepping over objects, and during any activity	• Age >60 years • Both sexes • Received any kind of shunt surgery • Able to follow instructions • No visual or auditory impairments after correction by glasses or hearing aid • Could walk with or without assistive device at least 10 m	• Age >18 years • Both sexes • Had not yet received shunt surgery	• Diagnosed with iNPH according to the international guidelines • Awaiting shunt surgery	• Diagnosed with iNPH according to the international guidelines • Awaiting shunt surgery	• Diagnosed with iNPH according to the criteria • Awaiting shunt surgery
Exclusion criteria	Not detailed.	• Non-responsive to shunt surgery • Unstable vital signs • Severe musculoskeletal problems • Severe pain affecting gait and mobility • Significant cognitive impairment • Unable to follow instructions	• Inability to walk • Severe labyrinth diseases • Psychiatric disorders • Parkinson's disease • Malignancy • Severe visual acuity limitation • Deficits in comprehension of verbal commands • Being in physical therapy treatment • Recent participation in physical therapy or a physical conditioning program	• MMSE <16 points • Inability to walk with or without walking aids for >10 m • Conditions precluding intensive exercise	• MMSE <16 points • Inability to walk with or without walking aids for >10 m • Conditions precluding intensive exercise	• Negative tap test • Previous shunt surgery • MMSE <18 points • Additional disorders interfering with gait • Inability to walk assisted or unassisted for at least 15 m
Control group	None	None	None. Both groups received the same exercise intervention.	A usual care routine about physical activity and 8-standardized low-intensity home-based exercises	No intervention	• Active control group: standard exercise • Inactive control group: none

(*continues*)

Table 1. Study Methods, Participant Characteristics, Outcomes, and Results and Conclusions of Included Studies (*Continued*)

Study ID	Fillmore et al. (2020)[17]	Hnin et al. (2021)[18]	Modesto et al. (2019)[19]	Rydja et al. (2021)[21]	Rydja et al. (2022)[22]	Nikaido et al. (2023)[20]
Dropouts	Dropouts $n = 0$ (0%)	Dropouts $n = 0$ (0%)	Dropouts $n = 0$ (0%)	Dropouts $n = 18$ (16.51%) *Exercise group n = 12 (24%)* *Control group n = 6 (10%)*	Dropouts $n = 18$ (16.51%)	Dropouts $n = 5$ (7.14%) *DEGT n = 1 (4.35%)* *SE n = 2 (8.70%)* *Control n = 2 (8.33%)*
Outcomes	BBS, TUG, TUG cognitive, ABC scale, 5TSTS test, and a timed floor transfer	Step length and time, stride length and time, cadence, gait speed, sit-to-stand time, 3-m walk time, turning time and step, and TUG	FIM, BBS, DGI, iNPH grading scale, QoL-AD scale, and TUG	iNPH total scale and subscale: gait, balance, neuropsychology, and continence and modified version of GAS	10MWT, 6MWT, 30sCST, number of steps per minute, TEE, MET, and proportions of time participants were asleep during daytime and nighttime	FGA, 10MWT, TUG, LSA, and fall incidence
Results and conclusions	Improvements, exceeding [a]MDC values, were noted onBBS (increased from 34 to 54 points), ABC (increased from 36.3 to 82.2%), faster floor transfer time (reduced from 8.26 to 5.56 s). No changes for TUG, TUG cognitive and manual, or 5TSTS times. Therapists may consider using LSVT-BIG exercise program in the training for iNPH, especially those who have hypokinesia and bradykinesia.	Significant improvements in step time ($P = 0.002$, [b]Cohen's $d = 0.7$), early step time ($P = 0.005$, $d = 0.6$), gait speed ($P = 0.044$, $d = 0.2$), sit-to-stand time ($P < 0.001$, $d = 0.4$), and turning time ($P = 0.049$, $d = 0.2$) were found after applying a single session of AO, whereas no change in the remaining outcomes. So, a single session of AO had a slight effect on improving the temporal parameters of gait temporal parameters of gait, sit-to-stand, and turn. This suggests that therapists may modify the AO method in the training program to improve gait and other mobility performance for individuals with iNPH.	Both shunted and non-shunted groups had improvements ($P < 0.001$) in FIM ($d = 0.2$ for both groups), BBS ($d = 0.2$ for shunted and $d = 0.1$ for non-shunted), DGI ($d = 0.2$ for shunted and $d = 0.1$ for non-shunted), and TUG ($d = 0.2$ for shunted and $d = 0.1$ for non-shunted) after 10-week exercise, and those improvements were maintained during the 18-week follow-up period. There was no significant difference in the data between both groups. No change for the iNPH grading and QoL-AD scales was found.	In both groups, significant improvements ($P < 0.001$) in the iNPH total scale and subscales were found after 12-week exercise (d ranged from 0.6 to 1.0 for exercise, and d ranged from 0.4 to 0.9 for control) and 6-month follow-up (d ranged from 0.6 to 1.3 for exercise, and d ranged from 0.6 to 1.1 for control) with no significant difference found between groups. Except for the balance subscale which showed more improvement in the exercise group ($P = 0.008$, $d = 0.6$) at the 6-month follow-up. The proportion of individuals who reached the goal was the same in both groups both after 12-week exercise and 6-month follow-up. Findings indicate that physical exercise and goal setting can be	All individuals with iNPH significantly improved ($P < 0.001$) at 3-month post-shunt surgery in the 10MWT ($d = 0.9$), 6MWT ($d = 0.6$), and 30sCST ($d = 0.7$), and the results were maintained after 6 months. Actigraphic recording for voluntary walking step and night time sleep were improved after 6 months. But no significant difference in measured variables between the exercise and control groups, except for daytime sleep after 3 months ($P = 0.042$, $d = 3.5$). In conclusion, the exercise program did not affect the measured outcomes.	Compared to the other two groups, the DEGT group demonstrated a significant improvement (group effect, $P = 0.039$) of FGA at 7-week post-intervention ($d = 1.1$ for DEGT × SE and $d = 1.1$ for DEGT × control) and 6-month follow-up ($d = 1.0$ for DEGT × SE and $d = 1.1$ for DEGT × control). DEGT group had a significantly lower fall incidence than the other two groups at follow-up (reduced from around 73 to 10% for DEGT, 72 to 32% for SE, and 60 to 35% for control). Significantly better LSA results were observed for all groups at follow-up compared to baseline ($d = 1.4$ for DEGT, $d = 0.9$ for SE, and $d = 0.6$ for control); however, no difference in LSA was observed between groups. So,

(*continues*)

Table 1. Study Methods, Participant Characteristics, Outcomes, and Results and Conclusions of Included Studies (*Continued*)

Study ID	Fillmore et al. (2020)[17]	Hnin et al. (2021)[18]	Modesto et al. (2019)[19]	Rydja et al. (2021)[21]	Rydja et al. (2022)[22]	Nikaido et al. (2023)[20]
				effective for individuals with iNPH.		DEGT was suggested to implement to improve gait-balance function and reduce the fall incidence of individuals with iNPH.

Abbreviations: 10MWT: 10-meter walking test; 30sCST: 30-second chair stand test; 5TSTS: 5-time sit-to-stand test; 6MWT: 6-minute walking test; ABC: Activities-Specific Balance and Confidence; AO: Action Observation; BBS: Berg Balance Scale; *d*: Cohen's *d*.; DEGT: Dynamic Equilibrium Gait Training; DGI: Dynamic Gait Index; FGA: Functional Gait Assessment; FIM: Functional Independence Measure; GAS: Goal Attainment Scale; iNPH: idiopathic normal pressure hydrocephalus; LSA: Life-Space Assessment; LSVT-BIG: Lee Silverman Voice Treatment-BIG; MDC: minimal detectable change; MET: metabolic equivalent of task; MMSE: Mini-Mental State Examination; MoCA: Montreal Cognitive Assessment; QoL: Quality of Life; QoL-AD: Quality of Life-Alzheimer's Disease; RCT: randomized controlled trial; SE: standard exercise; TEE: total energy expenditure; TUG: timed up and go test.

[a] MDC value criteria obtained from the studies conducted in patients with Parkinson's disease; MDC of BBS of 5 points,[24] MDC of ABC scale ranged from 11.1% to 13%.[24,28.]

[b] Cohen's *d* criteria for within- and between-group comparison classified into small (0.2), medium (0.5), and large (≥0.8) effect size.[23]

RESULTS

A total of 562 articles were retrieved. Fifty-four articles were identified in PubMed, 37 in Embase, 208 in LILACS, 21 in CINAHL, and 242 in SpringerLink. After excluding duplicates, 445 potential articles were identified. After examining titles and abstracts, 416 articles were excluded, leaving 29 articles for full-text review. Upon review, 5 articles met the inclusion criteria. One additional article was identified through a bibliographic search of the selected full-text articles. All 6 articles, representing 5 unique study projects, demonstrated moderate to good methodological quality, as screened by the JBI critical appraisal checklists according to the study design (Supplementary file 2. http://links.lww.com/JGPT/A296). Therefore, 6 articles were included in the scoping review process. The PRISMA 2020 flow diagram[15] of the study selection is shown in Figure 1.

Intervention Details and Replication

The study methods, participant characteristics, outcomes, and conclusions are summarized in Table 1. The included studies, which involved a total of 259 individuals with iNPH, were published between 2019 and 2023 and are summarized in this section. The study designs included a case study,[17] a single-group study,[18] a non-RCT study,[19] and two RCTs.[20-22] Notably, two articles reported on the same RCT with different outcome focuses,[21,22] while the third article involved a separate participant group.[20] The exercise interventions varied, including the Lee Silverman Voice Treatment (LSVT)-BIG exercise program,[17] Dynamic Equilibrium Gait Training (DEGT),[20] High-Intensity Functional Exercise (HIFE™),[21,22] Action Observation (AO),[18] and home-based exercise (stretching exercises for the back, gluteal, and trunk; strengthening exercise for shoulder, arm, and leg; and balance training).[19] Statistical significance was determined using *P*-values, and effect sizes (Cohen's *d*) were calculated to interpret the clinical importance of outcomes with small (0.2-0.49), moderate (0.5-0.79), and large (≥0.8) effects.[23]

The intervention details for each study, summarized in Table 2, followed the TIDieR checklist,[14] providing comprehensive information on procedure (100%), fidelity of implementation (60%), and tailoring and modifications (83%). All studies clearly outlined the rationale, theoretical background, and goals of the interventions. Most studies (67%) specified that physical therapists were the intervention providers; however, two studies did not explicitly state this despite the likelihood of physical therapist involvement.[17,18] Intervention settings ranged from clinics to participants' homes, with 1 study employing a one-on-one delivery format.[20] Adherence was reported in 1 study (20%), using exercise diary to maintain engagement.[19] Although some studies reported dropout rates, particularly in the HIFE™ program (up to 24%),[21,22] various strategies such as tune-up sessions,[17] videos,[18] and standardized manuals[21] were used to enhance implementation fidelity. No modifications to the interventions were reported in any of the studies.

Table 2. Intervention Details of Included Studies

Study ID	**Fillmore et al. (2020)[17]**	**Hnin et al. (2021)[18]**	**Modesto et al. (2019)[19]**	**Rydja et al. (2021)[21]**	**Rydja et al. (2022)[22]**	**Nikaido et al. (2023)[20]**	***n*/ *N* (%)**
Brief name	The LSVT-BIG exercise program	The AO	Home-based physical exercise program	The HIFE™ program	The HIFE™ program	The DEGT	6/6 (100)
Components of intervention	• Standardized 4-week LSVT-BIG training program • The additional home-based exercise program included 7 maximal daily exercises involving multidirectional movements and stretching, along with BIG walking and instructions to use maximal movements in daily activities. • 5 tune-up sessions of exercise. • Progression: increased exercise complexity repetitions, and reduced verbal, visual, and tactile feedback.	• Stretching and relaxation exercise with a breathing exercise followed by an AO protocol. • Video clips depicting healthy participants walking in a straight line and executing the timed up and go test from different perspectives (front, back, left, and right lateral views).	Active and passive range of motion for the back, gluteal, and trunk regions; strengthening for upper and lower limbs; balance training; gait; facilitating ADLs.	• All groups: Usual care routine with written and oral information about physical activity and low-intensity home-based exercise program • Additional in-clinic, physical therapist supervised HIFE program	Includes functional, weight-bearing exercises designed to improve balance and gait. It emphasizes lower limb strengthening, balance training targeting both static and dynamic stability, and high-intensity functional tasks based on daily activities, such as rising from a chair, walking over obstacles, and turning.	• All groups: Fall prevention education • After shunt surgery, the DEGT group engaged in specialized gait-balance training involving dynamic movements, while the SE group received standard exercises • The DEGT and SE groups were recommended to conduct the same program at home as self-exercise.	6/6 (100)
Procedures (frequency, duration, and intensity)	• **Frequency**: 4 sessions per week (clinic), daily home exercises (1-2 times per day). • **Duration**: 1.5 hours per clinic session, 30 minutes per home session (estimated)[*]. • **Total program length**: 4 weeks. • **Total dose**: 36 hours (24 hours of clinic-based exercise + 12 hours of home-based exercise). • **Intensity**: Maximal daily exercises with progression	• **Frequency**: 1 session. • **Duration**: 17.5-22.5 minutes (10-15 minutes for breathing exercises + 7.5 minutes for video clip watching) • **Total program length**: 1 day • **Total dose**: 17.5 to 22.5 minutes • **Intensity**: Not applicable (participants only engaged in breathing exercises and watched a video demonstration).	• **Frequency**: 3 sessions per week. • **Duration**: 60 minutes per session (estimated)[*]. • **Total program length**: 10 weeks. • **Total dose**: 30 hours (3 sessions × 60 minutes/ session × 10 weeks). • **Intensity**: Moderate intensity,	• **Frequency**: 2 sessions per week. • **Duration**: 60 minutes per session. • **Total program length**: 12 weeks. • **Total dose**: 24 hours. • **Intensity**: High-intensity functional weight-bearing exercises.	• **Frequency**: 2 sessions per week. • **Duration**: 60 minutes per session. • **Total program length**: 12 weeks. • **Total dose**: 24 hours. • **Intensity**: High-intensity functional weight-bearing exercises.	• **Frequency**: 1 session per week. • **Duration**: 60 minutes per session. • **Total program length**: 6 weeks. • **Total dose**: 6 hours. • **Intensity**: Moderate to high intensity, focusing on dynamic balance and gait training	6/6 (100)

(*continues*)

Table 2. Intervention Details of Included Studies (*Continued*)

Study ID	**Fillmore et al. (2020)[17]**	**Hnin et al. (2021)[18]**	**Modesto et al. (2019)[19]**	**Rydja et al. (2021)[21]**	**Rydja et al. (2022)[22]**	**Nikaido et al. (2023)[20]**	***n/ N* (%)**
	(increasing complexity and repetitions, decreasing feedback).		functional balance, and strengthening exercises.				
Intervention provider	Not clear	Not clear	Physical therapist specialized in neurological rehabilitation	Local physical therapists	Local physical therapists	Physical therapist	4/6 (67)
Fidelity of implementation	• The standardized LSVT-BIG training program, incorporating supervision and feedback, was used.	Not relevant	• An adapted exercise booklet was provided to help participants follow the program effectively. • The researcher conducted 3 home visits to facilitate the participant's learning of the exercise program.	• A standardized exercise manual and protocol were prepared and distributed to local physical therapists to ensure proper implementation of the program.	• Not clear	Not reported	3/5 (60)
Tailoring and modifications	The exercise program was tailored to the participant's goals and modified incorporate to participant's ability.	• The video was tailored to each participant by selecting a speed based on their baseline walking ability. To promote progression, the speed was then increased by 10-15% to provide a manageable challenge, to excourage motor	Designed and adapted individually to perform independently and safely.	• Both groups set their individual goals. • To increase exercise progression, a weight belt was used.	Not reported	Fequency and intensity of each exercise were adjusted by physical therapist according to the participant's ability.	5/6 (83)

(*continues*)

Table 2. Intervention Details of Included Studies (*Continued*)

Study ID	Fillmore et al. (2020)[17]	Hnin et al. (2021)[18]	Modesto et al. (2019)[19]	Rydja et al. (2021)[21]	Rydja et al. (2022)[22]	Nikaido et al. (2023)[20]	*n*/ *N* (%)
	🟩	learning and improvement.	🟩	🟩	🟥	🟩	
Comparator intervention(s)	Not relevant	Not relevant	None. Both shunted and non-shunted groups received the same exercise intervention.	Usual care routine with written and oral information about physical activity and a low-intensity home-based exercise program.	No intervention	• The inactive control (control) group received no exercise intervention.	3/4 (75)
Intervention adherence	Not reported	Not relevant	Exercise diary	Not reported	Not reported	Not reported	1/5 (20)

🟩 Fully reported 🟨 Partially reported 🟥 Not reported 🟦 Not relevant

Abbreviations: ADLs: Activities of Daily Living; AO: Action Observation; DEGT: Dynamic Equilibrium Gait Training; HIFE™: High-Intensity Functional Exercise; LSVT-BIG: Lee Silverman Voice Treatment-BIG; *n*: counted number; *N*: total number that should be reported; SE: standard exercise.

*Estimated duration: The durations marked as estimated (*) were not explicitly reported by the authors in the original paper. The estimated times were derived based on the exercise details and instructions provided in the study.

DISCUSSION

The findings of this review suggest that exercise prescribed by physical therapists may improve gait and functional performance in individuals with iNPH. However, it is important to acknowledge that the evidence is limited relying on studies with small sample sizes or methodological limitations, thus limiting its generalizability.

Physiological and Biomechanical Mechanisms of the Interventions and Their Impact on the Outcomes

Physiological and biomechanical mechanisms supporting the benefit of different types of exercise varied according to the specific concepts used. For example, motor neuron activation is a key mechanism in AO training, while amplitude training and sensory recalibration are important for the LSVT-BIG program. Muscle strengthening, along with improvements in balance and mobility, is the primary mechanism of the HIFE™ program. These mechanisms reflect the diverse approaches that may benefit individuals with iNPH.

LSVT-BIG: Although the pathophysiology of Parkinsonian symptoms in iNPH is not conclusively understood, it has been hypothesized that abnormal pulsation of CSF flow may produce secondary damage to the nigrostriatal dopaminergic pathway and downregulation of postsynaptic dopamine 2 receptor binding in the striatum and putamen.[24] Thus, individuals with iNPH can exhibit hypokinetic walking similar to individuals with Parkinson's disease (PD).[25] The LSVT-BIG exercise program is an established training program aimed to achieve bigger, faster, and more precise movements in persons with PD.[26]

In a case study involving an individual with iNPH, a standardized 4-week LSVT-BIG exercise program was implemented with ~1.5 hour sessions addressing the participant's distractibility.[17] An improvement of 20-point increase in Berg Balance Scale (BBS) score from baseline to post-intervention was noted. In addition, 5 tune-up sessions were performed at 7.5 months after the initial 4-week intervention. Tune-up sessions led to an increase of 6 points for BBS after it went down by 7 points at the 4-month follow-up time period. The training progressively incorporated more complex exercises, increased repetitions, and provided multisensory feedback (verbal, visual, and tactile). Outcomes also included significant improvement (45.9%) in Activities-Specific Balance Confidence (ABC) scores from baseline to post-intervention. This improvement decreased by 11.9% at the 4-month follow-up and remained unchanged following the tune-up sessions. These improvements exceeded the minimal detectable change (MDC) of BBS of 5 points[27] and the MDC of ABC scale that ranged from 11.1 to 13%.[27,28] Faster floor transfer time was found after the intervention, with a decrease of 3.16 seconds. While these improvements diminished over time, they were regained following the tune-up sessions. Thus, individuals with iNPH may need to continue exercising regularly to maintain their functional abilities. Larger clinical trials would be needed to effectively establish the effect of this intervention in individuals with iNPH.

AO: involves the dynamic process of observing meaningful actions with the intention to imitate and then practicing those actions.[29] Mirror neuron activation is observed not only during action performance but also during observation of the same action.[30] A study conducted by Hnin et al.[18] used video clips of a healthy older adult walking from various perspectives with different speeds shown to a small group of older adults with iNPH. A single session of AO training showed within-group benefits on several gait variables with small to medium effects, including the step time (d = 0.7), early step time (d = 0.6), gait speed (d = 0.2), sit-to-stand time (d = 0.4), and turning time (d = 0.2). However, this study did not include a control group. A single training session lacks therapeutic validity and larger clinical trials with an evidence-based dose of intervention would be needed to establish the effect of AO.

Home-based exercise including stretching exercises for the back, gluteal, and trunk; strengthening exercise for shoulder, arm, and leg; and balance training: Modesto et al.[19] reported that using a home physical exercise program for individuals with iNPH was feasible, with no adverse events and good adherence. Thirty sessions of a home-based program over a 10-week duration were sufficient to improve gait, balance, and Activity of Daily Living variables, with small effects (d = 0.2) in individuals with iNPH both with and without shunt surgery. Specifically, adherence was indicated by the completion of 30 sessions performed 3 times a week, with 84.6% of patients reporting that the program was effective and 82.7% reporting no difficulties in performing the exercises. The authors indicated that each exercise was performed for 20 repetitions for exercises 1-5 (stretching and strengthening exercises) and 10 repetitions for exercises 6-7 (balance exercises). All exercises were repeated twice with a 1-minute break between sets. Individuals were taught and guided through the exercise program by a neurological physical therapist. In addition, home visits were given by the research team to ensure effective implementation.

HIFE™: The exercise program initially developed by physical therapists, Håkan Littbrand, Erik Rosendahl, and Nina Lindelöf to train frail older adults,[31] was more recently adapted for individuals with iNPH.[21,22] The exercise program is designed to promote static and dynamic balance and lower extremity strength and mobility. Physical therapists select exercises based on a baseline assessment to best suit each patient's abilities.

In a study by Rydja et al., the effects of adding the HIFE™ program to a standardized home-based exercise routine for individuals with iNPH were compared to a home-based exercise routine alone.[21] Both the experimental and control groups received the same written and oral information about physical activity and performed 8 standardized low-intensity home-based exercises as part of usual care. The experimental group, in addition, participated in the HIFE™ program, which consisted of 1-hour sessions twice a week over 12 weeks. Using intention-to-treat analysis, improvements were observed in the iNPH scale and its subscales for both groups after the 12-week program and at the 6-month follow-up, with no significant differences between them in overall outcomes. However, the experimental group showed greater improvement in the balance subscale at the 6-month follow-up, with a medium effect size (d = 0.6). Furthermore, a higher proportion of participants in the experimental group achieved their set goals at the 12-week mark (65.9% in the exercise group vs. 52.0% in the control group), and similar proportions reached their goals at 6 months (56.5% in the exercise group vs. 54.0% in the control group).

Interestingly, no significant differences between the experimental and control groups were noted for 10-Meter Walk Test (10MWT), the 6-Minute Walking Test, or the 30-Second Chair Stand Test.[22] The only exception was daytime sleep, which showed a large difference at 3 months (d = 3.5). Notably, the control group received only usual care with no additional intervention. Interestingly, a high dropout rate (16.51%) was noted in this study, which might have affected some of their results. Effective exercise interventions often require adequate participant engagement and consistency to achieve meaningful outcomes. For older adults with poor mobility, engaging in exercise at least 3 times a week is crucial to strengthen major muscle groups, improve balance, and reduce the risk of falls.[32] This level of engagement may have been lacking due to the high dropout rate, limiting the potential benefits of their intervention, especially in frail older adults.

DEGT: The DEGT is an exercise method designed for individuals with iNPH to improve balance and decrease the risk of falls.[20] Individuals practice transferring weight and enhancing vestibular function over multidirectional movements. The exercise program included (1) acceleration-deceleration gait, (2) figure eight walking (repeated gait with horizontal head and body turning), and (3) tandem gait. Gait and mobility variables [Functional Gait Assessment (FGA), 10MWT, and timed up and go] were improved in all three groups of iNPH post-shunt surgery (DEGT, standard exercise, and controls). Improvement of the outcomes was maintained at the follow-up in all groups which was possibly a result of surgery. A superior benefit of DEGT was found on FGA with large effects after 7 weeks of exercise when compared to the standard exercise (d = 1.1) and control groups (d = 1.1) and at the 6-month follow-up (d = 1.0 and 1.1 when compared to standard exercise and control groups). In addition, the DEGT group showed a 63% reduction in fall incidence, which was significantly greater than the other two groups. Specifically, the fall incidence in the DEGT group was significantly lower compared to the standard exercise group (P = 0.016) and the control group (P = 0.034), indicating a substantial benefit of the DEGT in reducing fall risk for individuals with iNPH.

Factors Contributing to the Effect of the Intervention

The success of the exercise interventions is likely influenced by a range of factors, including age, duration of disease, duration post-shunt surgery, and comorbidity diseases. Notably, the mean age of the participants in almost all studies included in this review study was over 70 years.[18-22] Reporting of the higher mean age in these studies was consistent with a previous systematic review study that reported a higher pooled prevalence of iNPH in people older than 65 years.[33] The disease duration may be another factor affecting the treatment success; however, this factor is typically under-reported due to the exact disease duration being unknown and a lack of definitive methods to confirm the diagnosis.[34] Disease duration has been reported in some studies[17,19,20]; however, these studies did not report its influence on the changes in motor function.

Current medical diagnosis and treatment for iNPH focus on excessive CSF removal using tap test and shunt surgery.[6] It has been reported that the effectiveness of the shunt surgery depended on the age of the individuals and time after surgery and declines 4 years following surgery.[35] However, none of the studies reported a relationship between post-shunt surgery duration and exercise in individuals with iNPH. Only one reviewed study compared the effects of exercise between surgical and nonsurgical patients and found no statistically significant differences across testing variables.[19] Several comorbidity diseases such as hypertension,[17,18,21,22] diabetes mellitus,[17,18,21,22] heart disease,[18,21,22] PD,[18] smoking,[21,22] and stroke[21,22] were reported in individuals with iNPH. These comorbidity diseases can occur in an individual when age increases, and problems related to these comorbidities could affect the ability to follow exercise programs.[36]

The summary for this review study may be limited by a few number of studies and low research quality. A small sample size,[17,18,20] a large drop out of participants during the study,[21] physical therapist's expertise in a specific training program,[17,18,20,21] a lack of an active control group used to compare the effect of a proposed exercise program,[18] and/or no control group without iNPH used as the reference[19,21,22] made it difficult to recommend any exercise program. Additional considerations in choosing a form of exercise are suitability to the individual's problems, degree of severity, complications after shunt surgery, and difficulty of training. As observed from a high dropout rate in an intensive exercise program, this may be too difficult to follow by individuals with iNPH, especially those with moderate to high severity.

CONCLUSIONS

Several types of exercise programs prescribed by physical therapists including the LSVT-BIG exercise program; AO; home physical exercise including stretching exercises for the back, gluteal, and trunk; strengthening exercise for shoulder, arm, and leg; and balance training, HIFE™, and DEGT showed benefits to gait and functional performance in individuals with iNPH. The studies described the interventions well enough to allow the interventions to be replicated. However, there were serious limitations in the research quality and very few studies included measures of the effects of exercise on gait and balance. Therefore, larger-scale randomized clinical trial studies are needed to elucidate the effect of exercise in individuals with iNPH and to provide recommendations regarding the optimal mode and dose of exercise.

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