Digital Physiotherapeutic Vision-Specific Training System for Patients with Diabetic Retinopathy: A Propensity Score Matched Retrospective Cohort Study

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Supplementary Materials

Methods

Interventions

12-week training program for digital physiotherapeutic vision-specific training

Week	Goals	Assessments	Exercise Content & Frequency	Home Exercise	Weekly Progress Evaluation
Week 1 (Initiation)	Establish baseline functional status and safety. Introduce patient to the digital platform and exercise routine. Set personalized rehabilitation goals.	Baseline Evaluation: Comprehensive intake by physiotherapist via video. Measure initial visual function (VA, contrast), mobility (Timed Up and Go), balance (e.g. semi-tandem stance), and patient-reported difficulties. Evaluate home environment for safety (lighting, hazards).	Orientation & Basic Exercises: Guided by the app and therapist, learn fundamental exercises: simple eye movement and scanning drills, posture alignment, and gentle balance exercises with support (e.g. feet apart stance for 10–30s). Begin light stretching and lower-extremity strength exercises (sitting-to-standing practice, heel raises) . Frequency: 30 min daily (can be split into 10–15 min sessions), 5–6 days this week. Therapist conducts a 1-hour video call to coach and ensure correct form.	Setup & Habit Formation: Set up adaptive tools (proper lighting, contrast markings in home). Practice using the app independently. Perform short home tasks using new strategies (e.g. locating high-contrast objects in a room).	Progress Check: Ensure patient is comfortable with technology and exercises. Verify adherence through app logs and daily diary. Address any difficulties or safety concerns. No formal outcome measures this week beyond baseline, but patient feedback on exercise difficulty is recorded.
Week 2 (Foundation)	Improve foundational visual scanning and body awareness. Build confidence with basic	Technique Assessment: Therapist reviews Week 1 exercise technique during video session. Check balance with narrow stance (eyes open) duration and gait safety in home. Confirm patient can locate app interface elements	Visual Scanning & Stance: Continue Week 1 routines, increasing difficulty slightly: narrower stance balance exercises and longer hold times to improve stability. Introduce visual scanning exercises: e.g. finding letters or objects on a screen or in the room (using eccentric viewing if low central vision). Add light aerobic movement	Daily Home Practice: Perform scanning tasks around the home (e.g. identify five household items by sight each day to train visual search). Continue daily balance practice near a support (chair or wall) for safety. Maintain a log of	Progress Check: Monitor adherence (app data) and any symptoms (e.g. dizziness, fatigue). Therapist notes improvements in balance (e.g. able to stand semi-tandem longer) or scanning (quicker item location)

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	exercises.	(for accessibility).	in place (marching for 2–3 min) to begin endurance training. Frequency: 30 min daily (balance, stretching, scanning tasks), 5–6 days. One supervised video session (45 min) to reinforce techniques.	exercise completion (the app provides reminders).	qualitatively. Provide feedback and adjust exercise difficulty if tasks are too easy or hard.
Week 3 (Integration)	Integrate visual and motor skills (hand–eye coordination). Increase lower limb strength and dynamic balance.	Balance & Coordination Test: Assess single-leg stance (with support as needed) for a few seconds to gauge balance progression. Observe a simple hand–eye coordination task (e.g. reaching for moving object) during the video call. Ensure no new fall incidents.	Coordination Exercises: Add exercises that combine vision and movement: for example, catching a large contrast-colored ball from a short toss (or virtual ball-catching game in app) to train hand–eye coordination and reaction. Incorporate dynamic balance drills such as stepping in different directions to targets on the floor (using tape markers) while using gaze shifts to locate them. Continue strength training: wall push-ups, mini-squats or step-ups (holding a support) to build lower-body strength for mobility. Frequency: 30 min daily, including prior exercises and new additions. Supervised session (45 min) to practice coordination drills safely.	Home Exercise: Practice a coordination activity daily (e.g. throw and catch a beanbag with a family member or toss it against a wall and catch). Perform stepping tasks around the home: navigate to a specific object across the room, emphasizing turning the head and scanning with remaining vision rather than shuffling blindly. Continue prior balance and strength exercises on non-supervised days.	Progress Check: Note any improvement in coordination (e.g. patient can catch the ball more often or touch targets more accurately over the week). Review exercise log for compliance. If the patient felt unsteady, modify balance tasks (e.g. allow holding on with one hand). Ensure the difficulty is progressive but safe. Patient's confidence level in walking around home is discussed and compared to Week 1.
Week 4 (Enhancement)	Enhance balance under varying conditions and build endurance. Introduce dual-	Endurance & Balance Review: Measure ability to maintain tandem (heel-to-toe) stance for a set time and note any sway. Check aerobic endurance by a simple test	Advanced Balance & Aerobic Training: Progress balance exercises: tandem stance and single-leg stands (with support nearby) to challenge postural control. Add gentle dynamic moves like side-to-side weight shifts or a heel-to-toe walk along a	Home Exercise: Aim for at least 10 minutes of continuous brisk walking in place or corridor (if safe) each day to build stamina (can be broken into shorter bouts	Progress Check: Track improvement in endurance (patient reports less fatigue and can march longer). No falls or near-falls are reported this week; if any were,

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	task exercises (cognitive + motor).	(e.g. stepping in place for 2 minutes and rating perceived exertion). Assess ability to do a dual task (e.g. simple mental math while balancing) to see if balance worsens with distraction.	line on the floor. Introduce a low-impact aerobic component: e.g. marching in place or stationary cycling (if available) for 5–10 minutes to improve cardiovascular fitness and gait endurance. Begin dual-task practice: have patient count aloud or recite something while doing a balance exercise, mimicking real-life distractions. Frequency: 30–40 min daily (including 10 min aerobic activity) on 5 days; 1 day of rest. One video session to supervise new balance challenges.	initially). Continue daily balance practice now trying with slight head movements or reduced hand support as confidence allows (e.g. holding with one fingertip). Practice dual-task by doing a simple cognitive task (like naming items in a category) while balancing or walking with a sighted companion.	discuss circumstances and reinforce safety strategies. Balance confidence is re-assessed through patient's self-report (e.g. how comfortable they feel walking in dim areas now). Adjust exercise intensity (increase marching duration or add light ankle weights) if patient is tolerating well.
Week 5 (Visual Skills Focus)	Improve near-vision tasks like reading and object recognition. Introduce assistive device techniques (if needed).	Reading Ability Assessment: Using large-print text, have the patient read a short passage during the video call to gauge reading speed and accuracy with their current strategies or devices (if any). Evaluate use of any low-vision aids: ensure proper technique with magnifiers or text-to-speech apps.	Reading & Fine Task Training: Begin specific vision rehabilitation exercises: Reading training – practice with gradually smaller print or contrast-enhanced text for a few minutes at a time, encouraging use of optimal viewing position or magnifiers. Teach eccentric viewing techniques if central vision is impaired (patient learns to use peripheral vision by looking slightly off-center from the target). Fine motor visual tasks – e.g. sorting objects by color or threading a large bead, to improve visual attention to detail. Continue general exercises (balance, strength) to maintain gains. Frequency: At least 5 days this week: dedicate 15 min/day to visual exercises (reading	Home Practice: Assign daily reading practice (e.g. read a newspaper headline or short paragraph using a magnifier or the device's zoom feature) for 10 minutes in good lighting. If the patient has no optical aid, use the app's large print materials or audio feedback. Encourage identifying household items by reading labels (with aid as needed) to integrate skills into daily life (e.g. read a recipe or medication label with magnification). Continue physical	Progress Check: Monitor reading improvements: e.g. patient can read more words per minute or smaller print than at start of week, and reports less frustration. Address any device challenges (like alignment of magnifier or screen contrast settings). Also check that physical exercise routine is continuing (review app tracking). If patient felt eye strain, schedule shorter reading bouts with breaks. Reinforce that both visual and physical exercises are

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			or detail tasks) in addition to 15–20 min of balance/strength maintenance. One focused tele-session to coach reading strategies and device use.	exercises on schedule to reinforce prior improvements.	important, linking improved reading confidence to overall quality of life gains .
Week 6 (Midpoint Evaluation)	Re-assess overall progress at mid-program. Adjust individualized goals and exercise intensity based on results.	Mid-program Evaluation: Conduct a structured assessment this week. Repeat key outcome measures to quantify improvement: e.g. VFQ-25 or a short vision function questionnaire for self-reported progress, a Timed Up and Go test, and balance test (compare to Week 1). Check blood glucose log or general health if relevant (since exercise can affect diabetes management). Review patient's goal attainment (which initial goals are met or need work).	Customized Training: Based on assessment findings, modify the program. For example, if balance has improved significantly, introduce more challenging balance exercises (such as standing on a softer surface or gentle heel-to-toe walking with turns). If reading remains a major difficulty, allocate more time to visual training or consider introducing a new assistive tool (like electronic readers). Continue a balanced mix of exercises but intensify or add resistance as appropriate (e.g. ankle weights for leg lifts if strength gains plateau). Frequency: 30–40 min daily, with new adjustments in place. This week's supervised session includes a detailed feedback discussion and demonstration of any new exercises.	Home Exercise: Incorporate any new equipment or techniques into daily practice (e.g. if a contrast-enhancing reading lamp is provided, use it for nightly reading tasks). Maintain aerobic activity if vital signs and energy permit, possibly increase walking in place to 15 min/day. Focus home efforts on areas needing improvement: for instance, if mid-test showed persistent balance issues, do balance exercises twice daily (shorter sessions) with caregiver supervision.	Progress Check: Discuss mid-program assessment outcomes with patient – highlighting improvements (e.g. faster TUG time, higher questionnaire scores) to boost motivation. Also address any domains with less progress and brainstorm solutions (patient and therapist adjust goals collaboratively). Ensure the patient feels the program is appropriately challenging. The therapist records mid-point objective changes (for internal tracking), confirming the intervention is on track to meet noninferiority in functional outcomes compared to standard rehab.
Week 7 (Advanced Mobility)	Challenge the patient with more advanced	Mobility Safety Check: Verify that the patient uses safe techniques in mobility: during the video call,	Obstacle Navigation & Mobility: Create a simple obstacle course at home: e.g. place a few objects (boxes, pillows) in a hallway and have the patient	Home Exercise: With a family member or alone (if safe), practice a real-world navigation task this	Progress Check: Inquire about the patient's experience moving in a more complex setting – any

Week	Goals	Assessments	Exercise Content & Frequency	Home Exercise	Weekly Progress Evaluation
	mobility and real-world vision tasks. Improve confidence in navigating unfamiliar environments safely.	have them simulate walking through a doorway or around obstacles arranged in their home. Assess gait pattern and use of visual cues (do they scan their environment proactively?). If available, review any step counter or activity monitor data for changes in walking activity.	practice walking back and forth negotiating these obstacles under therapist guidance, using sight and cane (if they use one) or trailing technique (hand on wall) for safety. Teach strategies for mobility in low-vision: scanning head movements, using contrast (e.g. light-colored cane tip on dark floor), and safe obstacle avoidance posture (bending knees slightly, shuffling feet less). Continue balance and strengthening exercises emphasizing dynamic components (e.g. stepping over a low obstacle, tandem walk while turning head). Frequency: Daily practice (30 min) that includes 10 min of obstacle negotiation or targeted mobility drills, plus ongoing balance/visual exercises. Weekly video session focuses on observing and coaching these tasks.	week, such as walking to the mailbox or around the yard in daylight. Use techniques learned (bring attention to contrasts, scan for hazards). Indoors, continue obstacle exercises by rearranging the pattern every day to keep it novel. If the patient has a white cane or low-vision aid for mobility, incorporate its use daily, even for short distances, to build habit.	stumbles or anxiety? Note improvements like increased walking distance or willingness to go outdoors (if previously fearful). If the patient successfully navigated obstacles, therapist praises progress and possibly increases difficulty (smaller or more obstacles) next time. Ensure no falls occurred; if they did, conduct a brief root-cause analysis and adjust the program to prevent recurrence (e.g. more caregiver support or simpler tasks). Overall, assess confidence gain in mobility by asking if they feel safer walking compared to start of program.
Week 8 (Strength & Endurance Peak)	Further improve muscular strength and physical conditioning. Emphasize exercises that reduce fall risk	Strength Assessment: Check improvements in functional strength: e.g. how many chair stand repetitions in 30 seconds now vs baseline (sit-to-stand test), or ability to carry light objects across a room. Evaluate endurance	Resistance Training & Conditioning: Add moderate resistance exercises for major muscle groups: for instance, use resistance bands for arm curls and leg extensions to aid in carrying and mobility tasks. Incorporate more challenging balance with movement (like reaching out while standing on one foot, or stepping up onto a low	Home Exercise: Encourage integration of exercise into routine: e.g. doing heel raises while brushing teeth, or wall push-ups at the kitchen counter daily. Aim for at least 150 minutes of moderate physical activity this week	Progress Check: Compare strength and endurance to earlier weeks – patient likely reports daily activities (like climbing stairs or carrying groceries) feel easier than before. Any improvement is reinforced (“You did 3 more chair

Week	Goals	Assessments	Exercise Content & Frequency	Home Exercise	Weekly Progress Evaluation
	and improve daily stamina.	by asking the patient to walk in place during the call for 3 minutes and noting fatigue or shortness of breath (if any).	step stool and back down) to build leg power and vestibular compensation. Increase aerobic duration or intensity: e.g. 15–20 minutes of continuous activity (can be split into 2×10 min) such as brisk marching, dancing to music, or using a stationary bike if available. Continue some vision-focused tasks in between to keep integration (like identifying colored cones or taped markers while doing exercises). Frequency: 5 days/week of exercise; 1–2 days include longer aerobic sessions. Total daily exercise 40 min (including warm-up and cool-down). One tele-session to demonstrate proper form with bands and adjust any difficulties.	(accumulated) in line with general health guidelines, adjusted for visual safety. Continue vision exercises casually, e.g. while resting after aerobic effort, practice focusing on a distant object then a near one to train focusing ability and reduce eye fatigue.	stands than Week 1, which is excellent"). Check for any muscle soreness or joint pain due to increased load; ensure exercises are still done with correct form to prevent injury. Balance confidence and general physical confidence should be notably higher now; therapist may administer a quick questionnaire (e.g. Activities-specific Balance Confidence scale) to quantify this improvement. Adjust future exercises if needed to avoid overexertion as the program nears its peak intensity.
Week 9 (Applied Skills)	Apply visual and physical skills to complex daily tasks. Emphasize real-life scenarios (e.g. household chores, community tasks).	ADL Performance Check: Discuss a specific activity of daily living (ADL) that the patient attempted (e.g. cooking or shopping) and identify any challenges faced. If feasible, have the patient demonstrate a component via video (like pouring water into a cup with contrast markings).	Scenario-Based Training: Simulate common real-life tasks incorporating vision and mobility skills: for example, Kitchen task simulation, practice safe kitchen mobility and food preparation (therapist guides patient to organize workspace, use high-contrast cutting board, and locate items systematically). Outdoor scenario, discuss strategies for walking in a crowded area or crossing a street safely (may role-play during	Home Exercise: Each day, perform one practical activity using the learned techniques: examples, make a simple meal, do a load of laundry (with adaptations like safety pin on black socks to pair them), or visit a nearby shop with a family member, applying navigational strategies. Keep notes	Progress Check: The therapist reviews the patient's experiences: successes are praised (e.g. "prepared a meal independently") and difficulties are addressed with new solutions or tools. By this stage, patients often report greater independence and reduced fear in performing daily tasks. Any

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		Evaluate how well they utilize strategies (e.g. tactile markers on stove dials, proper lighting while chopping food).	session, focusing on visual scanning and auditory cues). Integrate prior exercises into functional tasks: e.g. squatting to pick up dropped objects (strength + balance), using memory cues to compensate for vision (like counting steps to a known location). Continue necessary core exercises but focus more on functional application this week. Frequency: Daily practice is oriented around functional tasks: patient chooses one challenging ADL or instrumental ADL each day (with therapist's guidance) to practice deliberately (e.g. one day sorting medication by label color, next day practicing dialing a phone with enlarged numbers, etc.). Formal exercise (balance/strength) is tapered to 20 min/day as active tasks themselves provide exercise. Weekly video session to debrief and problem-solve scenarios.	on what was difficult or what adaptations helped. Maintain light exercise on off-days to keep fitness (short walks or stretches), but the emphasis is on translating skills to daily life now.	persistent barriers are identified – for instance, if reading medication labels is still too hard, consider bump dots or audio labels as additional aids. The patient's self-rated confidence in managing at home and outside is discussed, likely showing improvement. The program is adjusted if needed for the final weeks to target any remaining problem areas.
Week 10 (Community Reintegration)	Solidify skills for outside home and social participation. Address psychological aspects	Psychosocial Assessment: Inquire about patient's mood and social engagement: use a brief depression screen or simply ask how they are feeling compared to start (earlier in the trial PHQ-9 is used, but here conversational	Community Mobility & Coping: Provide coaching on community mobility: e.g. using public transport with low vision (therapist educates on identifying the correct bus by number contrast or seeking help, if applicable). Practice safe techniques for crossing streets (scanning for traffic, listening for cues) during discussion.	Home Exercise: This week, if possible, do an accompanied community outing: for example, walk with a family member to a nearby park or store, practicing all safety and vision strategies in a real environment. Alternatively,	Progress Check: The therapist gauges the patient's readiness to function more independently beyond the program. Many patients by week 10 report improved emotional well-being and a greater willingness to engage in social or

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	(confidence, mood) as vision rehab nears end.	check). Assess if the patient has engaged in any social or recreational activity they enjoyed (or avoided due to vision), e.g. did they feel able to visit a friend or attend a community event recently? Note any persisting anxiety about falls or going out.	Introduce vision-specific coping strategies: relaxation techniques to manage frustration (deep breathing exercises after a visually demanding task), and positive visualization to build confidence (having patient mentally rehearse successfully navigating a public place). Continue moderate physical exercise to maintain fitness, but start tapering intensity slightly to prepare for post-program self-maintenance. Frequency: About 20–30 min of formal exercise daily (scaled-back intensity to avoid burnout), plus any community outing practice once this week. One tele-session focuses on discussion and mental strategies, with fewer new physical exercises.	attend a low-vision support group meeting via phone/online to build social confidence. At home, continue a basic exercise routine (balance stands, stretches) but also incorporate relaxation exercises (like 5 minutes of guided breathing or gentle music while resting eyes) each day.	outside activities. If any depression or anxiety symptoms remain high, therapist provides encouragement and may refer to counseling or peer support (as part of holistic care). Ensure the patient has a plan for seeking help in the community if needed (knowing who to ask or what resources exist, e.g. low-vision services or support clubs). No significant regression in physical abilities is noted during the taper; if anything, patient is maintaining gains. Plan for final assessments is reviewed so the patient knows what to expect in week 12.
Week 11 (Preparation for Independence)	Transition the patient to a self-directed maintenance program. Finalize any remaining skill	Readiness Assessment: Discuss with patient how confident they feel to continue exercises and activities on their own after week 12. Use a checklist to ensure all domains have been addressed (vision strategies, home safety,	Review & Mastery: Revisit any exercise or skill the patient still finds challenging for one more coached practice. This might include a final run-through of the exercise circuit the patient can do independently hereafter: balance drills, strengthening moves, and visual exercises consolidated into one routine (approximately 20–	Home Exercise: Begin following the post-discharge exercise plan on a trial basis: patient practices doing the routine without real-time guidance, to build confidence that they can maintain it. Identify a regular schedule for continued	Progress Check: The therapist evaluates the patient's self-efficacy: ideally the patient now expresses that they have the tools to manage their vision challenges (often reflected in higher self-efficacy questionnaire scores, as

Week	Goals	Assessments	Exercise Content & Frequency	Home Exercise	Weekly Progress Evaluation
	training and ensure resource connections.	exercise routine, assistive devices, etc.). If possible, involve family in this session to assess support system readiness.	30 min). Teach long-term maintenance: emphasize the importance of ongoing practice at least 2–3 times a week to preserve gains. Provide a written or audio summary of personalized exercises and adaptive strategies for the patient to keep. Also, introduce the concept of self-monitoring (e.g. using a weekly log or the app's maintenance mode to track activity post-program). Frequency: This week, formal exercise is slightly reduced (5 days/week of lighter exercise) as focus shifts to planning and fine-tuning. The video session (1 hour) is used to rehearse the independent routine and answer final questions.	exercise (e.g. "balance and walk every morning for 15 minutes, read with magnifier every afternoon for 10 minutes"). Encourage the patient to enlist a "buddy" (family or friend) to check in weekly after program end, to support adherence. Also remind them to keep using any low-vision techniques daily (like optimal lighting, contrast, scanning) as part of normal life, not just "exercises."	seen in low-vision rehab studies). Any final concerns are addressed, for example, if the patient worries about staying motivated, they are connected with community resources or the possibility of periodic follow-up calls. The week 12 outcome assessment is scheduled with the blinded assessor (for trial purposes), and the therapist makes sure the patient is comfortable with the process. The overall improvement from baseline is emphasized to the patient, reinforcing how far they've come in 11 weeks.
Week 12 (Program Conclusion)	Achieve final outcomes and document improvements. Encourage continuation of healthy activities post-trial.	Final Outcome Assessment: A masked evaluator conducts the 12-week follow-up tests (per trial protocol). This includes VFQ-48 or VFQ-25 questionnaire to measure vision-specific functional gains, visual acuity check, balance test (e.g. TUG), depression survey	Culmination Session: In the final therapy session, the patient performs a full routine incorporating all key elements one last time with supervision, essentially a "graduation" exercise session demonstrating improved capabilities (for instance, compare their first-week performance in a task to now). Therapist ensures the patient has mastered modifications for their environment and reinforces	Home Exercise: The formal program ends, but patient is prescribed a maintenance plan to continue at home indefinitely. They are advised to continue daily or at least thrice-weekly exercises (balance, walking, strength training) and to keep practicing	Weekly Assessment: Outcome Results: The results from the 12-week assessment are reviewed: typically, the digital training group is expected to show significant improvements in self-reported visual function and possibly physical performance, on par with

Week	Goals	Assessments	Exercise Content & Frequency	Home Exercise	Weekly Progress Evaluation
		(PHQ-9), and any other trial-specific outcomes. The physiotherapist separately gathers qualitative feedback from the patient about program satisfaction and any remaining difficulties.	all safety and technique points. The emphasis is on recognizing the patient's accomplishments and solidifying their commitment to ongoing exercise and use of vision strategies beyond the study. Frequency: This week's exercises are light and aimed at keeping the patient active without introducing anything new. The main activity is the final assessment and review.	visually guided tasks (like reading or craft work) to reinforce adaptation. They are also encouraged to follow up with their ophthalmologist and low-vision services periodically.	in-clinic rehab outcomes. The therapist discusses these outcomes with the patient (in lay terms), highlighting improvements (e.g. "Your vision-function score improved by over X points, which is a meaningful gain" or "You shaved Y seconds off your TUG time, indicating better mobility"). Feedback: The patient's feedback is recorded – most report high satisfaction and would recommend the program. Any suggestions for future improvement are noted. Closure: Finally, the patient is formally congratulated for completing the 12-week DVST program, and contact information is provided in case they have questions or need support maintaining their exercises.

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Sample Size Calculation

A priori sample size calculations were undertaken to ensure the study had sufficient power to detect meaningful differences (or establish non-inferiority) in the primary outcome. Drawing on prior literature for vision rehabilitation, we considered a non-inferiority framework: the goal was to determine if the digital home-based program could achieve visual functional outcomes not appreciably worse than standard in-clinic rehabilitation. We defined the non-inferiority margin (Δ) as 5 points on the VFQ-48 scale. This margin was chosen based on the minimal clinically important difference reported for the NEI VFQ-25 (approximately 4–5 points) and expert consensus that a difference smaller than 5 points would be clinically negligible to patients. Using this $\Delta = 5$ as the largest acceptable loss of efficacy, we computed the required sample assuming a one-sided $\alpha = 0.025$ (equivalent to a 95% confidence interval for the between-group difference) and 90% power to detect non-inferiority if the true difference in outcomes between DT and SR was zero. We anticipated the standard deviation of change in VFQ scores to be on the order of 10–15 points, based on previous low vision trials and the heterogeneity of our patient population. A conservative estimate of SD of

15 was used in calculations. Under these parameters, the sample size needed per group was approximately 188 to 190 patients to achieve 90% power for the non-inferiority test (ensuring the two-sided 90% CI for the group difference would stay within ±5 points). We aimed for 190 patients in each arm. This target of n=380 (total) also confers decent power (around 80%) to detect modest between-group differences in secondary outcomes (for example, a 2-point difference in PHQ-9 depression score with SD 5, or other functional measures), although the study was not primarily powered for those secondary endpoints. Anticipating some loss to follow-up, the initial recruitment was planned slightly higher; however, through the matching process, we achieved exactly 190 well-matched subjects in each group for analysis. The realized sample thus met the a priori calculated requirement, providing confidence that the study was adequately powered to address its primary objective.

Blinding

In this retrospective cohort study, explicit blinding was limited by the nature of the interventions. Participants were aware of whether they were performing home-based digital exercises or attending clinic sessions, and providers could not be blinded to the mode of rehabilitation they delivered. However, to reduce assessment bias, we implemented masking at the outcome evaluation stage as much as possible. Functional outcome questionnaires (such as the VFQ-48 and VFQ-25) and the PHQ-9 were administered by research staff who were not involved in the patients' care and were unaware of group assignment. These outcome assessors simply collected responses (often via telephone or at routine follow-up visits) without reference to the type of rehab the patient received, thereby blinding them to the intervention when measuring patient-reported outcomes. Similarly, technicians measuring visual acuity or conducting TUG tests at follow-up were not informed about which rehabilitation program the patient had undergone. All study data were coded such that the statistician performing the analysis was provided anonymized group labels (e.g. Group A vs Group B) instead of revealing "digital" or "standard" group, until after the primary analyses were

completed. By maintaining this assessor and analyst blinding, we aimed to minimize any observer bias in outcome measurement. It should be noted that because this was not a randomized trial, patients' treatment preferences could potentially influence their reported outcomes (expectation bias); we attempted to account for this in the statistical analysis by adjusting for stated preference. In summary, while full double-blinding was not feasible, the procedures above ensured that outcome data collection and analysis were as objective as possible, thereby strengthening the validity of comparisons between the two groups.

Propensity Score Matching

First, we calculated each patient's propensity score for being in the digital training group using a logistic regression model. In this model, the dependent variable was the treatment group and the independent variables were all the relevant baseline characteristics. These included demographic factors (age, sex, body mass index), socio-economic indicators (education level, insurance type, employment type), clinical history (duration of diabetes, duration of diagnosed DR, current use of insulin or oral hypoglycemic medications), comorbid health conditions (hypertension, cardiovascular disease, atrial fibrillation, chronic lung disease, arthritis or connective tissue disease, dyslipidemia, hypothyroidism, etc.), and baseline functional vision measures (baseline VA LV VFQ-48 score and baseline BCVA). By including this comprehensive set of covariates, the propensity model aimed to capture the likelihood of a patient being selected for the home-based program versus clinic rehab based on observed characteristics. Each patient in the DT group was then matched to a patient in the SR group with a similar propensity score. We employed 1:1 nearest-neighbor matching without replacement, using a caliper width of 0.2 times the standard deviation of the logit of the propensity score to avoid poor matches. Matches were formed sequentially, and any DT patient for whom an adequate match was not found within the caliper was excluded. After matching, we assessed the balance of baseline covariates between groups. Standardized mean differences for all variables in baseline characteristics were below 0.1, and no covariate showed a statistically significant difference between the DT and SR groups post-matching, confirming

successful balance. Thus, the matched sample served as the pseudo-population for subsequent outcome analyses, with baseline equivalence between groups approximating that of a randomized trial.

Statistical Analysis

All analyses were performed on an intention-to-treat (ITT) basis, including all matched patients in the groups to which they were assigned by the matching procedure, regardless of their adherence or completion of the rehabilitation program. Continuous outcome measures were summarized as mean ± standard deviation at each time point for each group, and their changes from baseline were calculated. Categorical variables (if any) were summarized as counts and percentages. The primary comparison of the change in VFQ-48 at 12 weeks between the DT and SR groups was analyzed using a linear mixed-effects model for repeated measures[9]. In this model, we included data from all three follow-up time points (12, 24, 48 weeks) to make use of the longitudinal nature of the measurements and to increase statistical power by leveraging all available observations. The mixed model incorporated a random intercept for each patient to account for within-patient correlation over time (thus handling the repeated measures in an appropriate manner[9]). Fixed effects included treatment group (DT vs SR), time (as a categorical factor with levels for 12, 24, 48 weeks), and the group × time interaction. By including a group-by-time interaction, we allowed the difference between DT and SR to vary at each follow-up, which was important for assessing whether any divergence in outcomes emerged or changed over time. We also included each patient's baseline VFQ-48 score as a covariate in the model (analysis of covariance approach), to adjust for any minor baseline differences and improve precision in estimating treatment effects. Additionally, given the observational design, we had recorded each patient's stated treatment preference at baseline (whether they initially preferred home-based or in-clinic rehab, when such preference was noted). We included this preference (yes/no for preferring digital program) as an exploratory covariate in the model, to adjust for potential expectation effects, the rationale being that a patient who strongly

favored one approach might try harder or report outcomes differently, so adjusting for preference helps isolate the effect of the intervention itself.

From the linear mixed model, we obtained the estimated mean change in VFQ-48 at 12 weeks in each group (adjusted for baseline VFQ and other covariates) and the mean difference between groups. To evaluate non-inferiority, we examined the 95% confidence interval of the group difference in 12-week VFQ improvement. The digital program would be declared non-inferior to standard rehab if the lower bound of this confidence interval was not below 5 points (i.e. did not cross the negative of the pre-specified margin). We also conducted a traditional two-sided hypothesis test for the difference at 12 weeks to see if there was any evidence of superiority of either approach, although the study was primarily designed for non-inferiority. For secondary outcomes, similar mixed-effects models were used including the same fixed effects (group, time, group×time) and adjusting for baseline values of the respective outcome. These models provided estimates of group differences over time and allowed us to test whether there were significant improvements within each group and whether those improvements differed by group. In all mixed models, an unstructured covariance matrix was used initially to model within-subject error, and model fit was checked; if convergence issues arose or a simpler structure was warranted (e.g. compound symmetry), we adjusted accordingly. Results from mixed models were reported as adjusted mean differences with 95% confidence intervals and p-values for the group effect, time effect, and interaction effect. The primary analysis on the ITT population was complemented by a per-protocol analysis as a sensitivity check. For the per-protocol analysis, we defined protocol adherence for the DT group as completing at least 10 out of 12 weekly video sessions and using the app regularly, and for the SR group as attending at least 4 of the 6 planned clinic sessions. We then re-ran the primary outcome analysis on the subset of patients who fulfilled these adherence criteria in their respective groups. The purpose was to see if restricting to those who actually received most of the intended intervention yielded results consistent with the ITT analysis, thereby testing the robustness of our findings.

For missing data, some patients missed one or more follow-up assessments (for instance, not all patients completed the 24-week or 48-week questionnaires, and

a few measures like TUG could not be obtained if a patient did not return for physical follow-up). We assumed that data were missing at random (MAR), conditional on the observed patient characteristics and outcomes. To avoid bias and loss of statistical power from incomplete cases, we employed multiple imputation to handle missing outcome data[9]. We used the chained equations method to create 20 imputed datasets for longitudinal outcomes at 12, 24, 48 weeks. The imputation model included all baseline covariates, treatment group, and all observed values of the outcome and other secondary measures, under the assumption that incorporating these would make the MAR assumption plausible. For example, a missing 48-week VFQ score might be predicted from that patient's baseline VFQ, earlier follow-up VFQ, group, age, etc. Imputed values were drawn using predictive mean matching for continuous outcomes. Each of the 20 imputed datasets was then analyzed with the same mixed-effects model framework described above, and results were pooled using Rubin's rules to obtain final estimates and standard errors that reflect uncertainty due to missing data[10]. This multiple imputation approach was chosen as it provides more robust estimates than, for instance, complete-case analysis or last-observation-carried-forward, especially in longitudinal studies with dropouts[9]. As a secondary check, we also performed analyses using the mixed models without imputation (which inherently use all available data at each time point under maximum likelihood, and are generally unbiased under MAR as well8). These gave very similar results, supporting the validity of the findings. All hypothesis tests were two-tailed with $p < 0.05$ considered statistically significant (except for the one-sided criterion used in non-inferiority testing). Data analyses were conducted using SPSS Statistics (IBM Corp., v.26) and R software (v.4.2.0) for the imputation and mixed models. No interim analyses were performed.

We performed 1,000 bootstrapping iterations on our dataset. For each iteration, we randomly sampled with replacement 190 patients from the DT group and 190 patients from the SR group from the multiple imputed dataset. For each bootstrap sample, we calculated: the incremental cost between the two groups (using the 48-week cost data, which we treated as the total cost for the entire period) and the nine incremental effectiveness measures (three outcome measures at three time points). These incremental effectiveness values were derived from the coefficients of the interaction terms in the adjusted linear mixed-effects

models described above. Based on these 1,000 bootstrap replicates, we constructed 95% confidence intervals (CIs) for all ICERs by extracting the 2.5th and 97.5th percentiles.

Finally, the results of the analyses were interpreted with clinical significance in mind alongside statistical significance. The primary outcome results were used to conclude whether the digital rehabilitation was non-inferior to standard care, and secondary outcomes were examined to ensure there were no concerning differences (for example, no worse depressive symptoms or balance issues in the digital group). The ITT findings were considered primary, while the per-protocol findings and other sensitivity analyses were reviewed to confirm consistency.

Supplementary Table 1 Baseline characteristics of the home-based digital physiotherapeutic vision-specific training group and standard in-clinic low vision rehabilitation group (per-protocol population)

PP	Sample characteristic	DT (N=171)	SR (N=168)	P value
Baseline characteristics	Male (no. [%])	82 (47.95)	69 (41.07)	0.202
	Female (no. [%])	89 (52.05)	99 (58.93)	0.292
	Age (yrs)	45 (12.10)	45 (10.89)	0.989
	BMI (kg/m²)	25 (4.27)	25 (4.50)	0.970
	Education Level (no. [%])			0.252
	Below high school	54 (31.58)	63 (37.50)	
	High school and higher	117 (68.42)	105 (62.50)	
	Insurance Type (no. [%])			0.028
	Government	114 (66.67)	101 (60.12)	
	Commercial	28 (16.37)	19 (11.31)	
	Self-financed	29 (16.96)	48 (28.57)	
	Type of work (no. [%])			0.843
	Labor	101 (59.06)	101 (60.12)	
	Non-labor	70 (40.94)	67 (39.88)	
Medical History	Duration of diabetes (years)	9 (3.37)	9 (3.44)	0.567
	Duration of diabetic Retinopathy (years)	5 (2.64)	5 (2.88)	0.767
	Diabetes medications use (no. [%])	167 (97.66)	165 (98.21)	0.720
	Insulin use (no. [%])	84 (49.12)	80 (47.62)	0.782
	Oral antidiabetic medications (no. [%])	146 (85.38)	150 (89.29)	0.280
	Hypertension (no. [%])	19 (11.11)	19 (11.31)	0.954
	Cardiovascular diseases (no. [%])	22 (11.58)	19 (10.00)	0.620
	Atrial fibrillation (no. [%])	3 (1.75)	3 (1.79)	0.983
	COPD (no. [%])	7 (4.09)	6 (3.57)	0.802
	Arthritis/connective tissue disease (no. [%])	8 (4.68)	8 (4.76)	0.971
	Dyslipidemia (no. [%])	39 (22.81)	37 (22.02)	0.863
	Hypothyroidism (no. [%])	7 (4.09)	6 (3.57)	0.802
Function	Veterans Affairs Low Vision Visual Functioning Questionnaire (VA LV VFQ-48)	143 (12.94)	145 (13.19)	0.203
	Best-corrected visual acuity (BCVA)	0 (0.08)	1 (0.09)	0.479
	HbA1c (%)	9% (0.48%)	9% (0.56%)	0.348
	Fasting plasma glucose (mg/dL)	110 (19.34)	111 (17.79)	0.639
	Fasting insulin (μIU/mL)	7 (1.22)	7 (1.21)	0.839
	Timed Up and Go (TUG) test	8 (0.98)	8 (0.98)	0.594
	NEI VFQ-25 questionnaire	65 (4.66)	65 (5.13)	0.886
	Patient Health Questionnaire-9 (PHQ-9)	14 (2.08)	14 (1.85)	0.979

PP: per-protocol; DT: home-based digital physiotherapeutic vision-specific training group; SR: standard in-clinic low vision rehabilitation group; BMI: body mass index; COPD: chronic obstructive pulmonary disease.

Supplementary Table 2 Changes in outcomes of the home-based digital physiotherapeutic vision-specific training group and standard in-clinic low vision rehabilitation group at week 12, week 24 and week 48 (per-protocol population)

PP	12-week			24-week			48-week		
	DT (N=171)	SR (N=168)	P value	DT (N=171)	SR (N=168)	P value	DT (N=171)	SR (N=168)	P value
Veterans Affairs Low Vision Visual Functioning Questionnaire (VA LV VFQ-48)	21.54 (6.51)	19.31 (3.58)	p<0.001	26.58 (6.48)	24.35 (3.58)	p<0.001	24.57 (6.60)	22.37 (3.62)	p<0.001
BMI (kg/m2)	-0.20 (0.05)	-0.19 (0.04)	0.094	-1.21 (0.21)	-1.18 (0.20)	0.292	-1.05 (0.25)	-1.03 (0.25)	0.300
Best-corrected visual acuity (BCVA)	0.10 (0.00)	0.10 (0.00)	0.110	0.16 (0.06)	0.15 (0.05)	0.236	0.09 (0.08)	0.09 (0.07)	0.585
HbA1c (%)	7.42 (0.54)	7.48 (0.60)	0.296	6.91 (0.54)	6.99 (0.60)	0.193	7.01 (0.54)	7.09 (0.60)	0.217
Fasting plasma glucose (mg/dL)	-5.43 (6.94)	-6.04 (1.25)	0.262	-8.51 (6.90)	-8.95 (1.33)	0.414	-7.47 (6.92)	-8.08 (1.71)	0.272
Fasting insulin (μIU/mL)	-0.48 (0.11)	-0.50 (0.09)	0.160	-0.98 (0.14)	-1.00 (0.15)	0.247	-1.07 (0.18)	-1.10 (0.16)	0.050
Timed Up and Go (TUG) test	-1.00 (0.13)	-0.98 (0.11)	0.092	-1.50 (0.16)	-1.47 (0.15)	0.122	-1.29 (0.18)	-1.28 (0.17)	0.487
NEI VFQ-25 questionnaire	6.15 (1.60)	6.13 (1.00)	0.884	9.17 (1.62)	9.10 (1.07)	0.618	7.09 (2.02)	7.11 (1.47)	0.919
Patient Health Questionnaire-9 (PHQ-9)	-2.06 (0.49)	-1.99 (0.13)	0.103	-4.05 (0.50)	-4.00 (0.15)	0.193	-3.56 (0.77)	-3.41 (0.52)	0.035

PP: per-protocol; DT: home-based digital physiotherapeutic vision-specific training group; SR: standard in-clinic low vision rehabilitation group; BMI: body mass index.

Supplementary Table 3 Effectiveness estimates from linear mixed effects models of the home-based digital physiotherapeutic vision-specific training group and standard in-clinic low vision rehabilitation group at week 12, week 24 and week 48 (per-protocol population)

PP	12-week			24-week			48-week		
	Coefficient	95% CI	P value	Coefficient	95% CI	P value	Coefficient	95% CI	P value
Veterans Affairs Low Vision Visual Functioning Questionnaire (VA LV VFQ-48)	-1.147	(-3.731, 1.437)	0.384	-0.840	(-3.405, 1.726)	0.521	-0.719	(-3.285, 1.848)	0.583
BMI (kg/m2)	-0.004	(-0.008, 0.001)	0.085	-0.010	(-0.026, 0.006)	0.219	-0.013	(-0.037, 0.011)	0.287
Best-corrected visual acuity (BCVA)	-0.006	(-0.024, 0.012)	0.514	-0.003	(-0.022, 0.015)	0.715	-0.003	(-0.021, 0.016)	0.783
HbA1c (%)	-0.039	(-0.099, 0.020)	0.197	-0.056	(-0.135, 0.022)	0.161	-0.064	(-0.152, 0.024)	0.155
Fasting plasma glucose (mg/dL)	0.957	(-2.243, 4.157)	0.558	0.981	(-2.204, 4.166)	0.546	1.029	(-2.151, 4.210)	0.526
Fasting insulin (µIU/mL)	0.168	(0.024, 0.311)	0.022	0.171	(0.026, 0.316)	0.021	0.176	(0.031, 0.322)	0.017
Timed Up and Go (TUG) test	-0.081	(-0.295, 0.133)	0.457	-0.090	(-0.303, 0.122)	0.405	-0.094	(-0.307, 0.119)	0.387
NEI VFQ-25 questionnaire	0.228	(-0.765, 1.221)	0.652	0.259	(-0.722, 1.241)	0.605	0.261	(-0.710, 1.232)	0.599
Patient Health Questionnaire-9 (PHQ-9)	-0.039	(-0.444, 0.366)	0.850	-0.045	(-0.451, 0.360)	0.826	-0.073	(-0.475, 0.329)	0.722

PP: per-protocol; DT: home-based digital physiotherapeutic vision-specific training group; SR: standard in-clinic low vision rehabilitation group; BMI: body mass index.

Supplementary Table 4 Costs of the home-based digital physiotherapeutic vision-specific training group and standard in-clinic low vision rehabilitation group at week 48 (per-protocol)

PP	**DT (N=171)**	**SR (N=168)**	**P value**
Total cost	7791 (109.98)	10349 (2743.21)	p<0.001
Intervention-related costs (CNY)	6980 (0.00)	0 (0.00)	/
Personnel cost (PT time, coaching hours) (CNY)	0 (0.00)	7848 (2711.70)	p<0.001
App development & maintenance (per patient) (CNY)	120 (0.00)	0 (0.00)	/
Facility and equipment usage (CNY)	151 (27.79)	405 (47.17)	p<0.001
Exercise equipment provided (CNY)	135 (62.99)	139 (59.61)	0.553
Patient transportation costs (CNY)	405 (85.47)	1957 (276.39)	p<0.001

PP: per-protocol; DT: home-based digital physiotherapeutic vision-specific training group; SR: standard in-clinic low vision rehabilitation group; CNY: Chinese Yuan

Supplementary Table 5 Adverse events and serious adverse events

Adverse events*	**DT (N=190)**	**SR (N=190)**
Patients with adverse events (no. [%])	9 (4.7)	8 (4.2)
Events related to study therapy (no.)	11	9
Trip during exercise	0	2
Muscle strain during exercise	2	1
Dizzy during exercise	3	2
Nausea during exercise	1	2
Frustration/demotivation with exercise difficulty	3	2
App technical issues causing stress	2	/
Events unrelated to study therapy (no.)	4	6
Ankle sprain	1	1
Low back pain	1	0
Cervical spondylosis	0	1
Anxiety about eye recovery	2	4
Serious adverse events*		
Patients with serious adverse events (no. [%])	3 (1.6)	5 (2.6)
Events related to study therapy (no.)	1	1
Fall during exercise (causing fracture)	0	1
Seriou depression during exercise	1	0
Events unrelated to study therapy (no.)	2	4
Hip fracture due to fall	1	0
Waist fracture due to fall	1	1
Unplanned surgery	0	3

DT: home-based digital physiotherapeutic vision-specific training group; SR: standard in-clinic low vision rehabilitation group

*Data of adverse events and serious adverse events were retrieved from HIS of Out-patient and ER; One patient in DT group developed serious depression and was transferred to psychology department. One patient in SR group sustained hip fracture during exercise and was transferred to ER.

Adverse events were defined as any undesirable experience during the 48-week follow-up. Each event was reviewed by the study team and classified as related or unrelated to the rehabilitation intervention. ‘Related’ events were those plausibly caused or exacerbated by the vision training (e.g., fall during exercise), whereas events due to underlying disease or other causes were labeled unrelated. All serious adverse events were independently reviewed by an ophthalmologist not involved in the rehab care.