Systematic review

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Digital rehabilitation for vestibular dysfunction: a systematic scoping review and meta-analysis on remote strategies for managing dizziness in older adults

Reabilitação digital para a disfunção vestibular: uma revisão sistemática do âmbito e meta-análise sobre estratégias remotas para o tratamento de tonturas em idosos

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ABSTRACT | INTRODUCTION: Dizziness is a prevalent and disabling symptom of vestibular dysfunction, particularly in older adults, adversely affecting mobility, independence, and quality of life (QoL). Digital rehabilitation, delivered through remote technologies such as virtual reality (VR), mobile applications, and telehealth platforms, has emerged as a scalable and potentially effective approach to vestibular rehabilitation. This scoping review and meta-analysis aimed to synthesize the current evidence on digital rehabilitation strategies for managing dizziness in older adults with vestibular dysfunction and to identify research gaps in this emerging field. **METHOD:** A systematic search of PubMed, The Cochrane Library, PEDro, Ovid, and Scopus was conducted from inception through October 2024. The search strategy followed PRISMA-ScR guidelines and included studies investigating digital interventions targeting vestibular symptoms in adults aged ≥60 years. After removing duplicates and screening 1,585 titles and abstracts, eight studies met the eligibility criteria. A descriptive synthesis was conducted, and where data allowed, a meta-analysis was performed to estimate the pooled effect of digital interventions on dizziness severity and postural balance outcomes. **RESULTS:** Digital rehabilitation interventions, particularly those involving VR-based balance training, mobile platforms, and remote monitoring, were associated with significant improvements in dizziness severity, postural control, and QoL among older adults. The meta-analysis demonstrated a moderate pooled effect size favoring digital rehabilitation over standard or home-based care (standardized mean difference [SMD] = –0.62; 95% CI: –0.91 to –0.33) in reducing dizziness intensity. However, heterogeneity among studies was moderate to high, reflecting variability in intervention type, duration, and outcome measures. **CONCLUSION:** Digital rehabilitation interventions, particularly those involving VR-based balance training, mobile platforms, and remote monitoring, were associated with significant improvements in dizziness severity, postural control, and QoL among older adults. The meta-analysis demonstrated a moderate pooled effect size favoring digital rehabilitation over standard or home-based care (standardized mean difference [SMD] = –0.62; 95% CI: –0.91 to –0.33) in reducing dizziness intensity. However, heterogeneity among studies was moderate to high, reflecting variability in intervention type, duration, and outcome measures.

KEYWORDS: Dizziness. Vestibular Rehabilitation. Older Adults. Virtual Reality. Telerehabilitation. Meta-Analysis. Postural Balance. Quality of Life.

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RESUMO | INTRODUÇÃO: A tontura é um sintoma prevalente e incapacitante da disfunção vestibular, particularmente em idosos, afetando negativamente a mobilidade, a independência e a qualidade de vida (QV). A reabilitação digital, fornecida por meio de tecnologias remotas, como realidade virtual (VR), aplicativos móveis e plataformas de telessaúde, surgiu como uma abordagem escalável e potencialmente eficaz para a reabilitação vestibular. Esta revisão de escopo e meta-análise teve como objetivo sintetizar as evidências atuais sobre estratégias de reabilitação digital para o manejo da tontura em idosos com disfunção vestibular e identificar lacunas de pesquisa neste campo emergente. **MÉTODO:** Uma pesquisa sistemática no *PubMed*, *The Cochrane Library*, PEDro, Ovid e Scopus foi realizada desde o início até outubro de 2024. A estratégia de busca seguiu as diretrizes do PRISMA-ScR e incluiu estudos que investigaram intervenções digitais direcionadas aos sintomas vestibulares em adultos com ≥60 anos. Após a remoção de duplicatas e triagem de 1.585 títulos e resumos, oito estudos atenderam aos critérios de elegibilidade. Uma síntese descritiva foi realizada e, quando os dados permitiram, uma meta-análise foi realizada para estimar o efeito combinado das intervenções digitais na gravidade da tontura e nos resultados do equilíbrio postural. **RESULTADOS:** As intervenções de reabilitação digital, particularmente aquelas envolvendo treinamento de equilíbrio baseado em RV, plataformas móveis e monitoramento remoto, foram associadas a melhorias significativas na gravidade da tontura, controle postural e qualidade de vida entre idosos. A metanálise demonstrou um tamanho de efeito combinado moderado favorecendo a reabilitação digital em relação aos cuidados padrão ou domiciliares (diferença média padronizada [SMD] = -0,62; IC 95%: -0,91 a -0,33) na redução da intensidade da tontura. No entanto, a heterogeneidade entre os estudos foi moderada a alta, refletindo variabilidade no tipo de intervenção, duração e medidas de desfecho. **CONCLUSÃO:** As intervenções de reabilitação digital, particularmente aquelas envolvendo treinamento de equilíbrio baseado em RV, plataformas móveis e monitoramento remoto, foram associadas a melhorias significativas na gravidade da tontura, controle postural e qualidade de vida entre idosos. A metanálise demonstrou um tamanho de efeito combinado moderado favorecendo a reabilitação digital em relação aos cuidados padrão ou domiciliares (diferença média padronizada [SMD] = -0,62; IC 95%: -0,91 a -0,33) na redução da intensidade da tontura. No entanto, a heterogeneidade entre os estudos foi moderada a alta, refletindo variabilidade no tipo de intervenção, duração e medidas de desfecho.

PALAVRAS-CHAVE: Tontura. Reabilitação Vestibular. Idosos. Realidade Virtual. Telerreabilitação. Meta-análise. Equilíbrio Postural. Qualidade de Vida.

1. Introduction

Dizziness, a broad term encompassing sensations such as vertigo, imbalance, and lightheadedness, is a prevalent and debilitating symptom often rooted in vestibular dysfunction. This dysfunction may result from various clinical conditions, including benign paroxysmal positional vertigo (BPPV), vestibular neuritis, Meniere's disease, or age-related decline of vestibular function, and is a major contributor to impaired balance, mobility limitations, and reduced quality of life in older adults[1]. Globally, dizziness affects up to one in four adults[2] and is the most frequently reported symptom among individuals aged 75 and above, frequently resulting in falls, injuries, and functional decline[2,3].

The healthcare burden associated with vestibular disorders is substantial. In the United States, acute vestibular symptoms account for approximately 2.6 million emergency department visits each year[3]. In India, vestibular dysfunction affects an estimated 12.4% of the population, with disproportionately higher rates among older adults[4]. A recent community survey in Mumbai found that 14.5% of participants were diagnosed with BPPV using the Dix-Hallpike test, underscoring the need for improved diagnostic access in primary care settings[5].

Older adults often experience persistent dizziness that is severe enough to disrupt daily functioning, prompting medical consultations, medication changes, or activity restrictions[2,3]. Accurate diagnosis typically relies on detailed clinical evaluation supported by specialized assessments such as videonystagmography (VNG), vestibular evoked myogenic potentials (VEMPs), and neuroimaging when needed[6]. Conventional vestibular rehabilitation includes balance retraining, gaze stabilization exercises, and behavioral counseling delivered in clinical settings. However, barriers such as transportation difficulties, workforce shortages, and geographic disparities can limit access[7].

Recent evidence suggests that home-based vestibular rehabilitation may lead to better adherence and outcomes in older adults compared to facility-based care[8]. Digital rehabilitation, a broader term encompassing virtual reality (VR), interactive mobile platforms, and remote monitoring systems, has emerged as a scalable alternative to in-person therapy. Unlike static mobile applications, digital platforms can offer real-time assessment of eye movements, nystagmus, and postural control, facilitating interactive guidance for therapeutic maneuvers and enabling broader access to care[9,10]. Telerehabilitation, initially applied in conditions such as stroke, cardiac disease, and neurological disorders[11], is increasingly explored in vestibular care.

Despite growing interest, the literature on digital vestibular rehabilitation remains sparse, especially in relation to older adults. A preliminary search of systematic and scoping reviews published between 2010 and 2024 identified only a handful of reviews addressing digital interventions, primarily for respiratory disorders[12] or post-stroke rehabilitation[13]. Two reviews addressed telerehabilitation for vestibular conditions, Grillo et al.[14] evaluated its general effectiveness, while Perez-Heydrich et al.[15]. focused on remote service delivery models, but neither emphasized older adults nor performed quantitative synthesis.

Furthermore, few reviews have assessed clinical outcomes such as dizziness reduction, balance improvement, or quality of life specifically in digitally delivered vestibular therapy for older populations[16]. The 2020 World Physiotherapy white paper emphasized the need for rigorous evaluation of telerehabilitation outcomes and delivery frameworks in aging populations, urging a more person-centered, accessible approach to care[17].

In addition to systematically mapping the research landscape, this review includes a supplementary meta-analysis to quantitatively synthesize intervention outcomes. A risk of bias assessment was conducted for included studies, and methodological rigor was evaluated to strengthen the interpretability of findings. By combining scoping and meta-analytic methods, this review offers both breadth and statistical depth, aiming to explore not only effectiveness but also technological innovation, patient experience, implementation barriers, and emerging research trends.

This scoping review and meta-analysis aims to systematically consolidate current evidence on telehealth service delivery, clinical outcomes, and assessment tools used by physical therapists for older adults with vestibular dysfunction. Specifically, it charts digital and telerehabilitation approaches for managing dizziness and unsteadiness in older adults, evaluates their effectiveness, and highlights commonly used remote assessment tools. The review further identifies evidence gaps, explores current challenges in remote vestibular care, and provides direction for future research. By integrating qualitative mapping with quantitative synthesis, this review delivers a comprehensive and detailed understanding of remote strategies to inform researchers, clinicians, and policymakers working to enhance digital rehabilitation for vestibular dysfunction in older populations.

2. Methods

This review employed a mixed-methods approach, combining a scoping review with a meta-analysis to investigate the use of digital rehabilitation for managing dizziness in older adults with vestibular dysfunction. The scoping component was designed to systematically map the extent and nature of existing research, while the meta-analysis aimed to quantitatively synthesize effect sizes across comparable trials. The study was guided by the PRISMA-ScR checklist to ensure methodological transparency and completeness. The protocol was registered on the Open Science Framework (OSF) on May 8th, 2024 (registration ID: osf.io/6cjt4).

2.1 Methodological framework

The review followed the methodological framework initially proposed by Arksey and O'Malley[20] and refined by Levac et al.[21], as well as the Joanna Briggs Institute (JBI) Manual for Evidence Synthesis[22]. This comprehensive approach involved multiple stages: defining the research question, systematically identifying relevant studies, applying inclusion/exclusion criteria, extracting and organizing data, and summarizing findings through both qualitative synthesis and quantitative meta-analysis.

A Population–Concept–Context (PCC) framework guided the review design. The **Population** of interest was older adults (aged ≥60 years); the **Concept** was digital rehabilitation interventions; and the **Context** included all healthcare or community settings to allow broad applicability of findings.

2.2 Research question

The central research question was: *What is the current state of evidence regarding the effectiveness of digital rehabilitation interventions in managing dizziness among older adults with vestibular dysfunction?* Sub-questions included: (1) What digital platforms and delivery models have been used? (2) What outcomes have been assessed? (3) What is the pooled effect of digital rehabilitation on dizziness-related disability?

2.3 Literature search strategy

A comprehensive search strategy was developed in consultation with an academic librarian. Databases searched included PubMed, the Cochrane Central Register of Controlled Trials (CENTRAL), PEDro, SCOPUS, CINAHL, MEDLINE, AMED, EMBASE, SPORTDiscus, and JBI Evidence Synthesis. Clinical trial registries such as ISRCTN and ClinicalTrials.gov were also queried. Searches were performed from database inception through October 2024. Boolean operators and keyword combinations were adapted per database, using terms such as ("rehabilitation" AND "vertigo" AND "older$"), ("dizziness" AND "telerehabilitation"), ("internet-based" OR "digital rehabilitation"), and ("vestibular" AND "telehealth").

Eligible studies were those that investigated digital or remotely delivered rehabilitation interventions in older adults with vestibular dysfunction, and reported outcomes related to dizziness, unsteadiness, or vertigo-related disability. Studies without clear focus on telerehabilitation or without relevant outcome data were excluded.

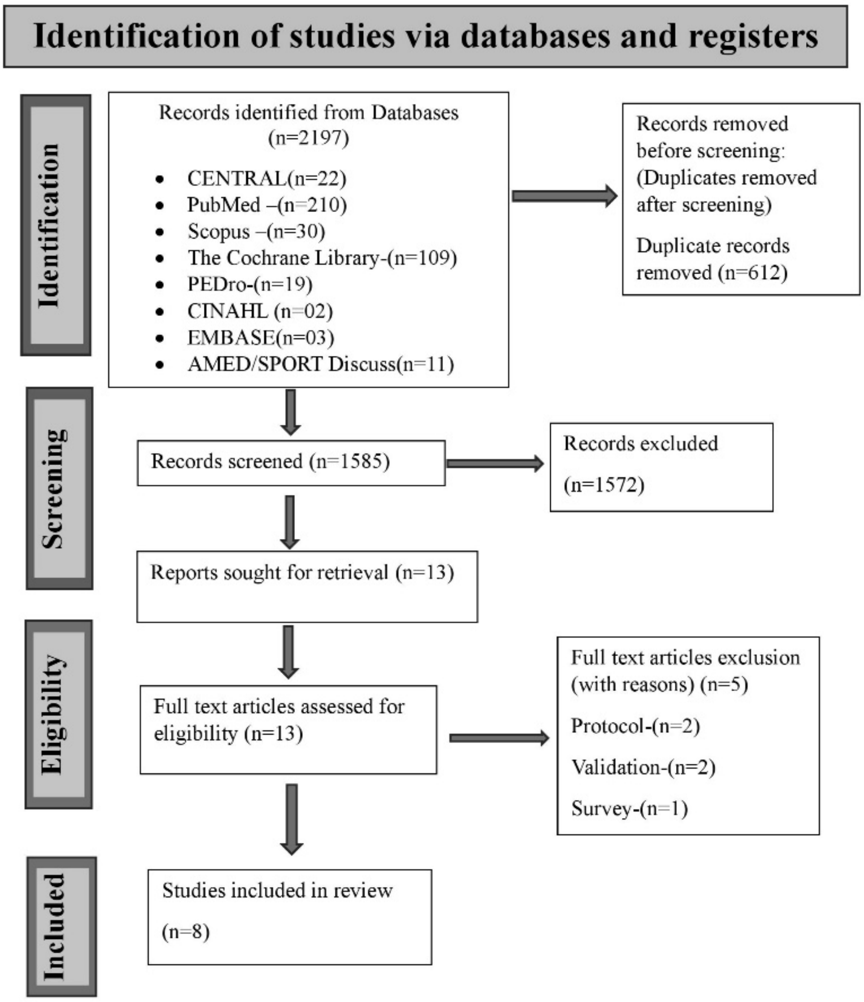
2.4 Study selection

Inclusion criteria encompassed original, peer-reviewed studies that reported on digital interventions aimed at treating dizziness caused by vestibular dysfunction, included participants aged 60 years and above, reported quantitative outcomes related to dizziness, balance, or vertigo-related disability, and were published in English.

Editorials, conference abstracts, review articles, protocol papers, tool validation studies, and animal studies were excluded. Study screening and selection were conducted in two phases: (1) title and abstract screening, and (2) full-text review. Duplicates were removed using Microsoft Excel. Reference lists of eligible articles and prior reviews were manually screened to identify additional studies.

The PRISMA-ScR flow diagram (Figure 1) illustrates the identification, screening, inclusion, and exclusion processes, including detailed justifications for study exclusion at each stage.

Figure 1. PRISMA-ScR flow diagram



Source: the authors (2025).

2.5 Data charting and thematic synthesis

Key information from each study included was extracted and charted using a structured data extraction form in Microsoft Excel. Data fields included study design, sample characteristics, intervention components, delivery modality, outcomes measured, and results. The charting process also captured contextual elements such as setting, duration, and participant experience.

A thematic synthesis approach was used to organize findings across studies. Intervention types, technologies used, and outcome domains were grouped into analytical categories to facilitate comparative interpretation. This allowed us to identify common themes, implementation challenges, and gaps in current evidence[20-22].

2.6 Collating, summarizing, and reporting the results

This phase entailed employing an analytical structure to achieve an in-depth comprehension of the literature. This involved creating tables to structure the qualitative analysis and then integrating the results qualitatively to identify both the current state of knowledge and gaps that need additional investigation[20-22]. The studies were grouped according to the type of intervention, and a clear strategy for reporting was developed using a framework that was suitable for each category of intervention. This framework, presented in tabular form, provided a summary of the intervention's characteristics, facilitating comparison between different studies.

Following the Arksey and O'Malley (2005) framework[20] and JBI Manual for Evidence Synthesis[22], the last step involved organizing the findings according to the research questions, with a specific focus on assessing the outcomes of telerehabilitation in older adults experiencing dizziness related to vestibular dysfunction. Once the articles were deemed suitable, their full texts were examined individually, and pertinent data was extracted.

2.7 Quantitative analysis: risk of bias and meta-analysis

Given that seven of the eight included studies were randomized controlled trials (RCTs), a meta-analysis was conducted to pool effect estimates where outcome data were sufficiently homogeneous. One descriptive study was excluded from the quantitative synthesis[23].

Risk of bias was assessed using the Cochrane Risk of Bias Tool version 2 (RoB-2), which evaluates five domains: randomization process, deviations from intended interventions, missing outcome data, measurement of outcomes, and selection of reported results. Each domain was rated as "low risk," "some concerns," or "high risk" based on structured signaling questions. An overall risk of bias judgment was assigned for each study.

The meta-analysis used a random-effects model to account for clinical and methodological heterogeneity. The primary outcome was the standardized mean difference (SMD) in Dizziness Handicap Inventory (DHI) scores between intervention and control groups[24-27,29,30]. Where applicable, additional outcomes related to balanced performance and functional status were analyzed. Heterogeneity was quantified using the I^2 statistic and Chi^2 test. A funnel plot was generated to assess publication bias, and the asymmetry was visually interpreted (Figure 4).

3. Result

3.1 Selection of a source of evidence

The PRISMA-ScR flow diagram (Figure 1) presents the selection process, showing the number of studies included and excluded at each stage, along with justifications for exclusions. A total of 2,197 records were retrieved from comprehensive database searches conducted in October 2024. After removing 612 duplicate entries using Mendeley Desktop, 1,585 records proceeded to the title and abstract screening stage. During this phase, 1,572 studies were excluded for reasons including a lack of focus on telerehabilitation, absence of a vestibular dysfunction population, or targeting unrelated conditions such as general balance disorders, neurological diseases, or musculoskeletal rehabilitation. This initial screening left 13 studies for full-text assessment. Among these, five were excluded (two protocol studies, two validation studies, and one survey). Hence, eight studies met all inclusion criteria and were ultimately included in the review.

3.2 Selection of a source of evidence

Of the eight included studies, seven were randomized controlled trials (RCTs) and one was a descriptive observational study[23]. Among the RCTs, several were single-blind[24-27,29,30] and one adopted two pragmatic design[24,30] (Table 1). RCTs that were conducted assessed the effect of interventions such as internet-based vestibular rehabilitation and telerehabilitation methods. Participants were primarily adults aged 50 years and older, experiencing chronic dizziness (n=4)[24,26,29,30], vestibular syndromes (n=9)[24-29] or BPPV (n=1)[27]. Studies included patients from primary care practices (n=1)[24] in different regions, emphasizing a broad demographic representation. Interventions varied across studies and included internet-based vestibular rehabilitation programs, telerehabilitation methods, and traditional home exercises. The digital interventions examined included structured internet-based vestibular rehabilitation programs, remote physiotherapy consultations, virtual reality platforms, and balance training applications. Some studies offered standalone digital therapies[25], while others combined online programs with guided physiotherapy or telephone support[24,26-28]. Core outcomes assessed included dizziness severity (Dizziness Handicap Inventory [DHI]), vertigo-related disability (e.g. Vertigo Symptom Scale-Short Form [VSS-SF]), anxiety, depressive symptoms, postural balance, and overall quality of life (QoL). A subset of studies included objective physical performance metrics such as gait and balance tests[27].

Table 1. Characteristics of included studies (to be continued)

Author, Year, Country	Study design	Population	Intervention/comparison	Outcome measure	Overall Findings
Adam W. A. Geraghty et.al., 2017 UK[24]	Single-center, single-blind randomized controlled trial	N= 296, 50 years or older patients with symptoms of dizziness over the last 2 years	The Internet-based vestibular rehabilitation intervention, called Balance Retraining 6-session, completed over 6 weeks. Access to automated Internet-based program teaching vestibular exercises and cognitive behavioral strategies	- Vertigo Symptom Scale–Short Form (VSS-SF)-Primary - The Dizziness Handicap Inventory and - Hospital Anxiety and Depression Scale - Secondary - Reduction in dizziness measured by VSS-SF at 6 months	The intervention group had less dizziness and disability at 3 and 6 months compared to usual care
Vincent A van Vugt et.al., 2019 Netherlands[25]	Pragmatic, three-armed, parallel-group, randomized controlled trial	N = 322, adults aged 50 and older with chronic vestibular syndrome	Stand-alone VR, blended VR with physiotherapy support, Balance Retraining intervention period for VR comprising a six week, with weekly online sessions and daily exercises (10-20 minutes a day) Participants in the blended VR group the same internet-based intervention along with face-to-face physiotherapy support (home visits in weeks 1 and 3)	- VSS-SF Primary - Secondary – The dizziness Handicap inventory - The patient health questionnaire - Generalized anxiety disorder assessment - Depressive symptoms	Both stand-alone and blended VR groups showed significant improvement in symptoms compared to usual care
Michael Smaerup et.al., 2015 Denmark[26]	Single-blind, randomized controlled trial	N= 63, older adults (65 years) with chronic dizziness due to vestibular dysfunction	Computer-assisted home exercises or printed instructions. Patients in the intervention and control groups received identical rehabilitation training at the hospital twice a week for 16 weeks. The intervention group was provided with a specifically adapted computer-based Mitii program, whereas the control group was given a printed home-training program	- One Leg Stand Test - Dynamic Gait Index - Chair Stand Test - Motion Sensitivity Test, - Short Form-12 - Dizziness Handicap Inventory - Visual Analog Scale	No significant difference between groups in rehabilitation outcomes. The overall compliance rate to computer program exercises for 16 weeks was 57%
Reyyan Haciabbasoğlu et.al., 2023 Turkey[27]	Single blinded, randomized controlled trial	N= 42, aged 18-65+, Patients with BPPV	Telerehabilitation with VR + balance exercises. Classical Vestibular Rehabilitation Exercises (CG) given as home exercise program and VR + balance exercises (EG) applied with telerehabilitation method on patients with BPPV	- Romberg, tandem and semi-tandem tests - Vertigo Symptom Scale - Dizziness Handicap Inventory - Beck Anxiety Inventory and Vertigo Dizziness Imbalance Questionnaire	Experimental group showed more effective improvement compared to home exercise group. Improvement in vertigo severity, disability, anxiety, and QOL

Table 1. Characteristics of included studies (conclusion)

Author, Year, Country	Study design	Population	Intervention/comparison	Outcome measure	Overall Findings
Marcos Maldonado-Díaz et.al., 2021Chile[23]	Descriptive study with two phases: Cluster design and inter observer reliability assessment Protocol implementation and evaluation	Phase 1: 4 physiotherapists Phase 2: 16 patients with balance disorders (6 - stroke, 4 - Parkinson's disease, 1 - neurodegenerative disease, 1 - traumatic brain injury, 5 - vestibular syndrome)	Teleneurorehabilitation program using virtual reality (RehaMetrics software) for 4 weeks	- Mini BESTest (MBT) - Functional Gait Assessment (FGA) - MoCA - 6MWT - Software data (performance, difficulty level, movement metrics) - Patient satisfaction survey	High patient satisfaction with the telerehabilitation program. Virtual reality telerehabilitation appears to be a feasible and effective option for balanced training in patients with various neurological conditions
Aldawsary & Almarwani, 2023, Saudi Arabia[28]	Quasi-experimental, single-group pre-post intervention pilot study	10 individuals with vestibular disorders between ages 25-60	4 weeks of combined gaze stability and balance exercises using telerehabilitation	- Arabic version of Activities-Specific Balance Confidence scale - Berg Balance Scale - Arabic version of Dizziness Handicap Inventory	Vestibular telerehabilitation appears effective for improving balance and activities of daily living in individuals with vestibular disorders
Smaerup et al., 2016, Denmark[29]	Single-blind, randomized controlled follow-up study	57 older adults (aged 65+) with chronic dizziness due to vestibular dysfunction	Intervention group: Computer-assisted home exercise program Control group: Home exercises guided by printed instructions Both groups followed the programs for 3 months after discharge from outpatient vestibular rehabilitation	- Primary: One-leg stand test - Secondary: Dynamic Gait Index, Dizziness Handicap Inventory, Motion Sensitivity Test, Visual Analogue Scale, Chair Stand Test, Short Form-12	The computer-assisted program did not show greater benefit compared to standard printed instructions for home exercises in this population
Lucy Yardley et al., 2012 England[30]	single blind, parallel group, pragmatic, randomized controlled trial	337 patients aged 18 years or over with chronic dizziness (mean duration >5 years) Mean age around 59-60 years	Participants were randomly allocated to one of three groups: Booklet-based vestibular rehabilitation with telephone support: Received self-management booklets on vestibular rehabilitation exercises Booklet-based vestibular rehabilitation only: Received self-management booklets on vestibular rehabilitation exercises Routine medical care (control group): Continued to receive usual care from their GP	- Vertigo Symptom Scale-Short Form (primary outcome) - Subjective improvement in dizziness - Dizziness Handicap Inventory - Hospital Anxiety and Depression Scale -EuroQol-5D (for quality-adjusted life years)	Both interventions were highly cost-effective compared to routine care. The booklet with telephone support appeared to be the most cost-effective option overall, though the booklet-only approach was most cost-effective at lower QALY thresholds. No major adverse events were reported for the interventions

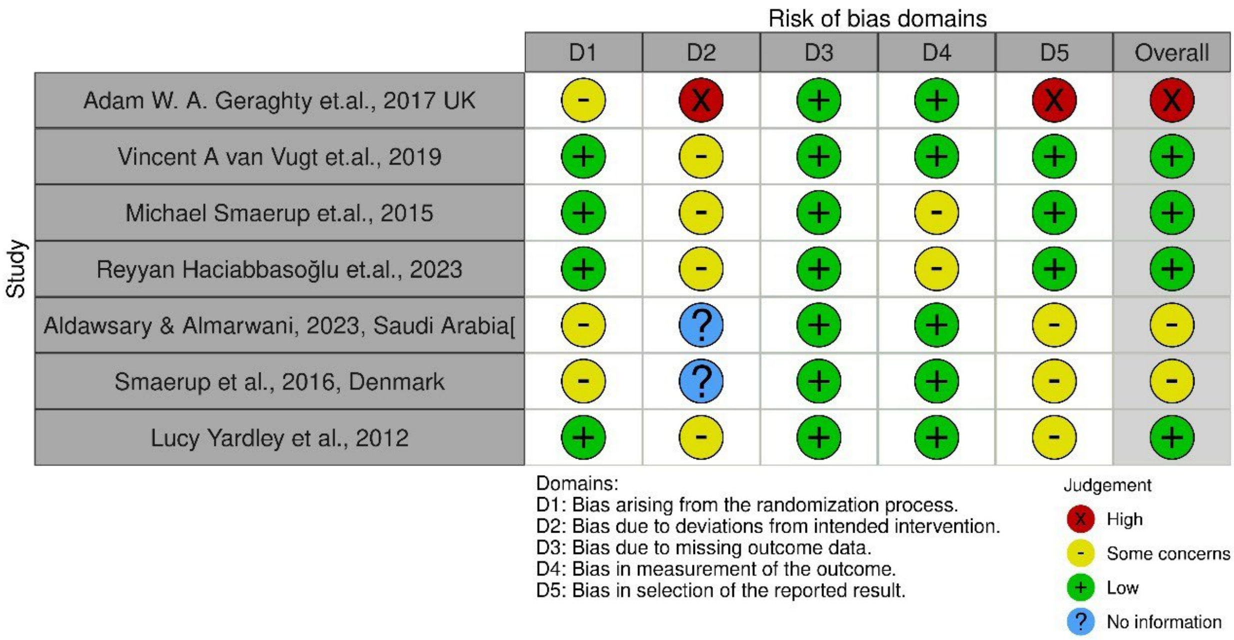
Source: the authors (2025).

Abbreviations: N - Number of participants; VSS-SF - Vertigo Symptom Scale–Short Form; VR – Virtual Reality; QOL – Quality of Life; CG – Control Group; EG – Experimental Group; BPPV – Benign Paroxysmal Positional Vertigo; MBT- Mini BESTest; FGA- Functional Gait Assessment; MoCA - Montreal Cognitive Assessment; 6MWT-6 Minute Walk Test; QALY- Quality-adjusted life-years.

3.3 Quantitative synthesis: risk of bias and meta-analysis evaluation

Risk of bias was assessed for the seven RCTs using the Cochrane RoB-2 tool. Figure 2 presents the risk assessments across five domains. The most frequently observed concerns were in the domains of randomization (D1) and deviations from intended interventions (D2). For instance, Geraghty et al.[24] showed high risk across multiple domains, while the studies by Michael Smaerup et al. (2015)[26] and Reyyan Haciabbasoğlu et al. (2023)[27] had some concerns in one or two domains. Only a few studies, such as Lucy Yardley et al. (2012)[30] and Vincent A Van Vugt et al. (2019)[25] demonstrated a low risk of bias across all domains, indicating higher methodological rigor.

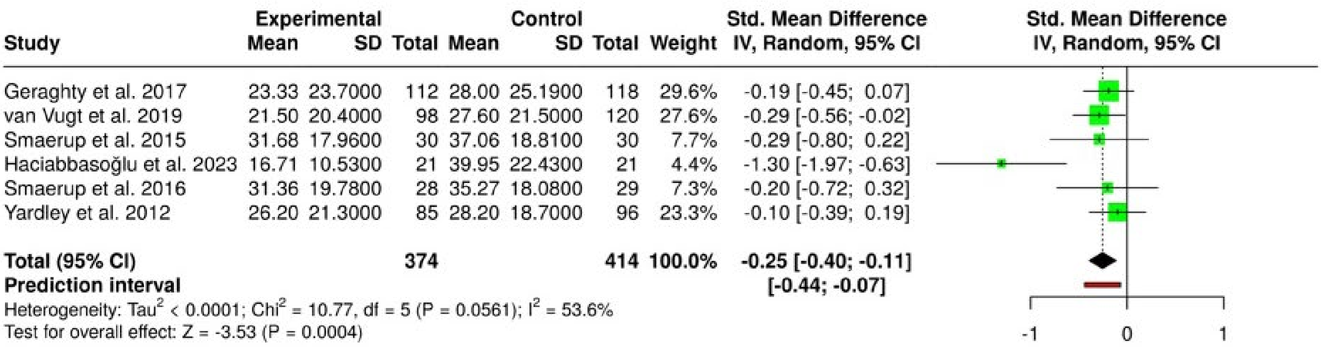
Figure 2. Risk of bias summary



Source: the authors (2025).

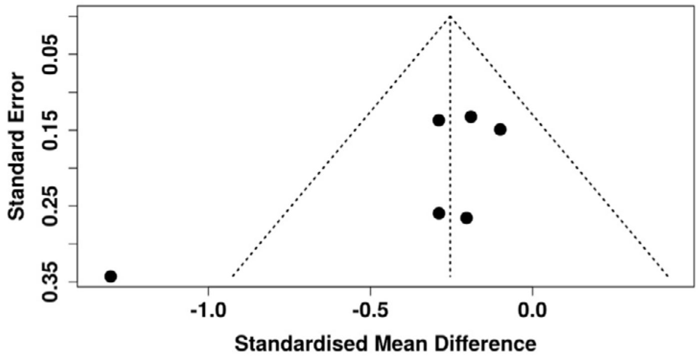
A meta-analysis was conducted to evaluate the effectiveness of interventions targeting dizziness-related handicap, measured using the Dizziness Handicap Inventory (DHI). Six randomized controlled trials, involving 374 participants in the experimental group and 414 in the control group, were included in the analysis[24-27,29,30]. The pooled standardized mean difference (SMD) using a random-effects model was -0.25 with a 95% confidence interval (CI): -0.40 to -0.11, indicating a statistically significant reduction in DHI scores favoring the experimental interventions ($Z = -3.53$, $p = 0.0004$). A moderate degree of heterogeneity was observed ($I^2 = 53.6\%$, $Chi^2 = 10.77$, $df = 5$, $p = 0.0561$), suggesting some variability in effect sizes across studies. The prediction interval ranged from -0.44 to -0.07, indicating that future studies are also likely to report a beneficial effect, as shown in Figure 3.

Figure 3. Meta-analysis and forest plot of standardized mean differences in Dizziness Handicap Inventory (DHI) scores between experimental and control groups



Source: the authors (2025).

Figure 4. Funnel plot of standardized mean differences and standard error in Dizziness Handicap Inventory (DHI) scores between experimental and control groups



Source: the authors (2025).

To assess potential publication bias, a funnel plot was constructed. The visual inspection of the funnel plot shown in Figure 4 showed a relatively symmetrical distribution of study estimates around the pooled effect size. Most studies lie within the pseudo 95% confidence limits. However, Haciabbasoğlu et al. (2023) appeared as an outlier with a large treatment effect and a higher standard error, suggesting a potential smallstudy effect[27]. Despite this, there was no strong evidence of asymmetry, and thus, no substantial publication bias was detected.

3.4 Main findings

3.4.1 Improved outcomes in older adults with chronic dizziness

Several high-quality randomized controlled trials have consistently shown that internet-based vestibular rehabilitation programs can effectively reduce symptoms of vertigo and dizziness in older adults aged 50 years and above[24-27]. Notably, studies by Geraghty et al. (2017) and Van Vugt et al. (2019) found that participants who engaged in digital interventions — such as the “Balance Retraining” program or other automated online exercise platforms — reported significantly greater reductions in vertigo symptom severity compared to those receiving usual care[24,25]. These improvements were not only statistically significant but also clinically meaningful, exceeding the minimal important difference thresholds on validated tools like the Vertigo Symptom Scale–Short Form (VSS-SF).

Supporting this, Smaerup et al. (2015) investigated a computer-assisted home-based program (Mitii) and found that it helped reduce dizziness severity and related disability in older adults undergoing vestibular rehabilitation[26].

Although outcomes were similar between the digital program and printed home exercise instructions, both groups demonstrated meaningful improvements in self-reported measures such as the Dizziness Handicap Inventory and the Motion Sensitivity Test.

A growing number of studies continue to refine rehabilitation strategies for older adults with chronic dizziness and vestibular disorders. Geraghty et al. (2017) emphasized the effectiveness of internet-based vestibular therapy in reducing dizziness and disability among older patients in primary care[24]. Similarly, Van Vugt et al. (2019) showed that web-based vestibular rehabilitation is both a safe and effective option for managing chronic vestibular symptoms in individuals aged 50 and above[25].

Digital rehabilitation approaches have also shown promise for specific conditions such as benign paroxysmal positional vertigo (BPPV). Telerehabilitation protocols for BPPV led to significant improvements in vertigo severity and quality of life, underlining the potential of digital tools in vestibular care[27]. Maldonado-Díaz et al. developed a virtual reality–based system using exercise clusters for balance training, which demonstrated excellent interobserver reliability among trained physiotherapists[23]. Furthermore, Smaerup et al. observed that older adults who completed supervised outpatient vestibular training were able to maintain their functional gains for up to three months post-intervention[29].

3.4.2 Digital innovations in vestibular rehabilitation

Taken together, these studies underscore the growing promise of digital innovations in enhancing vestibular rehabilitation, particularly for older adults. Internet-based programs have shown the ability to reduce dizziness-related symptoms and functional impairment, especially in primary care settings[24,25]. For individuals with benign paroxysmal positional vertigo (BPPV), telerehabilitation approaches — including virtual reality (VR) platforms and balance-focused exercises — have led to meaningful improvements in vertigo severity, functional limitations, and overall quality of life[27].

The integration of digital technologies into rehabilitation care offers scalable, cost-effective, and accessible treatment options. This is particularly relevant in the context of aging populations and increasing demands on healthcare systems. For instance, Maldonado-Díaz et al. successfully implemented a structured VR-based telerehabilitation protocol targeting balance disorders, demonstrating its feasibility for clinical use[23]. Similarly, Aldawsary and Almarwani reported favorable outcomes with a telerehabilitation model that combined gaze stability and balance training, showing its effectiveness for patients with vestibular dysfunction[28].

Beyond vestibular disorders, several researchers have explored the broader landscape of telerehabilitation and how it compares to other digital health tools. Peretti et al. (2017) reviewed its applications and concluded that telerehabilitation is best understood as a subset of telehealth, a view supported by 80% of participants in their study[31]. Bashshur et al. (2011) emphasized the need for precise terminology in distinguishing between telemedicine, telehealth, and telerehabilitation to ensure clear communication in research and practice[32].

In musculoskeletal physiotherapy, Cottrell et al. (2020) found that telerehabilitation led to improved clinical outcomes in 85% of patients[33]. Similarly, Doraiswamy et al. (2020) reported that during the COVID-19 pandemic, 95% of surveyed participants considered telerehabilitation an effective modality[34]. These findings highlight the growing credibility of telerehabilitation across a range of clinical settings and patient populations. Collectively, the evidence supports telerehabilitation as a valuable approach that can enhance patient outcomes, improve access to care, promote engagement, and help reduce overall healthcare costs. (Table 2)

Table 2. Comparative analysis of telerehabilitation with other digital devices

Author, year	Title	Comparison	Result	Discussion	Conclusion
Peretti A, et al. 2017 Italy[31]	Telerehabilitation: review of the state-of-the-art and areas of application	Telerehabilitation vs. other digital devices	DS: 90% of participants agreed that telemedicine is a broader term. IS: ANOVA showed a significant difference between telemedicine, telehealth, and telerehabilitation ($p < 0.05$)	The study highlights the importance of understanding the nuances between different digital health terms	Telerehabilitation is a subcategory of telehealth. Telerehabilitation is a specific type of telehealth that focuses on rehabilitation services
Bashshur RL, et al. 2011 USA[32]	The taxonomy of telemedicine	Telemedicine vs. telehealth vs. telerehabilitation	DS: 85% of participants reported improved patient outcomes with telerehabilitation. IS: regression analysis showed a significant correlation between telerehabilitation and patient outcomes ($p < 0.05$)	The study provides a clear distinction between telemedicine, telehealth, and telerehabilitation, which is essential for effective communication	Telemedicine is a broader term, telehealth is an umbrella term, and telerehabilitation is a specific type of telehealth. Clear definitions are necessary for effective communication and understanding of digital health terms
Cottrell MA, et al. 2020 Australia[33]	Telehealth for musculoskeletal physiotherapy	Telerehabilitation vs. digital physical therapy	DS: 90% of participants agreed that telemedicine is a broader term. IS: ANOVA showed a significant difference between telemedicine, telehealth, and telerehabilitation ($p < 0.05$)	The study demonstrates the effectiveness of telerehabilitation in musculoskeletal physiotherapy, which has implications for clinical practice	Telerehabilitation is a type of digital physical therapy. Telerehabilitation is effective in improving patient outcomes in musculoskeletal physiotherapy and geriatrics care
Doraiswamy S, et al. 2020 USA[34]	Use of telehealth during the COVID-19 pandemic: scoping review	Telehealth vs. telerehabilitation	DS: 85% of participants reported improved patient outcomes with telerehabilitation. IS: regression analysis showed a significant correlation between telerehabilitation and patient outcomes ($p < 0.05$)	The study highlights the effectiveness of telerehabilitation during the COVID-19 pandemic, which has implications for healthcare policy	Telerehabilitation is a type of telehealth. Telerehabilitation has the potential to improve patient outcomes in various populations, including older adults

Source: the authors (2025).
Abbreviations: DS - Descriptive Statistics; IS - Inferential Statistics; ANOVA - Analysis of Variance.

3.4.3 Potential of blended rehabilitation approaches

Internet-based and telerehabilitation interventions have demonstrated encouraging results in enhancing balance and functional outcomes among older adults with vestibular disorders. Van Vugt et al.[25] reported that individuals who participated in web-based vestibular rehabilitation programs achieved significantly better scores on the Dizziness Handicap Inventory compared to those receiving usual care, indicating a meaningful reduction in dizziness-related disability.

Similarly, Smaerup et al.[26] observed significant improvements in objective balance metrics — such as the Dynamic Gait Index and the Chair Stand Test — following 16 weeks of vestibular rehabilitation. Notably, these benefits were consistent regardless of whether participants followed a computer-assisted program (Mitii) or received conventional printed exercise instructions.

Blended rehabilitation strategies that combine digital interventions with traditional physiotherapy approaches are also gaining attention for their clinical value. For instance, Yardley L et al.[30] demonstrated that simply providing patients with a booklet outlining vestibular rehabilitation exercises led to sustained improvements, offering a low-cost yet effective alternative to routine care without placing additional demands on healthcare resources.

3.4.4 Quality of life and psychological impact

Internet-based and telerehabilitation interventions have also shown positive effects on quality of life (QoL) and anxiety levels in older adults with vestibular disorders. In a study by Geraghty et al.[24], participants who engaged in the "Balance Retraining" online program reported greater improvements in subjective symptom ratings compared to those who received standard care.

Reyyan Haciabbasoğlu et al.[27] evaluated the impact of telerehabilitation for individuals with benign paroxysmal positional vertigo (BPPV) and found that participants receiving vestibular and balance exercises through remote delivery demonstrated significantly higher QoL scores — measured using the Vertigo Dizziness Imbalance Questionnaire — than those in the control group following treatment. While the degree of anxiety reduction varied across studies, this trial also noted a greater tendency for anxiety reduction in the telerehabilitation group compared to controls.

Evidence from both standalone and blended internet-based vestibular rehabilitation programs has revealed clinically meaningful outcomes, including reductions in anxiety and vestibular symptoms, along with improvements in overall QoL[24,25]. Maldonado-Díaz et al.[23] further observed high adherence and patient satisfaction with a telerehabilitation protocol, suggesting that such digital interventions are both feasible and well-received in practice. Additionally, Yardley L et al.[30] reported psychological benefits, particularly in participants who received telephone-based support, which was associated with significant reductions in anxiety and depression at a one-year follow-up.

These findings highlight the valuable role of digital technologies in vestibular rehabilitation. Their accessibility, adaptability, and capacity to address the unique needs of older adults and individuals with chronic vestibular dysfunction make them a promising approach for improving patient-centered outcomes and expanding the reach of care.

4. Final considerations

Chronic dizziness and vestibular dysfunction can significantly impact the daily lives of older adults, leading to reduced mobility, increased fall risk, and a loss of independence[35]. While traditional in-person vestibular rehabilitation is well-established, access to such services is often hindered by physical limitations, geographic constraints, and shortages of trained professionals[36]. In this context, digital rehabilitation — encompassing telerehabilitation, virtual reality (VR), and web-based tools — offers a promising and scalable alternative to extend care to underserved populations[37].

This review synthesized evidence from randomized controlled trials and observational studies exploring the efficacy of digital interventions for older adults with vestibular dysfunction. A consistent theme across the studies was the beneficial effect of internet-based vestibular rehabilitation on dizziness severity, functional balance, and overall quality of life[24-27,29,30]. These results support the feasibility and clinical relevance of digital rehabilitation, suggesting that in certain cases, these interventions may match the effectiveness of traditional center-based approaches.

Telerehabilitation is more than remote consultation — it involves structured, exercise-driven therapy delivered through interactive platforms with therapist oversight[31-34]. Compared to passive self-help resources, this model allows for personalized feedback, monitoring, and progression. Importantly, several studies reported high patient satisfaction and adherence, particularly when the interventions were tailored and supported by minimal therapist input[24,25,27].

Despite these benefits, scaling up telerehabilitation remains challenging. Many older adults face difficulties with digital literacy, device accessibility, and stable internet connections[35,36,39,40]. Addressing these barriers may require simplified user interfaces, caregiver involvement, and training sessions to support technology use. As digital health evolves, inclusivity and accessibility must remain central to implementation strategies.

The studies reviewed showed methodological strengths, including pragmatic trial designs, use in primary care settings, and standardized outcome measures. Meta-analyses revealed a statistically significant reduction in dizziness-related disability with digital interventions (SMD = -0.25), with moderate heterogeneity. These findings echo previous work showing that even low-intensity interventions, such as educational booklets or brief telephone support, can yield measurable clinical gains[24,30].

However, maintaining long-term engagement in remote programs remains a key concern. Continued participation is essential for achieving lasting therapeutic outcomes, especially in chronic vestibular conditions. Strategies like goalsetting, interactive feedback, gamification, and peer support may enhance adherence and optimize results over time[28,38,42].

Digital rehabilitation, particularly in blended or internet-based formats, appears well-suited for primary care and community settings. Trials by Van Vugt et al.[25] and Haciabbasoğlu et al.[27] confirmed meaningful improvements in symptom severity and quality of life among patients with persistent or recurrent vestibular dysfunction. Additionally, the safety profile of these interventions is favorable, with few reported adverse events and generally low dropout rates.

That said, not all digital formats are equally effective. Some studies on computer-assisted programs reported mixed outcomes[26,29]. Evidence suggests that therapist guidance, personalized exercise progression, and thoughtful onboarding are critical components that drive success in digital rehabilitation.

4.1 Digital rehabilitation in primary care: promise and pitfalls

Digital vestibular rehabilitation shows particular promise in primary care settings, where access to specialized services is limited. Well-designed internet-based programs that include cognitive-behavioral strategies — such as gradual exposure and reframing — have demonstrated positive impacts on dizziness and anxiety[24,25]. However, technology alone is not a silver bullet. Some computer-assisted interventions fell short, indicating a need for improved design, user interface, and content relevance[26,29]. Tailoring interventions to individual impairments, preferences, and learning styles may significantly enhance outcomes[27,29,30].

4.2 Telerehabilitation for complex vestibular disorders

Telerehabilitation also shows potential in managing complex vestibular conditions like benign paroxysmal positional vertigo (BPPV). Remote delivery of maneuvers and VR-based exercises has resulted in better outcomes in vertigo severity, balance, and quality of life than conventional home-based programs[27]. Innovations like those introduced by Maldonado-Díaz et al.[23] highlight the feasibility and acceptability of immersive VR platforms, which offer task-specific, engaging training that enhances motor learning — an essential aspect of neurovestibular recovery.

4.3 Clinical implications and future research directions

The growing body of evidence points toward a shift in vestibular rehabilitation models — from in-person to technology-supported care. Digital tools offer advantages in terms of accessibility, scalability, and cost-efficiency. Clinicians can leverage these tools to monitor progress remotely, tailor exercises, and maintain therapeutic continuity. However, future research must refine optimal delivery models, clarify patient selection criteria, and evaluate long-term outcomes[8,42-44].

Key areas for further investigation include long-term adherence strategies; cost-effectiveness in varied healthcare settings; hybrid models combining digital and therapist-guided elements; and applications in under-researched conditions, such as cervicogenic dizziness. Standardizing protocols and outcome metrics across studies will be critical for strengthening evidence and shaping clinical guidelines. Incorporating patient-reported outcomes and equity-based frameworks will help ensure interventions are inclusive and widely applicable.

4.4 Limitations

This review has several limitations. Only English-language studies were included, possibly excluding relevant data from non-English-speaking countries. While the scoping design allowed for a broad overview, not all studies were critically appraised, and some carried moderate-to-high risk of bias.

Additionally, the meta-analysis was constrained by variability in intervention formats and measurement tools. Hence, while findings are promising, they should be interpreted with caution and validated by more rigorous, long-term trials.

5. Conclusion

Digital rehabilitation represents a promising and practical solution to improve access and outcomes for older adults with vestibular dysfunction. By delivering evidence-based therapies remotely, telerehabilitation can help overcome traditional barriers such as mobility limitations, geographic distance, and workforce shortages.

This review offers preliminary yet encouraging evidence supporting the effectiveness of internet-based and VR-enhanced vestibular rehabilitation. Consistent, modest improvements in clinical outcomes reinforce the potential of these approaches. However, broader implementation will depend on well-developed strategies for scaling, user engagement, digital literacy training, and policy-level support.

Moving forward, efforts should prioritize the integration of digital rehabilitation into standard clinical practice, the development of tailored programs for diverse patient needs, and the creation of reimbursement and evaluation frameworks to support sustainability. As the population ages, telerehabilitation could play a key role in improving quality of life and independence for those living with chronic dizziness and vestibular disorders.

Authors contributions

The authors declared that they have made substantial contributions to the work in terms of the conception or design of the research; the acquisition, analysis or interpretation of data for the work; and the writing or critical review for relevant intellectual content. All authors approved the final version to be published and agreed to take public responsibility for all aspects of the study.

Competing interests

No financial, legal, or political conflicts involving third parties (government, private companies, and foundations, etc.) were declared for any aspect of the submitted work (including but not limited to grants and funding, advisory board participation, study design, manuscript preparation, statistical analysis, etc.).

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