Original Paper

Virtual Reality Sickness and Safety During Use of a Purpose-Built Seated Virtual Reality System in Clinical Rehabilitation: Retrospective Single-Arm Cohort Study

Jaylen Dobelbower[1]; Bilal Saadi[1]; Ashley Galvan[1]; Kevin Zhou[1]; Zarqa Fathima[1]; Dhroov Pathare[1]; Yuichiro Murakawa[2]; Masatake Tamaki[2]; Masahiko Hara[2,3], MD, PhD

[1]The University of Texas at Austin, Austin, TX, United States

[2]mediVR Rehabilitation Center Osaka, Toyonaka, Osaka, Japan

[3]Shimane University Faculty of Medicine, Izumo, Shimane, Japan

Corresponding Author:
Masahiko Hara, MD, PhD
mediVR Rehabilitation Center Osaka
Ryokuchi Station Building 3F, Terauchi 2-chome 4-1
Toyonaka, Osaka
Japan
Phone: 81 90 7593 222
Email: hara@medivr.jp

Abstract

Background: Virtual reality (VR) sickness is a recognized barrier to the clinical adoption of immersive rehabilitation. Evidence on the tolerability of purpose-built clinical VR systems used at scale remains limited.

Objective: This real-world feasibility and safety study aimed to describe the frequency of recorded VR sickness in a primary cohort using a purpose-built, seated VR rehabilitation system (mediVR KAGURA), integrating 7 multisensory engineering principles, and characterize serious adverse events in a secondary postmarketing surveillance (PMS) cohort without assessing the causal effects of individual features.

Methods: We conducted a single-arm, retrospective observational cohort study (no comparison group) of 2 cohorts following the Journal Article Reporting Standards for quantitative research. The primary cohort comprised 3572 unique users (patients and the public; aged 3-100 years) identified from company records and server logs between November 2023 and June 2025 at our rehabilitation centers (n=578), institutional demonstrations (n=1715), and academic exhibitions (n=1279); typical exposure was 20 to 60 minutes at our rehabilitation centers and 5 to 10 minutes elsewhere. Its primary end point was VR sickness (user-reported nausea, dizziness, or malaise during or immediately after a session); secondary end points were adverse events (eg, falls or injuries). The secondary PMS cohort comprised all 337,577 therapeutic sessions (approximately 9306 patients) at 170 medical institutions from 2019 to 2025; its end points were serious adverse events and VR sickness requiring medical intervention. Sex and diagnoses were not available. All eligible records were analyzed without exclusions, and no outcome data were missing. Analyses were descriptive (95% CI through the Wilson score and exact binomial methods); no hypothesis tests were performed.

Results: In the primary cohort, 0.36% (13/3572) of users (95% CI 0.21%-0.62%) had recorded VR sickness, mostly mild and transient, and 0.03% (1/3572; 95% CI 0.005%-0.16%) discontinued a session early. No user required medical intervention, and no falls or injuries were recorded. In the PMS cohort, no serious adverse events or VR sickness requiring medical intervention were reported across 337,577 sessions (exact 95% CI 0%-0.0011%), although mild unreported symptoms cannot be excluded.

Conclusions: In this real-world dataset, recorded VR sickness was uncommon and mostly mild with a purpose-built seated VR rehabilitation system, and no serious adverse events or medically attended VR sickness were reported in the PMS. Earlier work mainly tested individual design features under controlled conditions, whereas this study documents an integrated multisensory design at scale in routine practice. Because it was uncontrolled and applied all features together, it cannot establish causality, attribute effects to individual features, or support comparison with other systems; the findings are proof-of-concept evidence. They suggest that seated, visually stable, and predictable designs can be deployed safely at scale in clinical rehabilitation and motivate prospective controlled studies with standardized symptom measures.

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KEYWORDS

biomedical engineering; motion sickness; somato-cognitive coordination therapy; virtual reality; sensory conflict; cybersickness; rehabilitation; patient safety; postmarketing product surveillance

Introduction

The application of virtual reality (VR) technology is expanding in medical rehabilitation, serving as a tool to supplement conventional therapies by providing immersive, engaging, and precisely quantifiable therapeutic environments [1-3]. VR systems permit clinicians to create individualized and reproducible interventions for patients with neurological disorders, gait and balance deficits, and chronic pain [1-3]. However, VR sickness remains a primary barrier to the clinical adoption of immersive technologies, often contributing to hesitation in its adoption by clinicians and difficulties with patient adherence to treatment [4-7]. Recent clinical studies have reported differing levels of cybersickness during immersive VR interventions. In a pilot randomized trial of VR-assisted lower-limb exercise for knee osteoarthritis, 33% (5/15) of participants in the immersive VR group reported cybersickness [8]. In contrast, a feasibility study of VR-based neurorehabilitation in 20 inpatients with acquired brain injury reported a low mean Simulator Sickness Questionnaire (SSQ) score and no notable cybersickness symptoms [9]. Because these studies differed in participants, tasks, exposure, and symptom measurement, their results are not directly comparable; however, both emphasize the importance of assessing tolerability for each specific clinical VR application.

VR sickness is a form of cybersickness specifically defined as visually induced motion sickness that occurs in response to VR exposure [4,5]. This syndrome, characterized by symptoms including nausea, dizziness, and malaise, is reported to affect a high proportion of users. Incidence rates in nonspecialized VR applications are cited across a wide range, often from 20% to 80% [6], with some studies finding 65.2% of participants experiencing symptoms, of whom 23.9% report severe symptoms [7]. These figures derive from heterogeneous applications that differ in content, visual motion, populations, exposure duration, and symptom assessment; they are therefore presented as background only, and direct numerical comparison with data from a static, seated clinical system is not statistically valid. Reported cybersickness incidence also depends on how symptoms are assessed and documented. A systematic review of adverse effect reporting in VR and augmented reality interventions in psychiatry found considerable variability: 45 of 73 studies did not mention adverse effects, and 21 reported none despite documenting mainly cybersickness in their own results [10]. Although that review concerned psychiatric rather than rehabilitation applications, it illustrates how assessment methods shape the conclusions that can be drawn. Standardized instruments such as the SSQ and the more recently validated Cybersickness in Virtual Reality Questionnaire can characterize the severity and type of symptoms beyond a binary report of sickness [9,11]. These measurement differences complicate comparisons across studies and underline the importance of clearly defined safety outcomes.

The prevailing etiological explanation for this phenomenon is the sensory conflict theory [4-7]. This theory posits that sickness arises from a neural incongruence between sensory inputs—primarily a mismatch between the visual system, which perceives motion in the virtual environment (eg, navigating a scene), and the vestibular and somatosensory systems, which sense that the body is stationary [6]. This visual-vestibular conflict is the physiological foundation of VR sickness symptoms [5-7].

Recent experimental studies have linked cybersickness to display lag–related differences between physical and virtual head pose [12] and have examined the roles of vection type and postural instability [13]. In a preliminary experiment, optical flow stimuli presented through a head-mounted display (HMD) induced body sway and visually induced motion sickness in healthy participants [14], and a visual rest-frame approach has been proposed as a mitigation strategy [15]. These findings provide a rationale for investigating stable visual environments, predictable spatial cues, and responsive display performance. However, evidence on individual mechanisms, largely from healthy participants under experimental conditions, does not establish the safety or tolerability of a complete clinical VR system, and large-scale clinical evidence from systems used in routine practice remains scarce.

To address this challenge, we developed a VR medical device incorporating integrated engineering principles designed to mitigate the root causes of sensory conflict. The aim of this study was to describe the frequency of recorded VR sickness in a primary cohort of users of this purpose-built, seated VR rehabilitation system and characterize reports of serious adverse events or VR sickness requiring medical intervention in a separate postmarketing surveillance (PMS) dataset. This descriptive study did not test prespecified hypotheses; the engineering principles are described as part of the system rather than as experimentally tested factors.

Methods

Study Design (Conditions and Design)

This was a single-arm, uncontrolled, retrospective observational cohort study of naturally observed use of the mediVR KAGURA system. No condition was experimentally manipulated, and no randomization or masking was applied (a nonexperimental, single-group design). It was intended to document real-world feasibility and safety rather than comparative effectiveness against conventional VR systems. The report follows the Journal Article Reporting Standards for quantitative research of the American Psychological Association for nonexperimental designs.

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Setting

Data for the primary cohort were collected between November 2023 and June 2025 at 3 settings: clinical rehabilitation sessions at our specialized centers (mediVR Rehabilitation Center Osaka, Tokyo, or Fukuoka), on-site demonstrations at internal and external medical institutions, and public exhibitions at scientific congresses. To complement the primary analysis with a broad assessment of safety and repetitive tolerability, we concurrently reviewed large-scale PMS records and server-side logs from 2019 to 2025 covering 170 medical institutions.

Inclusion and Exclusion

For the primary cohort, all unique users of the mediVR KAGURA system at the 3 settings during the study period were included. Eligibility was defined by use of the system only; no exclusion criteria were applied, and no users were excluded. For the PMS dataset, all therapeutic sessions recorded in PMS documentation and server-side logs from 2019 to 2025 were included without exclusions.

Participant Characteristics

The primary cohort spanned the ages of 3 to 100 years and included both clinical patients and members of the general public. Detailed demographic and clinical characteristics (eg, age distribution, sex, diagnosis, and baseline severity) were not recorded in the source records and, therefore, could not be reported (see the Limitations section). The PMS dataset covered a diverse clinical population with a broad range of ages and underlying conditions (Table 1 lists the conditions for which the therapy is used in clinical practice).

Table 1. Clinical domains with potential indications for somato-cognitive coordination therapy in current practice[a].

Clinical specialty	Specific conditions and clinical manifestations
Neurology and neurosurgery	• *Stroke* sequelae (infarction and hemorrhage), including hemiplegia • *Parkinson disease* • *Cerebellar ataxia* (eg, spinocerebellar degeneration and multiple system atrophy) • *Unilateral spatial neglect*
Orthopedics and musculoskeletal disorders	• *Spinal cord injury* and spinal cord infarction • *Adhesive capsulitis (frozen shoulder)* • Hip osteoarthritis • Knee osteoarthritis • Chronic pain conditions with a prominent nociplastic component
Pediatric neurology	• *Cerebral palsy* (particularly for spasticity management) • *Neurodevelopmental disorders* (eg, *autism spectrum disorder and attention-deficit/hyperactivity disorder*) • Spinal muscular atrophy
Oncology and cancer survivorship	• *Chemotherapy-induced peripheral neuropathy* • *Cerebellar ataxia following medulloblastoma treatment* (eg, tumor resection or radiation necrosis) • Cancer-related cognitive impairment (chemo brain)
Pain medicine and anesthesiology	• Central poststroke pain • Complex regional pain syndrome • Fibromyalgia • Restless leg syndrome
Internal medicine and geriatrics	• *Sarcopenia* (primarily for balance and postural control rather than muscle strengthening) • Frailty
Psychiatry	• Schizophrenia • Bipolar disorder (particularly in the depressive phase)

[a]The listed conditions are provided as representative examples, with disease entities and clinical manifestations intentionally presented in parallel for clarity. Conditions shown in italics indicate those most commonly applied in current clinical practice. The target population therefore spans a broad spectrum of central and peripheral nervous system disorders characterized by impaired neural coordination; notably, primary myopathies such as muscular dystrophy are excluded as the intervention specifically targets neural processing rather than intrinsic muscular pathology. While therapeutic gains are often sustained in most neurological conditions, chronic pain management, particularly for conditions with a prominent nociplastic pain component, typically requires repeated, periodic treatment cycles to maintain long-term clinical efficacy.

Sampling Procedures

No sampling or recruitment procedure was applied. All available records were analyzed (complete enumeration), so users were not approached for enrollment, and the percentage of those who participated is not applicable. Self-selection occurred at the level of attending the rehabilitation centers, the institutions arranging demonstrations, and congress attendees trying the system, which may limit generalizability. Study information was publicly disclosed with an opportunity to opt out (see the Ethical Considerations section); no opt-out requests were received, and no records were removed.

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Sample Size, Power, and Precision

No a priori sample size or power calculation was performed because all available records were analyzed; the achieved sample size equaled the intended sample size (primary cohort: n=3572 users; PMS dataset: n=337,577 sessions). Because events were expected to be rare, precision was expressed through 95% CIs for all proportions rather than through power for hypothesis tests. No interim analyses or stopping rules were used.

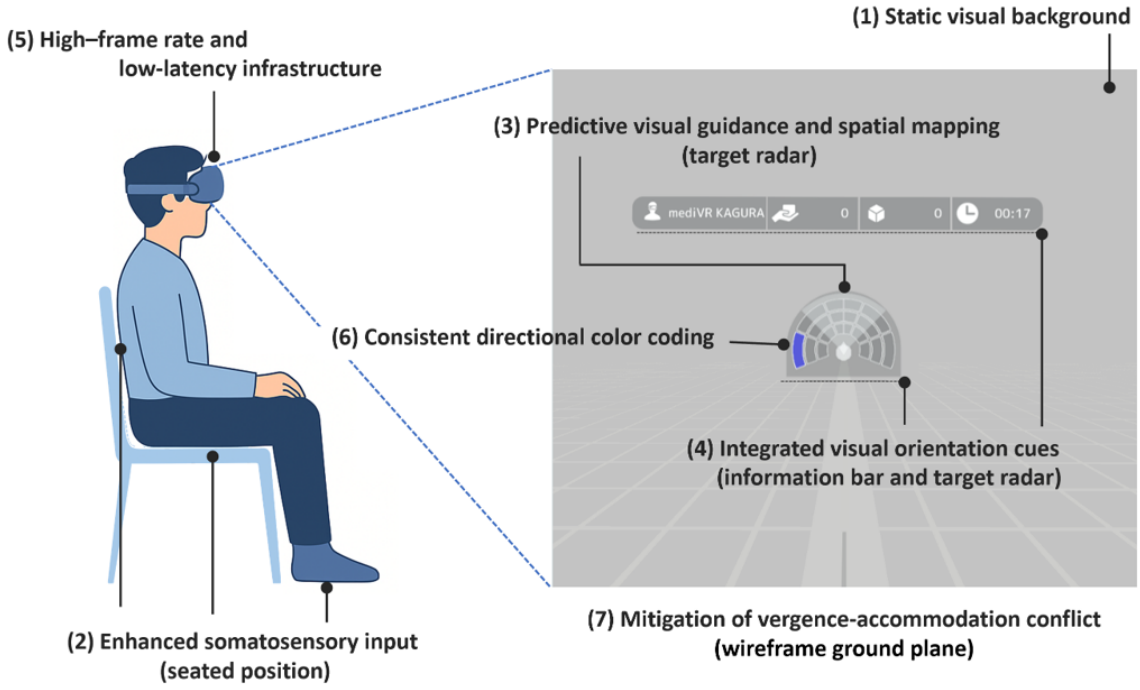
Intervention

The exposure, somato-cognitive coordination therapy (SCCT), is delivered via the mediVR KAGURA system. This immersive VR rehabilitation method reestablishes proprioception-based motor control by removing visual representations of the patient's body. SCCT is hypothesized to enhance the function of the somato-cognitive action network, a cooperative motor control network associated with the primary motor cortex and higher-order sensorimotor integration [16,17]. Through seated, alternate reaching tasks, SCCT has been reported to induce cross-modal functional improvements, including hand dexterity, gait performance, articulatory motor function, and selected cognitive impairments, regardless of the underlying pathology (Table 1) [17-24]. Diffusion tensor tractography suggests that SCCT may facilitate neural network reorganization and neuroplastic changes beyond spontaneous recovery [23,24].

Engineering Principles

The mediVR KAGURA system is founded on 6 primary engineering principles intended to limit sensory conflict and a secondary principle to reduce oculomotor strain. These principles are visually summarized in Figures 1 and 2.

Figure 1. Integrated engineering principles intended to reduce virtual reality (VR) sickness. The numbered labels (1-7) correspond to the engineering principles described in the Methods section.



Static Visual Background

The system uses a visually simple, nonmoving (world-fixed) background. This provides a stable visual rest frame that remains congruent with the user's stationary vestibular and somatosensory state. By eliminating large-field optic flow, the system avoids inducing vection (the illusion of self-motion), thereby limiting a potential source of visual-vestibular conflict.

Enhanced Somatosensory Input (Seated Position)

All therapy is primarily conducted in a stable, seated position using a chair with a backrest, with the user's feet planted firmly on the floor. For patients who require it, the intervention can also be performed in a semiseated position by elevating the backrest of a medical bed. This setup ensures continuous tactile and proprioceptive feedback, providing a solid physical rest frame that reinforces the brain's perception that the body is stationary. By aligning these somatosensory cues with vestibular signals, the system achieves multisensory grounding and is intended to limit the postural instability that contributes to motion sickness. The use of armrests is an optional addition that can further enhance the precision of this sensory feedback.

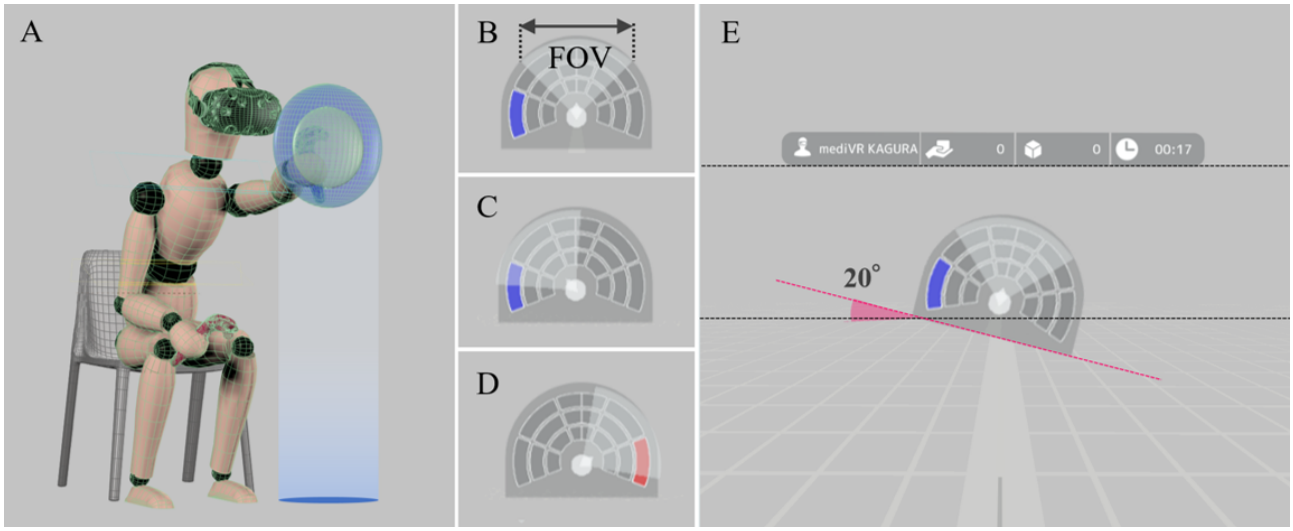
Predictive Visual Guidance and Spatial Mapping (Target Radar)

A central reticle is permanently displayed at the center of the field of view (FOV). Throughout the intervention, an 18-block radar interface—comprising 9 blocks per side spanning a 180° horizontal arc across 3 depth levels—remains visible as a permanent user interface element. Upon the onset of a task, the specific block corresponding to the target's spatial coordinates is illuminated (blue for the left side and red for the right) and

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remains lit until the task is completed, providing an instantaneous visual cue of the task's location. This radar functions as a dynamic spatial map visualizing the orientation of the HMD and its current FOV relative to the target. This feature allows the user to determine whether a target is within their direct line of sight or in the periphery. Crucially, the provision of spatial information regarding targets located outside the immediate FOV is intended to effectively bridge the gap between natural peripheral vision and the hardware-limited FOV of the HMD. Figure 2B-D illustrates this function: a target at the leftmost 0° position lies outside the current FOV (B), becomes partially visible as the user rotates the head approximately 45° leftward (C), and the 180° target becomes clearly visible after a head turn of approximately 150° rightward (D). By enabling the brain to establish an accurate predictive model—analogous to how a driver anticipates a vehicle's motion or how a passenger mitigates nausea by looking far ahead at the horizon to predict upcoming changes in trajectory—the system is intended to reduce the sensory surprise and mismatch between expected and actual sensory feedback that typically trigger nausea.

Figure 2. Visual interfaces for predictive spatial mapping and real-time orientation monitoring. (A) Representative clinical application of somato-cognitive coordination therapy. (B-D) Target radar function. (E) Integrated orientation cues.



Integrated Visual Orientation Cues (Information Bar and Target Radar)

The system provides coordinated visual references to maintain spatial orientation. A fixed information bar at the top of the display, together with the wireframe ground plane in the core training modes, functions as a stable artificial horizon representing the earth horizontal plane. While the target radar tilts in coordination with the user's head movement, these specific visual elements remain level and stationary. Figure 2E illustrates these cues during a rightward head or trunk tilt. Together with the target radar acting as a spatial anchor, these components provide a constant, earth-fixed reference for posture, anchoring the user in the stationary environment and reducing the spatial disorientation that often leads to discomfort.

High–Frame Rate and Low-Latency Infrastructure

The system uses a performance-first infrastructure that maintains a constant rate of 90 frames per second with motion-to-photon latency under 20 milliseconds [6]. This high level of stability is achieved by combining optimized low-polygon graphics to minimize graphics processing unit load, high-specification dedicated workstations for consistent processing power, and enterprise-grade VR hardware for precise tracking. By minimizing temporal lag, the system aims to limit the sensory mismatch between visual and vestibular inputs, providing the seamless integration needed to support therapeutic exercise.

Consistent Directional Color Coding

To further reduce cognitive load and spatial disorientation, the system uses a consistent, system-wide color-coding rule, with blue for movements on the left side and red for movements on the right side. This intuitive logic can help users recognize directional cues quickly. By simplifying spatial navigation and reducing the mental processing required for orientation, this color anchoring is intended to help maintain a stable mental state and reduce confusion that may contribute to VR sickness.

Mitigation of Vergence-Accommodation Conflict

As a secondary strategy, the system aims to reduce vergence-accommodation conflict—an oculomotor strain where the eyes' vergence (focusing on a 3D depth) conflicts with the fixed accommodation (focusing on the physical screen). To facilitate rapid and accurate spatial perception, the system provides unambiguous depth orientation cues: a target radar interface for depth anticipation, a wireframe ground plane for consistent environmental reference in the core training modes, and vertical pillars of light extending from the ground to each interactive object. These features enable the user to triangulate the target's precise spatial coordinates relative to the stationary environment. By providing the brain with clear, multimodal evidence of depth, the system is intended to reduce the physiological stress of ocular adjustment and visual fatigue.

Measures and Covariates

The primary outcome was the incidence of VR-induced sickness, defined as any patient-reported symptom (eg, nausea, dizziness,

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or malaise) sufficient to interrupt the session or be noted immediately following the SCCT. The secondary outcomes were the incidence of other adverse events, such as falls from the chair or injuries. Early session discontinuation due to discomfort was documented as part of VR sickness. In the PMS dataset, the outcomes were serious adverse events and VR sickness requiring medical intervention. The exposure was use of the mediVR KAGURA system (single-exposure group); setting and typical exposure duration were the only contextual variables available, and no other covariates or potential confounders were recorded or adjusted for.

Data Collection

Data sources were company records and synchronized server-side logs, which were reviewed for user identification, session counts, and adverse event documentation. Data were extracted from the company records and server-side logs by a systems engineer employed by mediVR. For the primary cohort, meticulous documentation was maintained using high-sensitivity monitoring to capture even mild, transient symptoms of VR sickness (eg, slight dizziness) that did not require medical intervention. In contrast, PMS documentation, in accordance with regulatory standards for medical device manufacturers, specifically targets the reporting of serious adverse events and incidents necessitating medical intervention. Symptom ascertainment therefore differed between the 2 datasets.

Quality of Measurements

To enhance data quality, the number of unique users identified from company records was cross-referenced with synchronized server-side logs (see the Results section). Training and interrater reliability of data collectors were not formally assessed.

Instrumentation

The exposure instrument was the mediVR KAGURA system (see the Intervention and Engineering Principles section). No validated or ad hoc symptom questionnaire was used; VR sickness and adverse events were documented as binary clinical reports.

Masking

Masking was not applicable because there was no experimental manipulation or condition assignment. Outcome documentation was not masked.

Psychometrics

Psychometrics were not applicable. VR sickness was recorded as a binary clinical report rather than using a standardized scale, so no reliability or validity coefficients were estimated (see the Limitations section).

Data Diagnostics

All eligible records were extracted (complete data extraction). No records were excluded after data collection, and no data were missing for any analyzed variable. Therefore, no test of the missing data mechanism and no imputation were required or performed. Outlier handling and data transformations were not applicable to the count-based outcomes.

Analytic Strategy

Analyses were descriptive given the retrospective design and the expected rarity of events. The primary outcome was the incidence of VR sickness; secondary outcomes were other adverse events. No hypothesis tests, exploratory subgroup analyses, or adjusted analyses were planned or performed. Categorical outcomes were summarized as numbers and percentages with 95% CIs (Wilson score method for the primary cohort; exact binomial method for the PMS dataset, in which 0 events were observed); the 95% CI corresponded to a 2-sided α level of .05. Because all 7 engineering principles were applied simultaneously and uniformly to every user with no experimental variation of individual components, the dataset did not permit correlation, regression, or clustering analyses to isolate the contribution of individual design elements; this constraint is inherent to the real-world, nonexperimental nature of the data rather than an analytical omission. The statistical analyses were performed by YM and MH, who are affiliated with mediVR (see the Conflicts of Interest section). The analyses were therefore not performed by an independent third party. All data processing and statistical calculations were performed using the Microsoft R Open software (version 4.0.2).

Ethical Considerations

Ethics Review and Approval

The study protocol complied with the Declaration of Helsinki and was approved by the external institutional ethics committee of the Japan Society of Clinical Research (approval 202501; approved on January 8, 2025) as part of the RECOVER RECORD (Reprogramming Coordination Through Virtual Environment Rehabilitation: Real-World Evidence From Clinical Observations and Records) trial, registered in the University Hospital Medical Information Network Clinical Trials Registry (UMIN000056624) on January 8, 2025.

Informed Consent

Given the retrospective nature of the data and the use of anonymized records, the ethics committee waived the requirement for written informed consent. In accordance with this waiver, study information was publicly disclosed on the University Hospital Medical Information Network Clinical Trials Registry website and the website of the Japan Society of Clinical Research, providing users with an opportunity to decline inclusion of their data (opt out). No opt-out requests were received.

Privacy and Confidentiality

Anonymized records were used for the analysis, and no personally identifiable information is reported in this manuscript.

Compensation

No compensation was provided to participants because the study was a retrospective analysis of existing records.

Identifiable Images

This manuscript and its supplementary material contain no images that could identify individual participants.

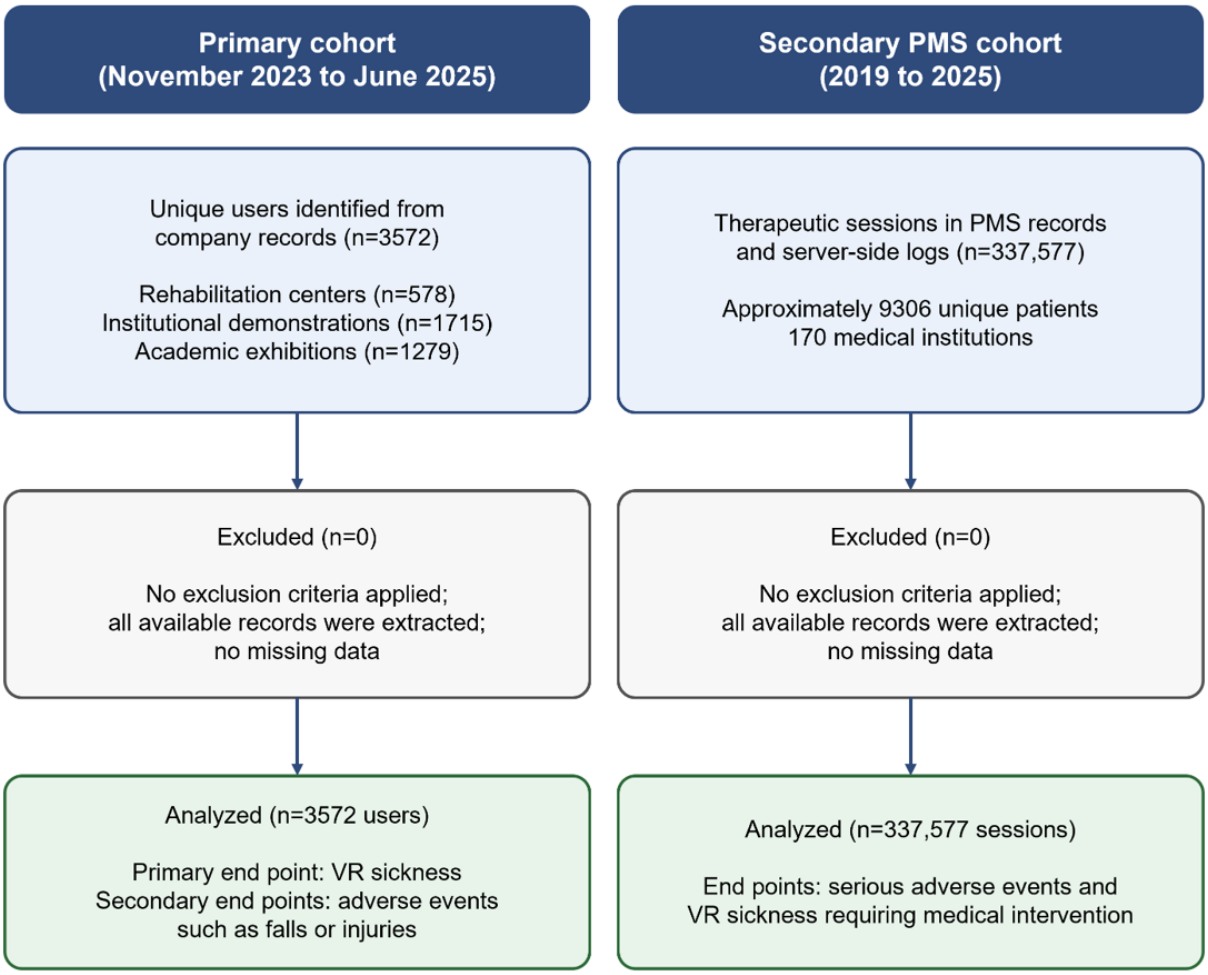
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Results

Participant Flow

Figure 3 shows the flow of users and records. All identified users and all recorded sessions were analyzed; no records were excluded, and no data were missing.

Figure 3. Flow of users and records in the primary cohort and the postmarketing surveillance (PMS) dataset. VR: virtual reality.



Recruitment

No recruitment was conducted. The primary cohort covers users recorded between November 2023 and June 2025, and the PMS dataset covers sessions recorded from 2019 to 2025.

Primary Cohort Analysis

A total of 3572 unique users were identified from company records between November 2023 and June 2025. This cohort included 16.2% (578/3572) at our rehabilitation centers, 48% (1715/3572) at institutional demonstrations, and 35.8% (1279/3572) at academic exhibitions. To validate this cohort size, we cross-referenced the data with server-side logs, which identified 3581 unique users over the same period. The 9 additional entries (0.25%) had names registered but no session data because the scheduled experience was canceled, supporting the reliability of our dataset.

Of 3572 users, 13 (0.36%; 95% CI 0.21%-0.62%) had a recorded event of mild VR sickness. The vast majority of these were mild, transient symptoms (eg, “felt slightly dizzy”) reported after the session concluded. Only 1 case (1/3572, 0.03%; 95% CI 0.005%-0.16%) resulted in the user stopping the session prematurely due to discomfort. No users required medical intervention, and all reported symptoms resolved spontaneously without sequelae. No secondary adverse events, such as falls from the chair or other injuries, were recorded during any session. Because all eligible records were analyzed, there were no missing outcome data.

Large-Scale Real-World Safety Record

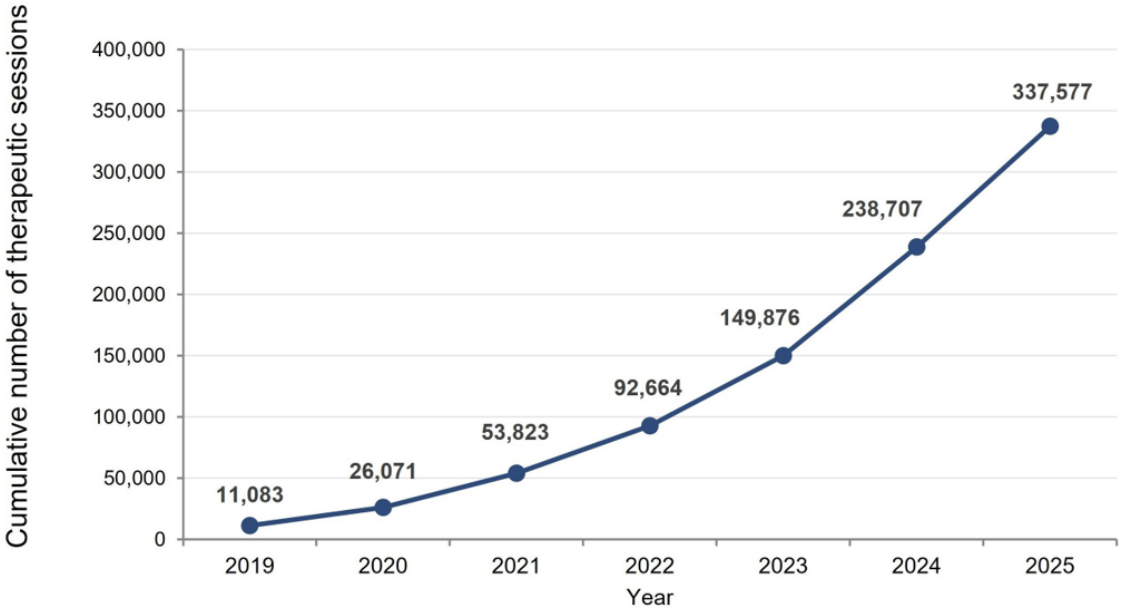
Analysis of the cumulative PMS data from 2019 to 2025 revealed a rapid and consistent growth in clinical adoption (Figure 4). As of the end of 2025, the system reached a clinical footprint of approximately 9306 unique patients, accounting

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for a total volume of 337,577 therapeutic sessions conducted across 170 medical institutions.

Throughout these 337,577 sessions, no serious adverse events such as falls or physical injuries and no cases of VR sickness requiring medical intervention were reported (0%, exact 95% CI 0%-0.0011%). This does not exclude mild symptoms that were not reported in PMS documentation, and the denominator was sessions rather than patients.

Figure 4. Cumulative growth in total therapeutic session volume of somato-cognitive coordination therapy (SCCT). Exact values are shown at each data point.



Discussion

Principal Findings

In this large real-world study, recorded VR sickness during use of the purpose-built seated VR system was uncommon in the primary cohort, was mostly mild and transient when it occurred, and rarely led to early session discontinuation. A separate, much larger PMS dataset recorded no serious adverse events and no VR sickness requiring medical intervention. These descriptive findings address the study aims by documenting the feasibility and tolerability of the system in routine clinical and nonclinical exposure settings. They do not establish that the engineering features caused the observed tolerability because there was no control group and the features were applied together. Cybersickness incidence in the literature varies widely [6-9]. Because these studies differ from ours in populations, tasks, visual motion, exposure duration, and symptom assessment, they provide context only; they are not a statistical comparator and should not be read as evidence of a relative risk reduction.

Integrated Engineering Design for Clinical Application

The favorable tolerability of our system may be attributable to its foundational design philosophy: the simultaneous alignment of 7 engineering principles intended to limit sensory conflict or vergence-accommodation conflict [4-7]. Because these 7 principles were applied together and uniformly to every user, this dataset cannot quantify the specific contribution of each component or rank their relative importance. On the basis of the sensory conflict theory [4-7], we speculate that the static visual background (principle 1) may play a particularly important role as it directly addresses the visual-vestibular mismatch underlying vection-induced discomfort [13-15]; however, this remains an untested hypothesis that would require a future controlled, dismantling-style study to confirm.

In addition, we highlight 3 factors that we hypothesize may have contributed to our system's favorable tolerability, consistent with sensory conflict theory although not individually tested in this dataset. First, enhanced somatosensory input (principle 2), through a stable seated posture with continuous tactile feedback, plausibly provides a reliable physical frame, potentially reducing postural instability and reinforcing congruence between vestibular and somatosensory inputs; postural instability has been examined in relation to cybersickness in recent experimental work [13]. We deliberately integrated the seated position as an engineering element of the system rather than only as a clinical instruction, but whether it contributes to tolerability was not evaluated here. Second, predictive visual guidance and spatial mapping via the target radar (principle 3) introduces a high degree of anticipatory control, allowing users to proactively coordinate required head movements before visual targets enter the FOV. Because unexpected vection has been associated with cybersickness [13], we speculate that minimizing sensory surprise through anticipatory cues may reduce VR-induced discomfort, although this remains to be formally tested [6]. Third, as integrated visual orientation cues, the system provides a permanent, earth-fixed visual reference. This is implemented via an information bar in the upper central FOV working in tandem with a centrally located target radar, offering continuous orientation anchoring. While the target radar serves as the primary focal point at the

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exact center of the display, its lower boundary dynamically reflects head tilting and provides an intuitive cue for angular deviation, whereas the information bar immediately above it provides a constant, earth-fixed horizontal reference. Our system concentrates these stable orientation anchors within the user's core FOV; whether this affects the sense of presence or task engagement was not assessed in this study. By providing constant access to a level reference, this implementation is intended to help users interpret head tilt and spatial alignment relative to a stable environment. Visual rest-frame approaches have been proposed as a mitigation strategy [15], and we speculate that a permanent, earth-fixed reference may play a similar role, although the information bar used here differs from the approach tested in the aforementioned work, and its effect was not evaluated. Together, these 3 factors illustrate one plausible route through which theoretical constructs can be translated into concrete, user-facing design elements; confirming their individual contribution, as noted above, would require future controlled, dismantling-style studies.

Clinical and Health System Implications

From a clinical perspective, the stabilization of spatial orientation may have implications beyond the mere prevention of VR sickness. By potentially reducing visual-vestibular sensory conflict, the system may support functional neural integration, which could be particularly relevant for patients with vestibular disorders such as persistent postural-perceptual dizziness, as suggested in a prior proof-of-concept report [18]. In such cases, our design may help attenuate visual hypersensitivity while providing the stable reference frames that could assist in reconstructing distorted spatial perception [18]. Furthermore, the noise-free sensorimotor signals provided by this integrated engineering design may plausibly serve as a substrate for neural plasticity. Unlike traditional task-oriented training, our approach emphasizes the generation and updating of internal body images through voluntary movements. The bilateral, alternating reaching tasks are hypothesized to facilitate cross-modal effects, potentially engaging neural networks that extend beyond simple motor execution [16,17]. In this context, a case-level report using diffusion tensor tractography has suggested that SCCT via this system may facilitate the reorganization of motor pathways following intracerebral hemorrhage [23], with reorganization observed involving not only the descending motor tracts but also transcallosal and cerebellar-cerebral connectivity; given the cerebellum's role in predictive motor control and the corpus callosum's function in interhemispheric integration, this observation is consistent with, though not proof of, a broader restructuring of the brain's internal motor models [23,24], which would require confirmation in larger, controlled samples. Finally, while experimental research often seeks to isolate single causal factors, the low frequency of recorded VR sickness in real-world settings is consistent with the pragmatic value of a multicomponent engineering approach. The accumulation of 337,577 clinical sessions without serious adverse events suggests that an integrated, digital polypill-like strategy—where multiple design elements are combined to address sensory conflicts—may be a promising model for future digital health and medical device development pending further validation.

Study Limitations

This study has several limitations that should be considered when interpreting the results. First, as noted in the Methods section, this was a single-arm, uncontrolled retrospective cohort study; it lacked a concurrent control group using conventional VR and, therefore, cannot support causal or comparative effectiveness claims regarding VR sickness rates. In addition, because all 7 principles were applied together, the contribution of individual design elements cannot be identified. Second, our assessment of VR sickness in the primary cohort and the PMS dataset relied on binary clinical reports, not a standardized, quantitative measure such as the SSQ [5,7]. Symptom ascertainment also differed between the 2 datasets, and the absence of reported serious or medically attended events in the PMS dataset does not exclude mild symptoms. It is possible that very mild, subclinical symptoms went unreported, and adverse effect reporting is known to vary across VR studies [10]. Future prospective protocols could incorporate repeated standardized symptom measures such as the SSQ or a more recently validated questionnaire [9,11] to capture subclinical or mild transient symptoms more precisely and should prospectively document exposure duration and clinical characteristics. Third, exposure duration varied by setting (typically 20-60 minutes at our rehabilitation centers and 5-10 minutes at demonstrations and exhibitions) and was not analyzed at the individual level; short exposures may not be long enough to induce sickness in all susceptible individuals. Fourth, the dataset lacked granular patient demographics such as precise age and gender distributions or detailed clinical profiles. This lack of patient background information precludes subgroup analyses to identify whether specific populations may be more susceptible to discomfort and precludes adjustment for covariates. In addition, the PMS dataset counts sessions rather than patients (approximately 9306 unique patients), so repeated sessions by the same patient are not independent observations. The exact CI assumes independence of sessions and should therefore be interpreted as approximate. Finally, all data were derived from a single specialized system and the device's developer, and participation reflected self-selection into clinical care, demonstrations, or exhibitions. This could introduce supervision or reporting bias and may not be directly generalizable to other VR hardware or software configurations that do not adhere to these specific multisensory design principles. Nevertheless, the scale of the PMS dataset (337,577 sessions) offers reassuring real-world context that should be interpreted alongside rather than as offsetting the methodological limitations mentioned above; prospective, controlled studies remain needed before broader claims about clinical adoption can be made.

Conclusions

This study provides real-world descriptive evidence that recorded VR sickness was uncommon and mostly mild during use of a purpose-built, seated VR rehabilitation system and that no serious adverse events or medically attended VR sickness were reported in a large PMS dataset. Its innovation lies in documenting an integrated multisensory design at scale in routine practice, whereas earlier work has largely tested individual design features in controlled settings. It thus adds

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real-world tolerability data on which clinicians, developers, and regulators can draw when considering immersive rehabilitation. The findings are descriptive and cannot establish that the engineering design caused the observed tolerability, attribute effects to individual features, or support comparison with other systems. In practice, they suggest that seated, visually stable, and predictable interface designs can be deployed safely at scale in clinical rehabilitation, and they motivate prospective controlled studies with standardized symptom measures to test individual design elements and determine generalizability to other populations and VR systems.

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Data Availability

Anonymized data that support the findings of this study are available from the corresponding author on reasonable request and subject to a formal data sharing agreement.

Generative AI Use

The authors declare the use of generative AI (GenAI) in the research and writing process. According to the Generative AI Delegation Taxonomy (2026), the following tasks were delegated to GenAI tools under full human supervision: text generation, proofreading and editing, and translation. The GenAI tools used were ChatGPT (GPT-6; OpenAI) and DeepL (DeepL SE). Responsibility for the final manuscript lies entirely with the authors. GenAI tools are not listed as authors and do not bear responsibility for the final outcomes. The authors reviewed the text and take full responsibility for the content of this manuscript.

Authors' Contributions

JD, BS, AG, KZ, ZF, DP, YM, MT, and MH provided substantial contributions to the conception or design of the study or the acquisition, analysis, or interpretation of the data; drafted the paper or revised it critically for important intellectual content; provided final approval of the version to be published; and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Conflicts of Interest

MH is the chief executive officer and a shareholder of mediVR. MT is an auditor and a shareholder of mediVR. YM is a director and holds stock in mediVR. mediVR holds 39 patents worldwide pertaining to the technology (mediVR KAGURA) evaluated in this study. All other authors declare no other conflicts of interest. mediVR develops and commercializes the mediVR KAGURA system evaluated in this study, and the analyzed data were derived from the company’s own records and server logs. The study protocol was approved by an external ethics committee (see the Ethical Considerations section), and the potential for reporting or interpretation bias arising from these affiliations is acknowledged in the Limitations section.

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Abbreviations

FOV: field of view
HMD: head-mounted display
PMS: postmarketing surveillance
RECOVER RECORD: Reprogramming Coordination Through Virtual Environment Rehabilitation: Real-World Evidence From Clinical Observations and Records
SCCT: somato-cognitive coordination therapy
SSQ: Simulator Sickness Questionnaire
VR: virtual reality

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