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Beyond Effectiveness: Feasibility, Acceptability, Engagement, and Safety of Virtual Reality and Exergaming Interventions in Individuals with Down Syndrome: A Systematic Review

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ABSTRACT: Virtual reality (VR) and exergaming are increasingly used in rehabilitation and physical activity programs for individuals with Down syndrome (DS), but implementation-related evidence remains insufficiently synthesized. This systematic review evaluated feasibility, acceptability, engagement, adherence, safety and tolerability, usability, accessibility, support requirements, and sustainability of VR and exergaming interventions in individuals with DS. MEDLINE via PubMed, Scopus, and Dimensions were searched from inception to September 1, 2026. Eligible studies included individuals with DS exposed to immersive or non-immersive VR or exergaming and reported at least one implementation-related outcome. Two reviewers independently performed study selection and data extraction, and risk of bias was assessed using design-specific Joanna Briggs Institute tools. Owing to substantial clinical and methodological heterogeneity, findings were synthesized narratively. Of 381 records identified, 20 reports representing 18 independent cohorts were included. Retention and adherence were generally high where explicitly reported, including 90%–96.5% adherence in several structured programs. Direct measures of acceptability and engagement were less frequently reported but were generally favorable, with variation across games and individuals. No serious intervention-related adverse events were reported in studies explicitly assessing safety, although mild transient symptoms such as dizziness and eye strain occurred in some immersive-VR users. Implementation was commonly supported by familiarization, individualized adaptations, caregiver involvement, professional supervision, and technical assistance. VR and exergaming appear implementable for many individuals with DS, but direct acceptability, long-term sustainability, and systematically assessed safety remain insufficiently studied.

1. INTRODUCTION

Down syndrome (DS) is associated with motor and health-related characteristics that may limit participation in physical activity. Among children and adolescents with DS, physical activity levels are often lower than those of typically developing peers, while participation is influenced by medical, family, social, environmental, program-related, and access-related barriers [1]. These challenges highlight the need for exercise and rehabilitation approaches that are adaptable, engaging, and accessible.

Virtual reality (VR) and exergaming offer interactive, movement-based activities that can integrate repetitive practice, visual feedback, task progression, and game-based engagement. Previous systematic reviews have reported potential benefits for motor proficiency, balance, functional mobility, and muscle strength in individuals with DS, although findings have not been consistent across all outcomes [2,3]. Boato et al. [4] further examined psychomotor and cognitive applications, while Piñar-Lara et al. [5] reported potential benefits for balance and muscular endurance in children and adolescents with DS.

However, therapeutic effectiveness alone does not establish whether an intervention is practical, acceptable, engaging, or tolerable in routine use. Recent studies have begun to evaluate these implementation-related dimensions more directly. A 12-week home-based exergaming program assessed retention, attendance, adherence, and safety while incorporating caregiver involvement and virtual coaching [6]. A companion qualitative study explored participant and caregiver experiences and barriers to participation [7], while an immersive VR pilot evaluated adherence, usability, cybersickness, and game experience [8]. Despite these emerging data, existing reviews have largely focused on therapeutic or developmental outcomes rather than implementation outcomes as their primary objective.

Therefore, this systematic review synthesized evidence on the feasibility, acceptability, engagement, adherence, safety and tolerability, usability, accessibility, support requirements, and sustainability of VR and exergaming interventions in individuals with DS across different ages, technologies, and delivery settings.

2. MATERIALS AND METHODS

2.1 Protocol and reporting

The review protocol was prospectively developed and registered in the International Prospective Register of Systematic Reviews (PROSPERO; CRD420261492864). Reporting followed the PRISMA 2020 statement [9]. Where applicable, quantitative findings synthesized without meta-analysis were additionally reported in accordance with SWiM guidance [10]. This review was specifically focused on implementation; therapeutic, motor, cognitive, behavioral, and functional outcomes were considered only to characterize the intervention context.

2.2 Review question and eligibility criteria

The review examined the feasibility, acceptability, engagement, adherence, safety, and related implementation outcomes of virtual reality (VR) and exergaming interventions in individuals with Down syndrome (DS). Eligibility criteria were defined using the PICOS framework (Table 1). Individuals of any age with DS were eligible, while studies involving mixed populations were included only when DS-specific data could be extracted separately. Eligible interventions included immersive and non-immersive VR, virtual environments, VR-based rehabilitation or training, exergaming, active video gaming, and motion-controlled gaming. A comparator was not required. Primary implementation outcomes included feasibility, acceptability, engagement, adherence or compliance, retention, and safety or tolerability. Additional outcomes included usability, accessibility, enjoyment, satisfaction, motivation, achieved intervention dose, burden, technical difficulties, assistance requirements, independent use, sustainability, and reported barriers or facilitators. These constructs were informed by established implementation-outcome terminology [11]. Acceptability was considered an experiential construct and was not inferred solely from retention or adherence [12]. Eligible study designs included randomized and non-randomized trials, crossover studies, pre-post studies, pilot or feasibility studies, single-arm studies, mixed-methods studies, and qualitative studies linked to actual intervention exposure. Studies were excluded when they assessed therapeutic effectiveness without extractable implementation data, used VR solely for diagnostic or experimental testing, or were reviews, editorials, protocols without results, insufficient conference abstracts, case reports, or animal studies. No publication-date restriction or language filter was applied during searching.

Table 1. PICOS Framework and Eligibility Criteria

Component	Eligibility criterion
Population	Individuals with Down syndrome of any age. Mixed intellectual or developmental disability populations were eligible only when data for participants with Down syndrome could be extracted separately.
Intervention	VR, virtual environments, VR-based rehabilitation or training, exergaming, active video gaming, or motion-controlled gaming delivered as an intervention or structured training program. Both immersive and non-immersive technologies were eligible, including Nintendo Wii/Wii Fit, Kinect, Nintendo Switch/Ring Fit Adventure, Oculus/Meta Quest, and comparable platforms.

Comparator	Usual care, conventional therapy or exercise, alternative intervention, no-treatment control, typically developing or other comparison groups, or within-participant comparison. A separate comparator was not mandatory.
Primary outcomes	Feasibility, acceptability, engagement, adherence/compliance, retention, and safety/tolerability.
Additional implementation outcomes	Usability, accessibility, enjoyment, satisfaction, motivation, achieved intervention dose, burden, technical difficulties, caregiver or professional assistance, independent use, willingness to continue, sustainability, and barriers or facilitators.
Contextual outcomes	Therapeutic, motor, cognitive, behavioral, physical, or functional outcomes were considered only to characterize intervention context and were not the primary focus of synthesis.
Eligible study designs	Randomized controlled trials, non-randomized intervention studies, crossover studies, pre–post studies, pilot or feasibility studies, single-arm intervention studies, mixed-methods studies, and qualitative evaluations linked to actual intervention exposure.
Main exclusions	Passive video viewing; conventional computer/tablet games without eligible VR or exergaming; telehealth without eligible VR/exergaming; augmented-reality-only interventions; VR used solely for diagnostic assessment, measurement, or experimental testing without intervention/training; studies without an extractable implementation-related outcome; reviews; editorials; protocols without results; insufficient conference abstracts; case reports; and animal studies.
Publication date	No restriction.
Language at search stage	No language filter applied.

Abbreviations: PICOS, Population–Intervention–Comparator–Outcomes–Study design; VR, virtual reality.

2.3 Information sources and search strategy

MEDLINE via PubMed, Scopus, and Dimensions were searched from inception to September 1, 2026. The searches identified 60 records from PubMed, 152 from Scopus, and 169 from Dimensions, yielding 381 records before deduplication (Table 2). Database searching was supplemented by backward reference screening and forward citation tracking. Search strategies combined terms related to DS with terms for VR and exergaming, including device-specific terminology. Implementation-outcome terms were not required in the searches in order to maximize sensitivity. Full database-specific search strategies are presented in Supplementary Table S1. The registered protocol initially specified PubMed, Scopus, Web of Science Core Collection, PEDro, and Dimensions. Before final eligibility decisions were locked, the search approach was amended to PubMed, Scopus, and Dimensions. This protocol amendment is reported transparently.

Table 2. Information Sources and Search Yield

Database/source	Search field	Coverage	Search date	Records identified
MEDLINE via PubMed	MeSH and title/abstract	Inception–September 1, 2026	September 1, 2026	60
Scopus	Title, abstract, keywords	Inception–September 1, 2026	September 1, 2026	152
Dimensions	Title and abstract	Inception–September 1, 2026	September 1, 2026	169
Total database records	—	—	—	**381**

Note: No publication-year or study-design filters were applied. Complete database-specific search strategies are provided in Supplementary Table S1.

2.4 Study selection and data extraction

Two reviewers independently screened titles and abstracts and subsequently assessed potentially eligible full-text reports. Disagreements were resolved through consensus or, when necessary, adjudication by a third reviewer. Reasons for exclusion at the full-text stage were documented. Data were independently extracted by two reviewers using a standardized form. Extracted information included study characteristics, intervention technology and modality, delivery setting, supervision and support, intervention dose and duration, comparator characteristics, and implementation-related outcomes. Companion publications arising from overlapping cohorts were linked, and participants were counted once at the cohort level while report-specific findings were retained.

2.5 Classification of implementation outcomes

Implementation findings were classified according to prespecified operational definitions (Table 3), informed by Proctor et al. [11] and Sekhon et al. [12]. Feasibility referred to the practical deliverability of the intervention; adherence to completion of the prescribed intervention; acceptability to participant, caregiver, or provider perceptions and experiences; engagement to behavioral or experiential involvement; safety and tolerability to intervention-related symptoms and adverse events; usability and accessibility to ease of use and access; support requirements to caregiver, professional, or technical assistance; and sustainability to the willingness or practicality of continued use. When findings could reasonably be assigned to more than one domain, classification prioritized the construct identified by the original study authors and was subsequently reconciled with the prespecified review definitions.

Table 3. Operational Classification of Implementation Outcomes

Outcome domain	Operational definition	Examples of eligible indicators
Feasibility	Extent to which the intervention could be successfully delivered or carried out in the intended population and setting	Recruitment, retention, completion, attendance, delivery of planned sessions, achieved intervention dose, logistical barriers
Adherence/compliance	Extent to which participants completed the intervention as prescribed	Sessions completed, attendance rate, gameplay minutes, proportion of prescribed dose achieved, compliance with intervention targets
Acceptability	Cognitive and emotional responses to the intervention and the extent to which it was perceived as appropriate, satisfactory, or agreeable	Satisfaction, enjoyment, preference, perceived burden, willingness to participate again, perceived suitability
Engagement	Behavioral or experiential involvement with the intervention	Attention, active participation, motivation, interest, enthusiasm, voluntary participation, independent gameplay
Safety/tolerability	Occurrence or absence of intervention-related symptoms, adverse events, or inability to tolerate exposure	Cybersickness, dizziness, nausea, visual discomfort, fatigue, pain, falls, injury, behavioral distress, intervention-related withdrawal
Usability/accessibility	Ease with which the technology could be understood, accessed, and operated by the intended users	Ease of use, learnability, usability scores, interaction errors, equipment fit, adaptations, technical difficulties
Support requirements	Assistance required to facilitate intervention delivery or technology use	Caregiver assistance, therapist or teacher supervision, remote coaching, physical/verbal assistance, troubleshooting

Sustainability	Potential or expressed willingness for continued, independent, or longer-term use	Intention or willingness to continue, independent use, home use, continued access, perceived longer-term practicality

Note: Acceptability was not inferred solely from retention, intervention completion, or adherence. Operational definitions were informed by established implementation-outcome terminology.

2.6 Risk-of-bias assessment

Two reviewers independently assessed methodological quality using design-specific Joanna Briggs Institute (JBI) critical appraisal tools (Table 4). Randomized controlled trials were assessed using the revised JBI tool for randomized controlled trials [13], quasi-experimental and non-randomized studies using the revised JBI quasi-experimental tool [14], and other study designs using the corresponding JBI checklist [15]. No aggregate quality score or arbitrary cutoff was applied. Risk-of-bias assessments informed interpretation of the evidence but were not used as an automatic basis for study exclusion. Item-level judgments are provided in Supplementary Table S2.

Table 4. JBI Critical Appraisal Framework Applied in the Review

Study design or analytic structure	JBI critical appraisal tool
Randomized controlled intervention study	JBI Critical Appraisal Tool for Randomized Controlled Trials (Barker et al., 2023)
Non-randomized or quasi-experimental intervention study	JBI Critical Appraisal Tool for Quasi-Experimental Studies (Barker et al., 2024)
Prospective or retrospective cohort study, where applicable	JBI Critical Appraisal Checklist for Cohort Studies (Aromataris et al., 2024)
Analytical cross-sectional study, where applicable	JBI Critical Appraisal Checklist for Analytical Cross-Sectional Studies (Aromataris et al., 2024)
Qualitative companion or implementation evaluation	JBI Critical Appraisal Checklist for Qualitative Research (Aromataris et al., 2024)

Abbreviation: JBI, Joanna Briggs Institute.

2.7 Data synthesis

Because of substantial heterogeneity in participant characteristics, technologies, intervention settings, study designs, implementation constructs, and outcome measurement methods, meta-analysis was not undertaken. Quantitative findings were synthesized descriptively, with SWiM principles applied where appropriate [10]. Findings were organized into four overarching domains: (1) feasibility and adherence; (2) acceptability and engagement; (3) safety and tolerability; and (4) usability, accessibility, support requirements, and sustainability. Study-specific numerators, denominators, proportions, percentages, and summary statistics were retained rather than pooled. Qualitative and quantitative findings arising from the same cohort were integrated at the cohort level. Therapeutic outcomes were not interpreted as implementation outcomes. Formal GRADE assessment and meta-analytic evaluation of publication bias were not undertaken because the review synthesized heterogeneous implementation constructs across multiple study designs rather than estimating a common intervention effect.

3. RESULTS AND DISCUSSION

3.1 Study selection

The database searches identified 381 records, comprising 60 from PubMed, 152 from Scopus, and 169 from Dimensions. After removal of 132 duplicates, 249 records underwent title and abstract screening, of which 225 were excluded. Twenty-four reports were sought for retrieval; two could not be retrieved, leaving 22 reports for full-text assessment. Two reports were subsequently excluded because one did not provide an extractable implementation-related outcome and the other used virtual reality solely

as an experimental motor-learning task. Ultimately, 20 reports were included, representing 18 independent cohorts after companion publications were linked (Figure 1).

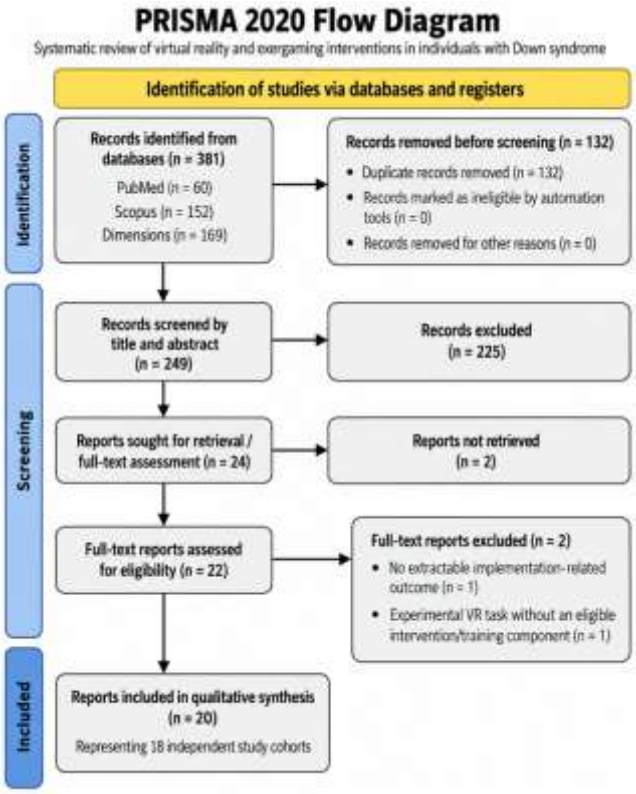

Figure 1. PRISMA 2020 flow diagram of study identification, screening, eligibility assessment, and inclusion.

3.2 Characteristics of included studies

The 20 included reports were published between 2010 and 2026 and involved children, adolescents, and adults with Down syndrome across five continents [8,16]. Study designs included randomized or comparative trials, quasi-experimental and within-subject studies, single-arm feasibility studies, and qualitative evaluations [6,7,17,18]. Two sets of companion publications originated from the same underlying cohorts: GameSquad-DS [6,7] and NCT06146907 [19,20]. Characteristics of the included studies are summarized in Table 5.

Table 5. Characteristics of the Included Studies

Study	Country	Study design	Sample and groups	Age	Setting
Abdel Rahman (2010)	Saudi Arabia	Two-group controlled intervention study	30 children; Wii-Fit n=15, traditional PT n=15	10–13 years	Down Syndrome Charitable Association, Riyadh
Wuang et al. (2011)	Taiwan	Controlled intervention study with randomized active-treatment groups	155 analyzed; Wii-VR n=52, standard OT n=53, no-treatment n=50	7–12 years	Pediatric OT setting; participants recruited from schools and hospitals

Reis et al. (2017)	Brazil	Quasi-experimental controlled study	12; VRT n=7, control n=5	VRT: 9±2.5; control: 8±2.5 years	APAE, Patos de Minas
Abdel Ghafar & Abdelraouf (2017)	Saudi Arabia	Randomized comparative study	26; Wii n=13, traditional PT n=13	6–9 years	Pediatric rehabilitation setting
Silva et al. (2017)	Portugal	Randomized controlled trial	27 randomized; 25 completed	18–60 years	Occupational centers
Torres-Carrión et al. (2019)	Spain	Controlled experimental study	6; intervention n=3, control n=3	Intervention: 18–29; control: 9–19 years	Down Tenerife
da Cruz Netto et al. (2020)	Brazil	Controlled pre–post intervention study	30 enrolled; demographic data available for 27*	10–22 years	APAE special-education setting
Perrot et al. (2021)	France	Randomized controlled pilot trial	12; exergaming n=6, control n=6	35–64 years; mean 50.35±7.45	Lejeune Institute
Michalski et al. (2022)	Australia	Within-subject experimental study	17 recruited; 16 analyzed	Mean 25.25±6.61 years	Disability-services learning program
Rosa et al. (2023)	Brazil	Prospective two-phase study	34 participants with DS; 34 TD comparators in the initial phase	≥10 years	Home-based telerehabilitation
Gaber (2024)	Saudi Arabia	Quasi-experimental three-group study	18 boys; n=6 per group	8–12 years; mean 9.45±1.47	Day-care center, Al-Ahsa
Ghouri et al. (2024)	Pakistan	Comparative pre–post intervention study	24; VR n=12, traditional therapy n=12	VR: 8.08±0.79; control: 7.61±0.94 years	Rehabilitation setting, Karachi
Yunus et al. (2024)	Indonesia	Randomized controlled pre–post trial	20; VR n=10, control n=10†	9–18 years	Rumah Pintar Pucang Gading, Semarang
Suire et al. (2025a, 2025b)	United States	Single-arm feasibility study with qualitative companion report	20 enrolled; 19 completed¶	18–30 years; mean 23.5±4.0	Home-based intervention with remote coaching
Shaheen et al. (2025)	Saudi Arabia	Single-group feasibility and acceptability pilot study	11 children	8–14 years; mean 10.45±1.75	Down syndrome association centers, Riyadh
Ardai et al. (2026)	Hungary	Randomized comparative study	31 participants with DS; Wii n=16, control n=15‡	18–30 years; mean 21.2±2.2	Special-education centers

Cancela-Carral et al. (2026)	Spain	Prospective single-arm pilot clinical trial	20 adults	17–44 years	Down Syndrome Association of Pontevedra
Halwsh et al. (2026); Algabbani et al. (2026)	Saudi Arabia	Single-blinded randomized comparative trial	23; exergaming n=11, CMDT n=12§	8–14 years	Down syndrome association centers, Riyadh

Notes:

* da Cruz Netto et al. (2020) reported 30 participants in the intervention study, whereas demographic data were available for 27 participants.

† Yunus et al. (2024) reported a total sample of 20 participants in the abstract, methods, allocation, and group analyses despite an inconsistent count in one descriptive table; therefore, *n*=20 was retained.

‡ Ardai et al. (2026) additionally included typically developing comparison participants; only the 31 participants with Down syndrome relevant to this review are shown.

§ Halwsh et al. (2026) and Algabbani et al. (2026) were companion reports from the same registered trial (NCT06146907) and were treated as one independent cohort.

¶ Suire et al. (2025a, 2025b) were quantitative and qualitative companion reports from the same GameSquad-DS cohort; 20 participants enrolled and 19 completed the intervention.

Abbreviations: CMDT, cognitive–motor dual-task; DS, Down syndrome; OT, occupational therapy; PT, physical therapy; TD, typical development; VR, virtual reality; VRT, virtual reality therapy.

3.3 Characteristics of virtual reality and exergaming interventions

The interventions varied considerably in technology, therapeutic purpose, intervention dose, and level of support (Table 6). Nintendo Wii or Wii Fit was the most frequently used platform and was primarily applied for balance training, sensorimotor rehabilitation, physical fitness, and functional mobility [16,17,21–25]. Other technologies included Xbox Kinect [26], TANGO:H with Kinect [27], the *Nossa Vida* virtual environment [28], MoveHero [29], customized interactive three-dimensional environments [30], Nintendo Switch-based exergaming [6,19,20,31], Oculus Quest [18], goggles-based sensory-motor VR [32], and Meta Quest 3 [8]. Intervention exposure ranged from a single session to programs lasting several months. Delivery commonly involved support from rehabilitation professionals, caregivers, researchers, or technical personnel, depending on the intervention setting and participant needs.

Table 6. Characteristics of Virtual Reality and Exergaming Interventions

Study	Technology and modality	Intervention purpose	Dose and duration	Supervision/support
Abdel Rahman (2010)	Nintendo Wii Fit with Balance Board; non-immersive motion-controlled VR	Balance training	Three Wii-Fit balance games; 6-week program adjunctive to traditional PT	Therapist-guided alongside conventional PT
Wuang et al. (2011)	Nintendo Wii; non-immersive motion-controlled VR	Sensorimotor function, motor proficiency, and visual/sensory integration	60 min/session; 2 sessions/week for 24 weeks	Individually delivered by pediatric therapists

Reis et al. (2017)	Xbox 360 Kinect; non-immersive controller-free VR	Motor coordination and balance	16 sessions; ≤20 min/session; 4 sessions/week for 4 weeks	Structured institutional delivery
Abdel Ghafar & Abdelraouf (2017)	Nintendo Wii/Wii Fit; non-immersive exergaming	Functional balance	30 min/session; 3 sessions/week for 8 weeks (24 sessions)	Therapist-supervised
Silva et al. (2017)	Nintendo Wii; Wii Fit, Wii Sports, Wii Sports Resort, and Just Dance 2; non-immersive exergaming	Physical fitness, motor proficiency, and functional mobility	60 min/session; 3 sessions/week for 2 months	Structured supervised exercise sessions
Torres-Carrión et al. (2019)	TANGO:H with Microsoft Kinect; non-immersive gestural interaction	Cognitive visual-motor stimulation	Four weekly training sessions over 1 month; approximately 20 min/session	Professional guidance during training
da Cruz Netto et al. (2020)	*Nossa Vida (Our Life)*; computer-based interactive virtual environment	Memorization of daily routines and functional learning	10 sessions × 50 min; 2 sessions/week for 5 weeks	Researcher-guided with multidisciplinary input
Perrot et al. (2021)	Nintendo Wii with Wii Sports/Wii Fit Plus; non-immersive exergaming	Physical fitness, functional mobility, and cognitive stimulation	60 min/session; 2 sessions/week for 12 weeks (24 sessions)	Individually supervised by an adapted-physical-activity professional
Michalski et al. (2022)	Oculus Quest HMD with Google Tilt Brush; immersive VR	Interactive drawing and classroom-related behavioral experience	Single VR exposure; 7–10 min	Researcher-guided; support staff observed subsequent behavior
Rosa et al. (2023)	MoveHero on computer/tablet with webcam-based interaction; non-immersive virtual game	Physical activity and motor performance	11-session home-based protocol; approximately 20 min of gameplay per practice session	Remote researcher supervision with family support
Gaber (2024)	Customized interactive 3D program with 360° imagery; immersion level NR	Independence and self-care skill training	50 sessions; 20 min/session; 3 sessions/week over 4 months	Structured guided training with repeated practice and reinforcement

Ghouri et al. (2024)	Nintendo Wii/Nintendo Fit; non-immersive exergaming	Static and dynamic balance	Approximately 30–40 min/session; 3 sessions/week for 8 weeks (24 sessions)	Structured rehabilitation delivery; specific supervision NR
Yunus et al. (2024)	Sensory-Motor VR (VR SenMor); goggles-based VR	Static and dynamic balance and sensorimotor training	20 min/session; 2 sessions/week for 4 weeks (8 sessions)	Researcher-guided; equipment adapted when required
Suire et al. (2025a, 2025b)	Nintendo Switch *Ring Fit Adventure* with Ring-Con and leg strap; non-immersive home exergaming	Moderate-to-vigorous physical activity and strength/cardiorespiratory exercise	12 weeks; progressive target from 60 to ≥120 min/week*	Parent/caregiver involvement plus weekly virtual health coaching and technical troubleshooting
Shaheen et al. (2025)	Nintendo Switch; Nintendo Switch Sports and Family Trainer; non-immersive exergaming	Feasibility, usability, engagement, and enjoyment of physical-activity games	Single 40-min session involving 10 selected games	Structured researcher-led session
Ardai et al. (2026)	Nintendo Wii with Wii Balance Board; Penguin Slide and Soccer Heading; non-immersive exergaming	Balance and motor learning	8 sessions; 2 sessions/week for 4 weeks	Familiarization, verbal/physical assistance, visual feedback, and investigator-operated console
Cancela-Carral et al. (2026)	Meta Quest 3 with FitXR Combat Studio; immersive VR exergaming	High-intensity exercise and strength training	2 sessions/week for 12 weeks; progressive 5-, 7-, and 9-min exercise levels	Supervised by exercise and health professionals with real-time monitoring
Halwsh et al. (2026); Algabbani et al. (2026)	Nintendo Switch with Joy-Con controllers and Family Trainer; non-immersive exergaming	Balance, functional mobility, and cognitive–motor training	12 sessions; 2 sessions/week for 6 weeks; approximately 40–45 min/session†	Structured supervised intervention

Notes: * Suire et al. (2025a) reported weekly 30-min virtual health-coaching sessions, whereas the qualitative companion report Suire et al. (2025b) described 15-min coaching sessions; both reports described the same GameSquad-DS cohort and 12-week gameplay intervention.

† Halwsh et al. (2026) and Algabbani et al. (2026) were companion reports from trial NCT06146907; session duration was reported as approximately 40 and 45 min, respectively.Abbreviations: HMD, head-mounted display; NR, not reported; PT, physical therapy; VR, virtual reality.

3.4 Implementation outcomes

Implementation-related findings are summarized in Table 7. Feasibility was most commonly reflected by retention, intervention completion, attendance, and achieved intervention dose. In GameSquad-DS, 19 of 20 participants were retained, corresponding to 95% retention; virtual coaching attendance reached 93%, and weekly gameplay targets were achieved during 90% of

intervention weeks [6]. Perrot et al. [23] reported 96.5% session adherence, while Cancela-Carral et al. [8] reported 90% adherence. Wuang et al. [17] retained 105 of 110 randomized participants, whereas Silva et al. [22] reported two dropouts. Reis et al. [26] observed variable achieved gameplay time across participants during a 16-session intervention. Ghouri et al. [24] included all 24 participants in post-intervention analyses but did not report a formal adherence measure. Because intervention schedules and adherence definitions differed substantially across studies, these outcomes were not pooled.

Direct evidence regarding acceptability was reported less frequently. Participants and caregivers in GameSquad-DS described engagement, increasing autonomy, technology-related experiences, and interest in continued use [7]. Children interacting with the *Nossa Vida* virtual environment requested additional play and expressed interest in playing again [28]. Shaheen et al. [31] identified game-specific differences in usability, engagement, and enjoyment. Gaber [30] reported greater participation, concentration, motivation, and enjoyment, although these observations were not based on a validated acceptability instrument. Michalski et al. [18] found generally favorable preferences toward VR, although responses varied according to question format. Retention and adherence were not interpreted as proxies for acceptability.

Safety and tolerability were inconsistently assessed across studies. No serious intervention-related adverse events were reported in GameSquad-DS, while Abdel Ghafar and Abdelraouf [21] reported no adverse effects or musculoskeletal injuries. Cancela-Carral et al. [8] found very low Simulator Sickness Questionnaire scores. Mild and transient symptoms were nevertheless reported in some immersive-VR studies. Michalski et al. [18] documented eye strain, dizziness, or other mild symptoms in 5 of 16 participants, while Yunus et al. [32] reported one episode of dizziness that resolved after rest. These findings are reassuring in studies that explicitly assessed safety, but they do not establish safety across all intervention types and settings.

Formal usability evaluation was uncommon. Cancela-Carral et al. [8] reported high System Usability Scale scores ranging from 92.88 to 95.03 out of 100. GameSquad-DS incorporated caregiver support, virtual coaching, assist modes, and troubleshooting, with qualitative reports suggesting increasing independence and willingness to continue using the intervention [7]. Other studies described familiarization procedures, individualized progression, remote supervision, or equipment adaptation as implementation supports [25,29,32]. Evidence regarding sustained independent use beyond the intervention period remained limited.

Table 7. Implementation Outcomes of Virtual Reality and Exergaming Interventions

Study	Feasibility and adherence	Acceptability and engagement	Safety and tolerability	Usability, accessibility, support, and sustainability
Abdel Rahman (2010)	All 30 participants included in analysis; structured 6-week intervention	NR	NR	Therapist-guided Wii-Fit training
Wuang et al. (2011)	105/110 completed treatment and assessment; intervention-fidelity median 4/4	NR	NR	Individual therapist delivery using a standardized training manual
Reis et al. (2017)	16-session VR protocol completed; active gameplay time varied between participants	NR	NR	Familiarization and supervised delivery
Abdel Ghafar & Abdelraouf (2017)	Participants completed the supervised treatment protocol as reported	NR	No adverse effects or musculoskeletal injuries reported	Therapist-supervised Wii training
Silva et al. (2017)	12/14 participants allocated to Wii exercise completed; 2 dropouts	NR	NR	Structured supervised exercise program

Torres-Carrión et al. (2019)	NR	Engagement supported through gamification and progressive tasks; no formal acceptability measure	NR	Personalized Kinect-based activities; adaptable difficulty, time, movement range, and feedback
da Cruz Netto et al. (2020)	Intervention successfully delivered; detailed attrition reporting limited	Children frequently requested additional play time, played continuously, learned controls, and wanted to play again	NR	Approximately 85% had compatible home technology; specialist usability evaluation; responsive platform with parent/professional monitoring
Perrot et al. (2021)	96.5% adherence to prescribed Wii sessions	NR	NR	Individually supervised by an adapted-physical-activity professional
Michalski et al. (2022)	16/17 consenting participants completed VR exposure; 2/16 ended exposure early	All 12 completing the preference assessment indicated liking VR/willingness to repeat; 5/12 gave inconsistent preference responses across formats	5/16 reported mild, transient symptoms: eye strain (n=3), dizziness (n=1), unspecified (n=1)	Researcher guidance and adapted communication/choice procedures
Rosa et al. (2023)	Home-based 11-session protocol implemented remotely	NR	Physical effort monitored using RPE; specific adverse-event reporting NR	Computer, webcam, and internet required; familiarization, remote researcher monitoring, and family assistance
Gaber (2024)	All six VR-group participants represented in post-intervention assessment	Author-reported increased participation, focus, motivation, and enjoyment; no validated acceptability measure	NR	Repeated guided practice; long-term continued use not directly evaluated
Ghouri et al. (2024)	All 24 participants represented in post-intervention analyses	NR	NR	Structured rehabilitation delivery

Yunus et al. (2024)	No dropout reported; VR group completed eight sessions	NR	One transient dizziness episode, resolved after approximately 10 min rest	Modified/smaller goggles used for two children when standard equipment was unsuitable
Suire et al. (2025a, 2025b)	19/20 completed (95% retention); coaching attendance 93%; weekly gameplay goals achieved 90%; mean 39 min/session and 123 ± 33 min/week	Qualitative themes indicated engagement, autonomy, ownership, and interest in continued use	No serious adverse events reported	Minor technical issues; caregiver/coach troubleshooting; built-in assist modes; increasing independent use; willingness to continue
Shaheen et al. (2025)	All 11 participants completed the single-session pilot exposure	Direct usability, engagement, and enjoyment assessment; marked game-specific differences in ratings	NR	Intuitive mechanics, visual appeal, responsive feedback, and straightforward instructions favored
Ardai et al. (2026)	All 31 participants with DS completed the study; DS Wii group completed eight training sessions	Training described as engaging; no validated acceptability measure	NR	Familiarization; verbal/physical assistance; continuous visual feedback; investigator-operated console; individualized progression
Cancela-Carral et al. (2026)	20 completed the 12-week program; adherence 90%	Positive game experiences increased; no negative experiences reported on GEQ	SSQ 2.12→1.98/48; minimal cybersickness	SUS 92.88–95.03/100; supervised and progressively adapted immersive exercise
Halwsh et al. (2026); Algabbani et al. (2026)	23/24 completed; one participant in exergaming discontinued because of lack of interest	NR as a directly measured implementation outcome	NR	Licensed therapists; standardized protocol; therapist training and weekly protocol-adherence supervision

Abbreviations: DS, Down syndrome; GEQ, Game Experience Questionnaire; NR, not reported; RPE, rating of perceived exertion; SSQ, Simulator Sickness Questionnaire; SUS, System Usability Scale; VR, virtual reality.

Note: NR indicates that the relevant implementation outcome was not explicitly reported and should not be interpreted as evidence that the outcome or event did not occur. Retention or adherence alone was not classified as evidence of acceptability unless participant- or stakeholder-reported experience, preference, enjoyment, satisfaction, or a comparable acceptability construct was available.

3.5 Risk of bias

Critical appraisal using design-specific Joanna Briggs Institute tools indicated generally adequate outcome measurement, follow-up, and statistical analysis, although methodological limitations varied according to study design (Figure 2; Supplementary Table S2).

Among eight randomized or comparative reports, baseline comparability was judged adequate in seven, whereas allocation concealment was clearly reported in only one and assessor blinding in three. Among 11 quasi-experimental, non-randomized, or single-arm reports, follow-up completeness and outcome measurement reliability were adequate in 10. Several feasibility studies appropriately did not include comparison groups because of their study objectives. The qualitative GameSquad report demonstrated good methodological congruity, with the main uncertainty relating to researcher positioning and reflexivity. No study was excluded solely on the basis of critical appraisal.

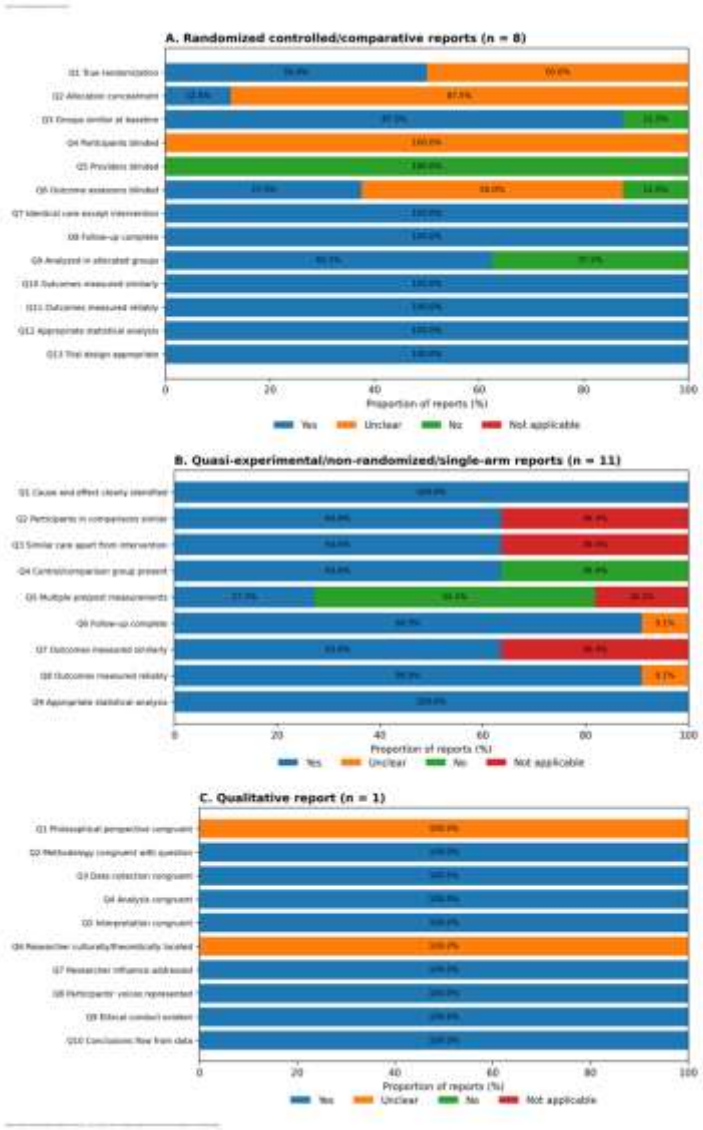

Figure 2. JBI critical appraisal summary of included reports. Proportions of Yes, Unclear, No, and Not Applicable judgments are presented separately according to the design-specific Joanna Briggs Institute critical appraisal tools. Detailed report-level assessments are provided in Supplementary Table S2.

3.6 Discussion

This implementation-focused review found that virtual reality (VR) and exergaming interventions were generally deliverable across clinical, educational, and home-based settings for individuals with Down syndrome (DS). Retention and adherence were often high when these outcomes were explicitly reported, whereas direct assessment of acceptability, usability, safety, and long-term sustainability was less consistent. Support requirements also varied substantially according to technology, participant characteristics, and delivery setting. These findings extend previous DS-specific reviews, which have primarily emphasized therapeutic and developmental outcomes such as motor proficiency, balance, functional mobility, muscle strength, and cognition rather than implementation as the primary focus [2–5].

Several of the most detailed feasibility studies incorporated structured progression and ongoing support and reported favorable retention or adherence. GameSquad-DS retained 95% of participants, achieved 93% coaching attendance, and met weekly gameplay targets during 90% of intervention weeks [6]. Similarly, Perrot et al. [23] and Cancela-Carral et al. [8] reported high adherence within structured intervention programs. However, these observations should not be interpreted as evidence that structured progression or support directly caused better feasibility. Studies differed substantially in participant age, hardware, intervention dose, setting, and caregiver or professional involvement. Such variability is consistent with implementation frameworks emphasizing that implementation outcomes are shaped by interactions among intervention characteristics, recipients, and contextual factors [33].

Acceptability and engagement require more cautious interpretation because they were assessed directly in relatively few studies. Participants and caregivers in GameSquad-DS described enjoyment, motivation, increasing autonomy, technological challenges, and interest in continued use [7]. Michalski et al. [18] likewise reported generally favorable preferences for immersive VR, although responses were not entirely consistent across different preference formats. These findings highlight the distinction between behavioral indicators, such as attendance or retention, and the cognitive and emotional experience of participating in an intervention. Accordingly, acceptability should be measured directly rather than inferred solely from adherence or study completion [11,12].

Safety findings were generally reassuring in studies that explicitly assessed or described adverse effects, but the evidence remains incomplete. No serious intervention-related adverse events were reported in studies with dedicated safety reporting. GameSquad-DS reported no serious adverse events [6], while the InDown pilot showed very low Simulator Sickness Questionnaire scores [8]. Nevertheless, mild transient symptoms were observed with immersive VR, including eye strain and dizziness reported by Michalski et al. [18]. Broader evidence from head-mounted display and VR research indicates that cybersickness may vary according to visual content, locomotion, exposure duration, user characteristics, and system-related factors [34,35]. Safety and tolerability should therefore be monitored prospectively rather than inferred from intervention completion.

Usability and accessibility also appeared to depend strongly on intervention configuration and the availability of support. The InDown pilot reported high System Usability Scale scores [8], whereas GameSquad-DS incorporated caregiver involvement, assist modes, virtual coaching, and technical troubleshooting [6,7]. Its qualitative companion study further suggested that participant independence increased after routines became familiar [7]. Other included studies used familiarization procedures, accessible communication, verbal or physical assistance, individualized progression, or equipment adaptation [18,25,32]. These findings indicate that accessibility and support are integral implementation components rather than secondary logistical considerations, consistent with contemporary implementation frameworks emphasizing the interaction between intervention characteristics, users, and context [33].

Future studies should prospectively define implementation outcomes and specify how recruitment, retention, adherence, achieved dose, technical failures, and adverse events will be measured. Acceptability should be evaluated directly using approaches appropriate for individuals with DS, potentially combining accessible self-report with observation and caregiver or provider perspectives when necessary [12,18]. Longer follow-up is also required to determine whether initial engagement and supported intervention use translate into sustained or independent use. Greater conceptual separation between implementation and therapeutic outcomes would further improve comparability across studies [11,36].

This review has several strengths, including its explicit implementation focus, inclusion of multiple study designs, linkage of companion reports to avoid participant double-counting, and separate examination of major implementation domains.

Nevertheless, several limitations should be acknowledged. Technologies, intervention protocols, populations, and outcome definitions were highly heterogeneous, and several pilot studies included small samples. Implementation outcomes were inconsistently reported, particularly in earlier studies primarily designed to assess therapeutic efficacy, which precluded quantitative pooling. The final database set was narrower than originally registered, although this amendment was made before final eligibility decisions were completed, and two potentially relevant reports could not be retrieved. Similar heterogeneity has also been reported in previous DS-focused VR and exergaming reviews and in the broader intellectual-disability literature [3,5,37,38].

4. CONCLUSION

VR and exergaming interventions appear feasible and engaging for many individuals with Down syndrome across clinical, educational, and home settings, although many studies incorporated individualized adaptation and caregiver, professional, or technical support. However, direct evidence on acceptability, usability, long-term sustainability, and safety remains limited and inconsistently reported. Mild transient symptoms have occurred with some immersive VR applications, underscoring the need for active monitoring. Future studies should prospectively define implementation outcomes, use standardized and accessible measures, and evaluate whether successful short-term participation can be sustained with decreasing levels of caregiver or professional support.

AUTHOR CONTRIBUTIONS

RM: Conceptualization, Methodology, Investigation, Literature Search, Study Selection, Data Extraction, Formal Analysis, Visualization, and Writing – Original Draft.

RH: Methodology, Investigation, Study Selection, Data Extraction, Risk-of-Bias Assessment, Validation, and Writing – Review & Editing.

NM: Conceptualization, Methodology, Supervision, Validation, Interpretation of Findings, and Writing – Review & Editing.

MW: Methodology, Supervision, Validation, Interpretation of Findings, and Writing – Review & Editing.

All authors critically reviewed the manuscript, approved the final version, and agreed to be accountable for the accuracy and integrity of the work.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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ETHICS STATEMENT

Ethical approval and informed consent were not required for this systematic review because it synthesized data from previously published studies and did not involve direct recruitment of human participants or collection of identifiable individual-level data. The review protocol was prospectively registered in PROSPERO (CRD420261492864).

DATA AVAILABILITY STATEMENT

All data supporting the findings of this systematic review were derived from the published studies included in the review and are presented within the article and its supplementary materials. Additional review data are available from the corresponding author upon reasonable request.

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