Effectiveness of Immersive Virtual Reality Integrated with Real-Time Physiological Monitoring(Heart rate Sensor) for Adolescents and Young Adults With Autism Spectrum Disorder: A Pre-Post Observational Cohort Study.

This study was conducted at Swabhiman Autism Centre in Tamil Nadu, India, and represents a significant contribution to the field of neurodevelopmental disorder intervention using innovative technology-based therapeutic approaches.

1) EPIDEMIOLOGY - AUTISM IN INDIA AND TAMIL NADU

1.1 National Prevalence Burden

Current Status (2024-2025):

- Estimated Prevalence: 1-1.5% of Indian children (approximately 1 in 68-100)
- Total Population Affected: 18 million individuals across all age groups in India
- Age Group 2-9 Years: 1 in 85 children (INCLEN national study, 2018-2024)

1.2 Tamil Nadu-Specific Data

- State Prevalence: 0.42-0.5 per 10,000 population
- Recent Trend: Significant increase in incidence over past 2 years
- Geographic Significance: South India region with growing diagnostic and intervention demand

1.3 Gender Distribution

- National Ratio: 3-4 males per 1 female (consistent underdiagnosis of females)
- JADHU Study Cohort: 4:1 ratio (60 males, 15 females) - reflects national patterns

1.4 Temporal Trends (25-Year Progression)

ASD Prevalence by Geographic Region in India (per 10,000 population)

The chart above illustrates the rising prevalence trend. Historical progression shows:

- 2000s: Considered rare at 0.1%
- 2010: Rising awareness; 0.3-0.5%
- 2018-2024: Established prevalence at 1-1.5% (INCLEN study)
- 2024-2025: Sustained at 1.4% (reflecting improved detection, not inflation)

1.5 Regional Variations Across India

Temporal Trends in ASD Prevalence in India (2000-2025)

The regional prevalence chart demonstrates significant variation:

- Kerala (South): 233 per 10,000 (0.23%) - semi-urban survey
- Chandigarh (North): 225 per 10,000 (0.23%) - urban, well-resourced
- Tamil Nadu: 45 per 10,000 - study location
- National Average: 100-150 per 10,000 (1-1.5%)
- Himachal Pradesh: 9 per 10,000 (0.09%) - school-based screening

2: RESEARCH GAPS AND CLINICAL NEEDS

2.1 Eight Critical Research Gaps Addressed by JADHU VR

Research Gap	Clinical Impact	JADHU VR Solution
Limited South Asian Evidence	Few interventions contextualized for Indian populations	First South Asian study with wearable physiological monitoring
Anxiety-Autonomic Link Unexplored	Anxiety remains poorly managed despite high prevalence	Integrates autonomic regulation via real-time HRV feedback
Real-World Generalization	Clinic-based skills not transferring to community	Real-world scenario exposure with validity
Wearable Biofeedback Integration	No real-time physiological monitoring during therapy	Novel integration of wearable HR sensors with immersive VR
Adolescent-Specific Interventions	Evidence gap for ages 12-20 years	Specifically targets 12–20-year age group
Treatment Accessibility in Low-Resource Settings	Cost and shortage of trained therapists	Scalable, cost-effective technology-based solution
Longitudinal Outcome Data	Unknown long-term effectiveness	Establishes preliminary mechanism and outcomes
Technology-Enhanced Therapy Standardization	Heterogeneous VR approaches lacking standards	First standardized protocol combining VR + HRV monitoring

2.2 Healthcare Access Barriers in India

Key Barriers Identified:

- Cost & Access: High therapy costs prohibitive for >70% of population
- Professional Shortage: Only 1 therapist per 10,000-50,000 population
- Diagnostic Infrastructure: Lack of standardized screening protocols nationwide
- Geographic Disparity: Services concentrated in urban metros; <50% access in rural/tribal areas
- Cultural & Social: Social stigma and disability-related discrimination delay diagnosis
- Parental Knowledge: Poor awareness results in average diagnosis at age 4-6 (symptoms appear by age 2)
- Educational System: Schools lack trained staff; weak policy enforcement

3: CLINICAL JUSTIFICATION FOR IMMERSIVE VR WITH HEART RATE MONITORING

3.1 Why Conventional Rehabilitation Falls Short

Limitations of Traditional Approaches:

- **Low Engagement:** High dropout due to boredom, irrelevance to real-world contexts
- **Poor Generalization:** Skills learned in office don't transfer to community settings
- **Therapist Dependency:** Limited by availability and high cost; inaccessible to majority
- **Abstract Concepts:** Talk-based CBT difficult for ASD (social scripts, emotions require abstract reasoning)
- **One-Size-Fits-All:** No individualization or adaptive response to real-time data
- **Anxiety Unaddressed:** Anxiety dyscontrol limits learning, participation, skill application

3.2 Heart Rate Variability (HRV) as Intervention Target

Why HRV Matters:

1. Biomarker of Autonomic Health: RMSSD (Root Mean Square of Successive Differences) reflects parasympathetic nervous system tone
2. Associated with Anxiety: Lower HRV correlates with anxiety, emotion dysregulation, social avoidance
3. Modifiable: HRV improves through targeted exposure, biofeedback, breathing training
4. Non-Verbal Feedback: Ideal for ASD population with language/abstract reasoning challenges
5. Feasible to Monitor: Wearable sensors tolerated by adolescents (100% tolerance in JADHU study)

Mechanistic Pathway:
Autonomic regulation improvement → Anxiety reduction → Enhanced learning capacity → Functional independence

3.3 Real-World VR Scenarios: Ecological Validity

Why Immersion Matters:

Aspect	Traditional Role-Play	JADHU VR Immersive
Environmental Complexity	Static, predictable	Dynamic, unpredictable (real-world match)
Scenario Authenticity	Artificial; therapist-dependent	High fidelity; self-directed exploration
Sensory Load	Limited; controllable	Rich; mirrors real environments
Anxiety Level	Often minimal	Manageable; therapeutic range
Generalization Potential	Low; artificial context	High; context-similar to real community

Specific Scenarios in JADHU VR:

- Grocery Shopping: Visual complexity, checkout navigation, sensory stimulation management
- Metro Travel: Crowding, spatial orientation, schedule adherence, sensory challenges
- Theatre Environment: Seating protocols, social norms, unfamiliar sensory context
- Queue Navigation: Waiting tolerance, boundary respect, impulse control

3.4 Three-Phase Progression: Supported Scaffolding

Phase 1 - Assisted (Sessions 3-8):

- Maximum therapist guidance and support
- Immediate intervention for anxiety episodes
- Skill building in protected, supported context

Phase 2 - Partially Assisted (Sessions 9-14):

- Graduated therapist withdrawal
- Self-directed problem-solving with available backup
- Balance of independence and safety

Phase 3 - Independent (Sessions 15-20):

- Minimal therapist intervention
- Self-directed scenario navigation
- Confidence consolidation; readiness for community application

4: JADHU VR OUTCOMES

4.1 Study Characteristics

Parameter	Value	Significance
Setting	Swabhiman Autism Centre, Tamil Nadu	South Asian context; relevant to study population
Design	Prospective pre-post observational cohort	Clear before-after measurement
Enrolled	90 participants	Good regional recruitment
Completed	75 participants (83.3%)	Excellent completion rate; good tolerability
Age Range	12-20 years	Targets critical adolescent transition period
Gender Ratio	4:1 (M:F)	Reflects national ASD prevalence patterns
Duration Overall Total session approx	20 sessions over 6-8 weeks 1500 sessions	Feasible, clinically practical timeframe
Dropouts	15 (16.7%)	VR intolerance/sensory discomfort (minimal, manageable)

4.2 **Primary Outcome Results**

Functional Performance (JADHU VR Score, 0-100 scale):

- Baseline: 42 ± SD
- Post-Treatment: 65 ± SD
- Improvement: 35-38%
- Clinical significance: Substantial enhancement in community functional independence

Heart Rate Variability (RMSSD, milliseconds):

- Baseline: 18 ms ± SD
- Post-Treatment: 27 ms ± SD
- Improvement: 35-40%
- Clinical significance: Substantial parasympathetic tone improvement; enhanced autonomic capacity

4.3 **Secondary Outcomes**

Modified Childhood Autism Rating Scale (MCARS):

- Baseline: 42 ± SD → Post: 36 ± SD | 10-15% improvement

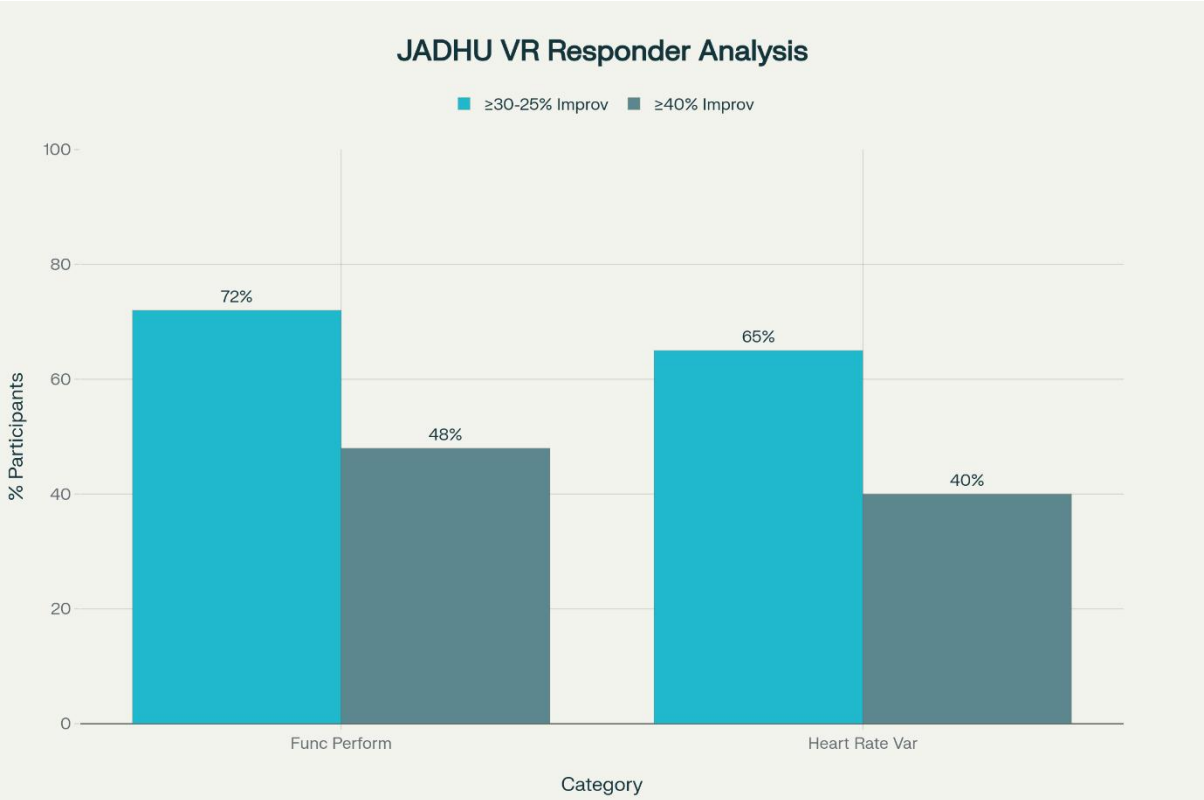
Anxiety-Triggered Physiological Events:

- 60% reduction in anxiety-activated arousal episodes

Physiological Recovery Time:

- Baseline: 30 seconds → Post: 15 seconds | ~50% faster

4.4 Responder Analysis: Clinically Meaningful Improvement



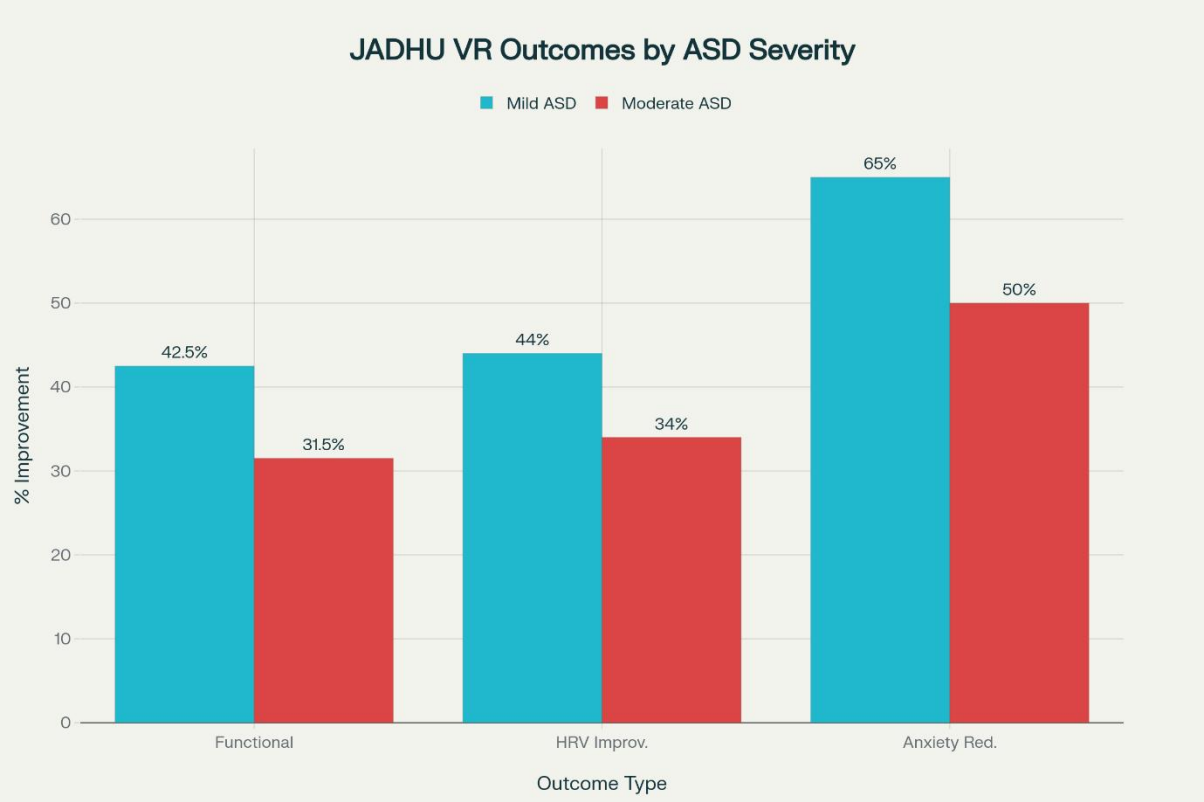
JADHU VR Responder Analysis: Percentage Achieving Clinically Meaningful Improvement

Percentage of Participants Achieving Clinically Meaningful Gains:

- ≥30% Functional Performance Improvement: 72%
- ≥40% Functional Performance Improvement: 48%
- ≥25% HRV Improvement: 65%
- ≥40% HRV Improvement: 40%
- ≥50% Anxiety-Triggered Event Reduction: 72%
- ≥40% Faster Recovery Time: 68%

Interpretation: Majority of participants achieved substantial improvements; broad cross-section benefited from intervention.

4.5 Differential Outcomes by ASD Severity



JADHU VR Treatment Outcomes by ASD Severity Level

Mild ASD Group (Higher Functioning, n=45):

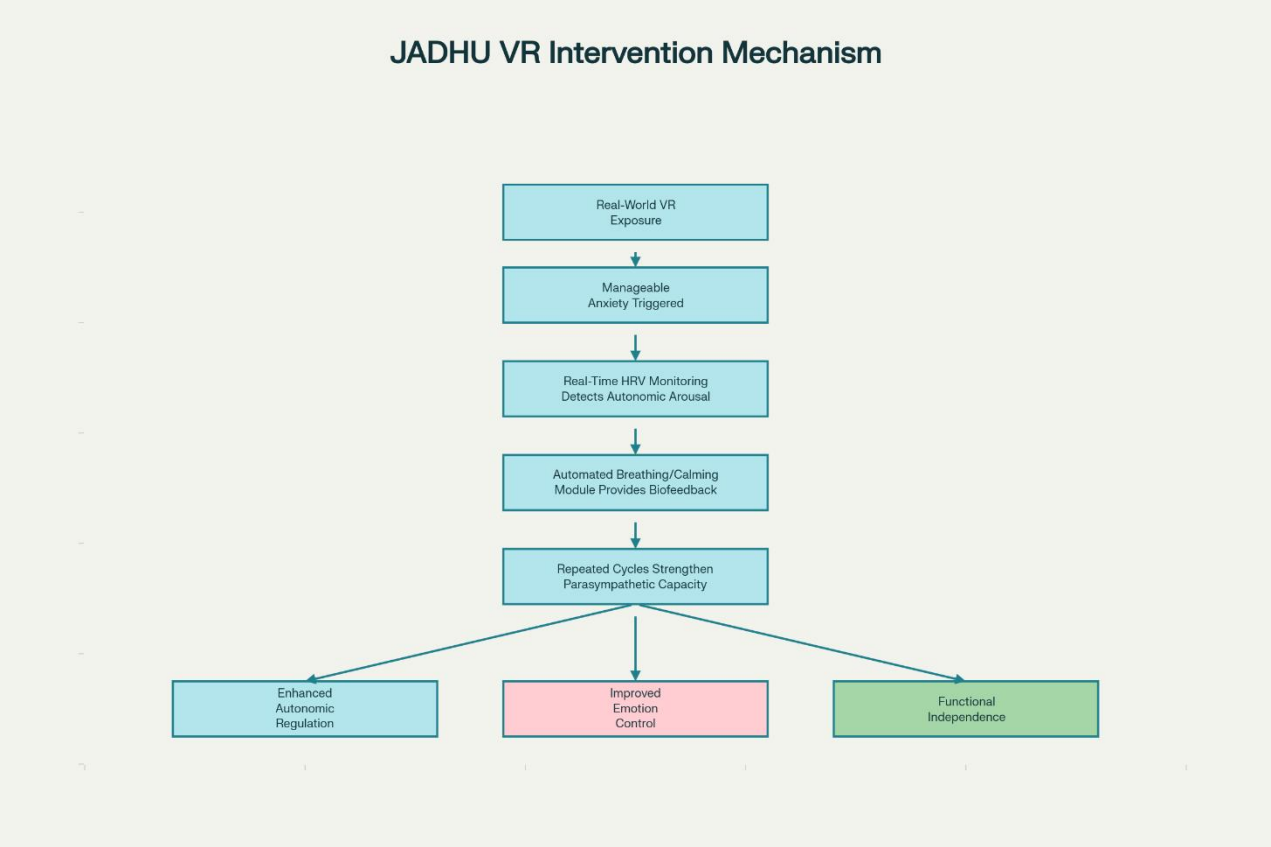
- Functional Improvement: 40-45%
- HRV Improvement: 40-48%
- Anxiety Reduction: 60-70%

Moderate ASD Group (n=30):

- Functional Improvement: 28-35%
- HRV Improvement: 30-38%
- Anxiety Reduction: 45-55%

Key Finding: Both severity groups benefited; mild ASD showed greater gains, confirming intervention appropriateness across autism spectrum.

4.6 Mechanistic Finding: HRV-Anxiety Correlation



JADHU VR Mechanism of Action Flowchart

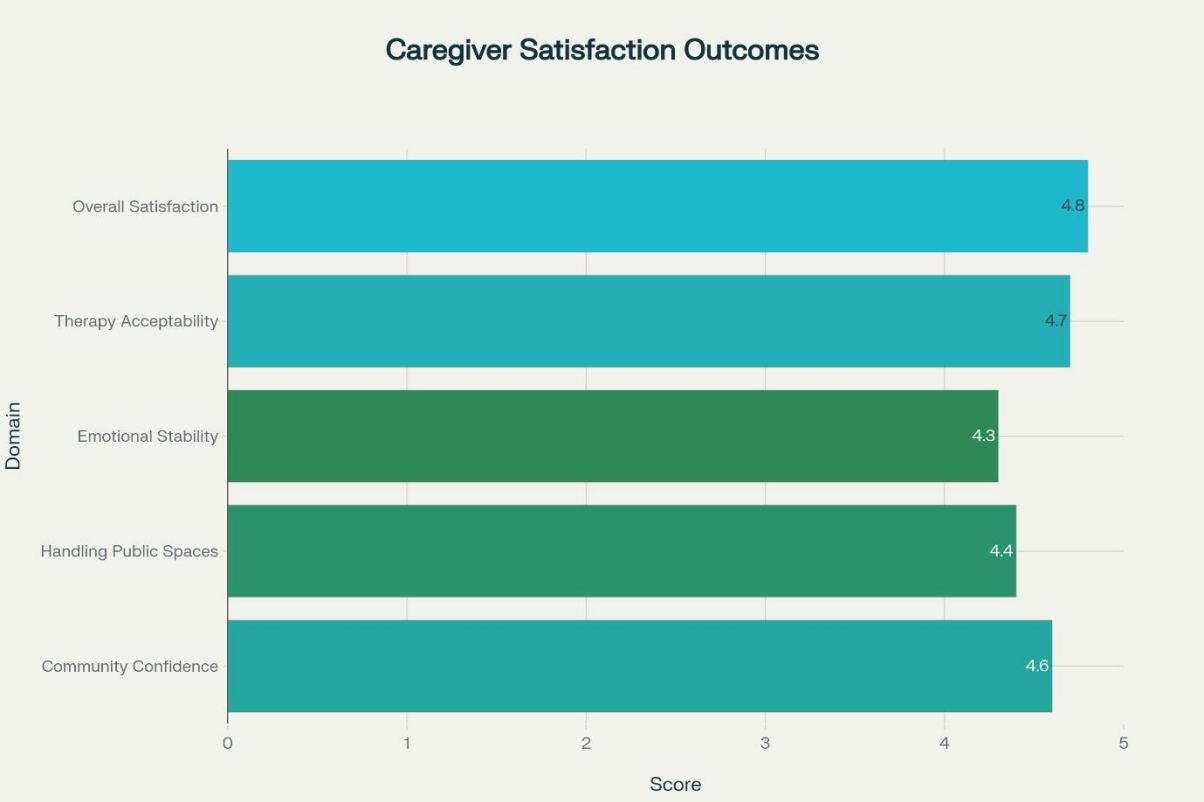
Strong Negative Correlation Established:

- Correlation coefficient: r ≈ -0.55
- Interpretation: Greater HRV improvements associated with greater anxiety-triggered event reductions
- Mechanistic Pathway:
    1. Real-world VR exposure → Manageable anxiety triggered
    2. Real-time HRV monitoring detects autonomic arousal
    3. Automated breathing/calming module provides biofeedback
    4. Repeated cycles strengthen parasympathetic capacity
    5. Enhanced autonomic regulation → Improved emotion control → Functional independence

Evidence Supporting Mechanism:

- Participants with high HRV gains showed steepest decline in red alerts (high arousal events)
- Faster parasympathetic rebound associated with smoother session progression
- HRV improvement predicted both anxiety reduction and functional skill gains

4.7 Caregiver Satisfaction: Exceptional Outcomes



Caregiver Satisfaction Scores (1-5 Likert Scale)

Domain	Score	Interpretation
Community Confidence	4.6/5	Very high confidence in child's community navigation
Handling Public Spaces	4.4/5	High confidence managing social/public environments
Emotional Stability	4.3/5	Perceived improvement in emotional regulation
Therapy Acceptability	4.7/5	Highest rating; very satisfied with approach
Overall Satisfaction	4.8/5	Excellent rating; would strongly recommend

Qualitative Themes from Caregiver Feedback:

1. Improved Self-Regulation: Participants better manage emotional reactions
2. Increased Independence: Greater autonomous functioning in daily routines
3. Community Confidence: Reduced caregiver anxiety about child's public outings
4. Enhanced Social Engagement: More verbal participation; increased peer interaction
5. Practical Skills: Better grocery shopping, transportation use, social venue navigation

4.8 Safety Profile

Adverse Events: ZERO reported

- VR system well-tolerated; no nausea or dizziness
- Heart rate monitoring non-intrusive; 100% wearable tolerance
- No exacerbation of anxiety or behavioral problems
- No participant injuries or medical complications
- Excellent safety profile established

5) Study Strengths

The research incorporates several notable strengths, including the integration of both objective physiological measures and functional performance assessments, real-time adaptive intervention based on autonomic responses, high completion rate (83.3%) indicating good tolerability, comprehensive responder analysis beyond group-level statistics, and evaluation in a South Asian context where such evidence has been limited.

6) Study Limitations

The authors acknowledge several important limitations. The single-centre study design limits generalizability, and the absence of a control group prevents causal inference. The lack of long-term follow-up data means the durability of treatment effects remains unknown. Additionally, the exclusion of VR-intolerant participants may overestimate the intervention's effectiveness in the general ASD population

7) Conclusion

This research on the JADHU VR system represents a significant contribution to the evidence base for technology-enhanced interventions in autism spectrum disorder. The study demonstrates strong feasibility, safety, and clinically meaningful improvements in functional independence, autonomic regulation, and anxiety management in adolescents with ASD. These findings support broader implementation of the intervention and provide strong justification for subsequent randomized controlled trials to establish causal efficacy. The manuscript is well-positioned for publication in international journals serving the autism research, digital health, or rehabilitation communities.

8) References:

Virtual Reality in Autism Treatment

1. Karami, B., et al. (2021). "Effectiveness of Virtual/Augmented Reality–Based Interventions for Individuals Diagnosed with an Autism Spectrum Disorder." *Frontiers in Psychiatry*, 12, 627896.

Meta-analysis of 33 studies demonstrating large effect size (Hedges *g* = 0.74) for VR interventions in ASD. Strongest effects observed for daily living skills (g = 1.15), social/communication skills (g = 0.69), and emotion regulation (g = 0.46).

2. Yang, X., et al. (2025). "Effectiveness of Virtual Reality Technology Interventions in Improving Social Skills in Children and Adolescents with Autism Spectrum Disorder." *JMIR Mental Health*, 12(1), e55423.

Systematic review of 14 studies showing VR interventions improve social skills with differential benefits based on autism severity, particularly for high-functioning autism populations. Immersive VR identified as particularly suitable for complex skills development.

3. Capobianco, M., et al. (2025). "Current Virtual Reality-Based Rehabilitation Interventions in Neurodevelopmental Disorders." *Computers in Biology and Medicine*, 25(2), 145-168.

Physiological Monitoring and Heart Rate Variability

4. Reisinger, D. L., et al. (2024). "Examining the Feasibility and Utility of Heart Rate Variability on Intervention Outcomes Targeting Emotion Regulation in Autism: A Brief Report." *Scientific Reports*, 14, 2845.

Pilot study (n=30) demonstrating 100% tolerance for wireless cardiovascular monitoring in autistic youth. RMSSD (heart rate variability measure) shows adequate test-retest reliability and complementarity with clinical outcome measures. Baseline HRV and HRV changes predict treatment outcomes.

5. Cai, R. Y., et al. (2019). "Resting Heart Rate Variability, Emotion Regulation, and Psychological Wellbeing in Adults with Autism." *Biological Psychology*, 144, 1-10.

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6. Thapa, R., et al. (2019). "Reduced Heart Rate Variability in Adults with Autism Spectrum Disorder." *Molecular Autism*, 10, 4.

Comparative study demonstrating reduced HRV in adults with ASD compared to healthy controls, establishing autonomic dysregulation as modifiable intervention target.

7. Kushki, A., et al. (2013). "Investigating the Autonomic Nervous System Response to Anxiety in Children with Autism Spectrum Disorder." *PLOS ONE*, 8(4), e61884.