RESEARCH PROTOCOL

Acute Effects of Immersive Virtual Reality Exergaming Versus Matched Non-Virtual-Reality Exercise on Reaction Time, Functional Performance, Postural Control, and Neuromuscular Activity in Children Aged 10–14 Years: A Stratified Randomized Controlled Trial

Pediatric randomized controlled trial • CONSORT-C 2026-informed

Protocol ID: PED-VR-EMG-2026-01

Protocol version/date: 1.0 | 29 October 2026

Registry: ClinicalTrials.gov; NCT number pending assignment

Ethics reference: 18.231/10.11.2025 | Babeș-Bolyai University Ethics Subcommittee, Cluj-Napoca (reported by investigator)

Study investigator: Ghejan Horațiu-Dacian, PhD candidate

Proposed principal testing facility: Gh Kineto Complex, Cluj-Napoca, Romania; additional recruitment/testing sites to be confirmed

Sponsor/responsible party and institutional data controller: to be confirmed in institutional records

Study phase: Not applicable (behavioral/non-drug intervention)

Study status: Planned; not yet recruiting

Protocol synopsis

Field	Planned specification
Design	Two-arm, participant-level, stratified, parallel-group randomized controlled trial; single testing visit.
Setting	Romania; national gymnastics recruitment is possible; testing locations and recruitment permissions to be documented.
Participants	Children aged 10–14 years, all sexes; 120 rhythmic gymnasts, 120 other competitive athletes, 120 non-athlete/low-active children.
Allocation	Within each athletic-background stratum, 1:1 to immersive VR exergaming or active non-VR exercise using an R/Rcmdr-generated sequence.
Sample target	N = 360; 60 per randomized condition within each athletic-background stratum. A priori power analysis outstanding.
Experimental intervention	Meta Quest 3 with Beat Saber, Easy difficulty; one approximately three-minute standardized song.
Active comparator	Duration-matched, movement-cued non-VR activity; precise sequence, dose and matching verification TO FINALIZE.
Primary outcome	Change from baseline in median correct two-choice visual reaction time (ms), analyzed as post-intervention RT with baseline adjustment.
Secondary outcomes	Five Times Sit-to-Stand time (s); mean balance errors per 20-second single-leg trial.
Other prespecified outcomes	Choice-task accuracy; normalized bilateral rectus femoris EMG during sit-to-stand; shank IMU angular-speed variability during balance; further EMG/IMU features only if prospectively specified.
Masking	Participants and intervention deliverer unmasked; independent outcome assessor and non-delivering investigator masked only when operationally feasible.
Ethics	UBB ethics reference 18.231/10.11.2025 as confirmed by investigator; verify this version and subsequent amendments are covered.

Contents

1. Rationale and research questions • 2. Design and objectives • 3. Recruitment and eligibility • 4. Interventions and visit sequence • 5. Outcomes and instruments • 6. Randomization and masking • 7. Statistical analysis plan • 8. Safety and pediatric safeguards • 9. Data governance and quality assurance • 10. Ethics, registration and dissemination • Appendices A–D and references.

1. Scientific rationale and research questions

Immersive VR exergaming requires rapid visuomotor responses and repetitive coordinated movement. Its immediate effects on cognitive-motor outcomes, lower-limb functional performance and postural control after a very brief bout remain uncertain. Existing athletic participation may relate to baseline motor ability and responses to a standardized activity, but athletic background is not randomized and cannot be used to infer that sports training caused observed differences.

Rhythmic gymnastics places pronounced demands on coordinated upper- and lower-limb movement and static postural control. Comparing gymnasts with other competitive athletes and children without organized sports training creates an opportunity to test whether the randomized VR-versus-non-VR contrast differs across pre-existing movement backgrounds. An active exercise control is essential because the same post-test improvement could reflect task familiarization, movement-induced arousal, or generalized practice rather than immersion.

1.1 Primary research question

Does a standardized brief immersive VR exergaming session lead to a different immediate post-intervention choice reaction time compared with a duration-matched non-VR movement session, after adjustment for pre-intervention reaction time?

1.2 Key effect-modification question

Does the randomized treatment contrast for choice reaction time vary among rhythmic gymnasts, athletes from other competitive sports, and non-athlete/low-active children? This hypothesis is prespecified; confirmatory inference depends on a completed interaction-specific a priori power analysis and the agreed multiplicity strategy.

1.3 Secondary questions

- Do the two interventions differ in immediate Five Times Sit-to-Stand completion time?
- Do the two interventions differ in the number of single-leg balance errors?
- How do task-specific EMG and IMU signals change, and how do they differ across the activity conditions and athletic-background strata?

No claim of long-term adaptation, treatment efficacy or sport-training causality will be made on the basis of a single-visit study.

2. Trial design, objectives and estimands

2.1 Trial structure

Individual allocation, two randomized interventions and three pre-existing athletic-background strata. Each child completes consent/assent and eligibility screening, familiarization and baseline testing, one assigned activity and identical post-intervention testing during one visit. The overall intervention contrast is randomized; comparisons among the three athletic populations remain observational.

Athletic-background stratum	VR	Active non-VR	Planned total
Rhythmic gymnasts	60	60	120
Other competitive athletes	60	60	120
Non-athlete/low-active children	60	60	120
TOTAL	180	180	360

2.2 Primary estimand

Population: enrolled eligible children aged 10–14 years. Treatment: assigned VR versus assigned active non-VR activity. Variable: post-intervention median correct choice reaction time in milliseconds, with baseline reaction time as a covariate. Summary: adjusted mean difference (VR minus active control), averaged with equal weight across the three planned athletic-background strata. Intercurrent events: assigned-group analysis regardless of adherence when an outcome is available; inability to complete the reaction time test is missing data, not an imputed favorable or unfavorable result.

Lower reaction-time values reflect faster responses. A negative adjusted difference favors the VR condition for speed, provided accuracy is not adversely affected. Accuracy will therefore be reported alongside reaction time.

2.3 Hypothesis tests

H0, overall: the baseline-adjusted VR-versus-control mean difference in post-intervention reaction time is zero. H0, effect modification: the intervention effect is equal across athletic-background strata (a two-degree-of-freedom interaction). The analysis tests differences between interventions, not within-group statistical significance.

3. Recruitment, screening and eligibility

3.1 Recruitment framework

Rhythmic gymnasts may be approached through Romanian gymnastics clubs and authorized sporting organizations. Other competitive athletes and non-athlete children should ideally be recruited across overlapping geographical areas and age distributions. Recruitment site, sport type, club and contact pathway must be recorded so that center effects and selection limitations can be evaluated. No club will be described as a trial site unless assessments actually occur there.

3.2 Inclusion criteria

- Age 10–14 years inclusive, with parent/guardian verification of eligibility and age-appropriate child assent.
- Belonging to exactly one prespecified athletic-background stratum: competitive rhythmic gymnastics; competitive sport other than rhythmic gymnastics; or non-athlete/low-active group.
- Able to understand standardized instructions and safely attempt both interventions and all three outcome assessments.

- Written parent/legal guardian permission and affirmative child assent before any research measurements.

3.3 Exclusion criteria

- Current injury, pain or physical restriction that precludes safe sit-to-stand, balance or movement tasks.
- Known photosensitive seizures or other relevant contraindication to immersive VR, including significant vestibular symptoms or prior severe VR intolerance.
- Uncorrected vision problems preventing reliable reaction-time testing or safe headset use.
- Neurological or medical conditions that substantially compromise safe participation or interpretation of the proposed tasks, according to prespecified screening criteria.
- Skin disorder or relevant adhesive intolerance that prevents six-sensor sEMG application.
- Child refusal, guardian refusal, or inability to meet verified VR account/age restrictions.

3.4 Athletic-background classification (TO FINALIZE)

Define objectively before recruitment: (a) rhythmic gymnast: current organized competitive rhythmic gymnastics participation and minimum training exposure; (b) other competitive athlete: current organized competitive participation excluding gymnastics, with sport and weekly training recorded; (c) non-athlete/low-active: no organized sports training during a defined period AND a prespecified activity measure if the term “sedentary” is retained. Absence of club sport alone does not establish sedentary behavior. Set thresholds in a dated screening manual before enrollment and use consistently across locations.

3.5 Baseline descriptors

Record age (years), sex as appropriately reported, stature and body mass if approved, dominant leg, sport and discipline, competition experience, years of training, weekly training hours, prior VR exposure, time since last intense exercise, relevant sleep/illness or safety symptoms, and recruitment site. Any additional maturation-related variables require age-appropriate ethical justification and a standardized procedure.

4. Interventions and single-visit procedures

4.1 VR intervention

A supervised Meta Quest 3 Beat Saber session at Easy difficulty will be administered using one age-appropriate, standardized song lasting approximately three minutes. The same headset model, controller configuration, game/software version, selected song, difficulty, modifiers, player boundary, sound level and safety briefing will be used across participants. The child will remain within a cleared play area and will not be encouraged to take unnecessary steps. A supervisor will be able to terminate the game promptly.

TO FINALIZE before recruitment: song title and exact runtime; virtual cue frequency; allowed modifiers (for example, fail/no-fail setting); headset firmware and game build; controller grips; whether spectacles or corrective inserts are used; permitted gameplay restarts; headset fit and hygienic cleaning; accounts, age rating and privacy restrictions; and how unsuccessful completions are handled. The final song must be accessible to the 10–12-year-old accounts used in the study.

4.2 Active non-VR comparator

A supervised non-immersive movement sequence lasting the same time will approximate the core directional arm movements and lower-limb stance demands of the VR task. Participants will receive standardized external cues without wearing a VR headset. The movement script, auditory/visual cue schedule, and number of intended bilateral actions must be reproducible and fixed prospectively. Equivalence of the two activities cannot be presumed merely because both last three minutes.

TO FINALIZE: cue presentation modality, movement directions, target frequency, movement range, stance/step rules, script or demonstration source, permitted corrections and stopping rules. Record observed movement counts, completed duration, deviations and a simple age-appropriate perceived exertion rating, if approved. Exertion is a fidelity descriptor and may differ between conditions; it is not automatically an ANCOVA covariate because it can be affected by treatment.

4.3 Standardized single-visit sequence

Order	Procedure	Recording and control

Order	Procedure	Recording and control
1	Eligibility, guardian permission, child assent; symptom/health screen	Assign study ID; confirm ability to participate; no research data before permission.
2	Baseline descriptors, six-sensor setup and signal checks	Record age, athlete stratum, headset eligibility, device/sensor identifiers.
3	Task familiarization and muscle-specific reference contractions	Instructions and trial number identical; reference method TO FINALIZE.
4	Pre: two-choice visual reaction time	30 scored trials after practice; correct-trial median (ms) and accuracy (%).
5	Pre: Five Times Sit-to-Stand	One scored standardized 5xSTS; synchronized sEMG/IMU.
6	Pre: single-leg stance	Three 20-second trials per leg; fixed leg order; errors and shank angular motion.
7	Reveal concealed allocation and deliver assigned 3-minute activity	Only intervention operator sees the assignment; record duration, fidelity, adverse symptoms.
8	Post: reaction time, 5xSTS, single-leg stance (same order)	Record exact start time of each test relative to intervention end.
9	Adverse-event check; sensor removal; debrief	Document reason for incomplete tasks, reactions and safety follow-up.

The exact visit duration is TO FINALIZE using a timed rehearsal. The protocol time frame registered for each pre/post outcome is baseline and within 30 minutes after intervention; the actual elapsed interval to each post-test must be captured because outcomes are assessed sequentially. No second study visit is planned.

5. Outcome specifications and measurement methods

5.1 Primary outcome: choice reaction time

Task: a computerized two-alternative visual discrimination test (left/right), administered on the same validated hardware/software configuration. After standardized practice, obtain 30 scored trials at baseline and 30 post-intervention. Primary score: median stimulus-to-response latency (ms) among correct scored trials in each session; change is post minus pre. Prespecify timeouts, anticipatory responses, delayed responses and handling of zero correct trials before data acquisition. Use a prespecified pseudo-random left/right sequence, fixed response mapping and same latency correction at both time points. Document display and response-device timing properties.

5.2 Secondary: Five Times Sit-to-Stand

The participant rises from a chair and returns to sitting five times, with arms crossed over the chest, after standardized instruction and practice. Record total completion time in seconds from the agreed start trigger to the agreed end event. Use a reproducible chair-height rule accounting for child size, stable flooring, standardized footwear, and the same assessor instructions. One scored trial per time point is proposed; if multiple trials are ultimately used, this change must be applied prospectively to registry and protocol.

5.3 Secondary: single-leg stance errors

Firm surface, eyes open, hands on hips, facing a fixed visual target. Each leg completes three 20-second trials at baseline and post-intervention, in the same leg order and with predefined rest. Count standardized balance errors (support-foot displacement, unintended non-support-foot touchdown, or a hand leaving the hips) using an error-scoring manual; score mean errors per trial averaged over six attempts. Prespecify handling of early termination, falls and repeated errors. This is a modified single-leg stance protocol, not the complete Balance Error Scoring System. The test could show a floor effect among trained gymnasts; shank motion is an additional metric.

5.4 Prespecified additional outcomes

Outcome	Planned operational definition	Interpretation / caveat
Choice-task accuracy	Correct responses / 30 scored trials × 100; change in percentage points.	Inspect speed–accuracy trade-off.

Outcome	Planned operational definition	Interpretation / caveat
Rectus femoris sEMG during 5xSTS	Mean bilateral RMS amplitude, each channel normalized to the participant's within-visit standardized reference; post−pre in percentage-reference units.	Relative muscle excitation, not strength or efficiency.
IMU angular-speed variability during stance	Within-trial SD of resultant 3D shank angular speed (degrees/s), averaged over six 20-second trials; post−pre.	Segment motion proxy, not center-of-pressure sway.
Other six-sensor descriptors	Gastrocnemius and deltoid bilateral activity during comparable tasks, left/right asymmetry and movement features, if specified in a dated analysis annex.	Task-specific/descriptive unless multiplicity and analysis specified.

Direct between-arm comparison of muscle RMS during VR versus non-VR activity requires similarity of movement demands and cautiously defined interpretation. Baseline/post EMG comparisons should use the same standardized motor task and the same normalization reference within a visit, rather than comparing unlike movement epochs.

6. Six-channel sEMG/IMU acquisition and processing

Sensor	Anatomical location	Primary role
1	Left gastrocnemius medialis	Calf excitation and shank movement.
2	Right gastrocnemius medialis	Contralateral calf excitation and shank movement.
3	Left rectus femoris	Thigh excitation during sit-to-stand.
4	Right rectus femoris	Contralateral thigh excitation during sit-to-stand.
5	Left middle deltoid	Shoulder excitation during arm movement.
6	Right middle deltoid	Contralateral shoulder excitation during arm movement.

Electrode locations, inter-electrode distance (if relevant to device), orientation, skin preparation and fixation will follow device instructions and established anatomical guidance (e.g., SENIAM) where compatible. Record the device manufacturer, model, firmware, all sampling rates, IMU coordinate convention, time synchronization method, system accuracy checks and signal losses. sEMG quality will be checked before task collection to identify poor contact, motion artifact, clipping and interference.

6.1 Proposed offline processing rules (TO FINALIZE and lock)

- Export raw sEMG and IMU data with unchanged participant IDs and event timestamps; maintain immutable raw files.
- Adopt manufacturer-compatible sEMG bandpass/filter settings, an explicit strategy for 50-Hz mains interference, and recorded rationales; document whether filtering is causal or zero-phase.
- Calculate RMS over a prespecified moving window and define the movement epoch for each repetition and trial. Avoid arbitrarily choosing the most favorable epoch after inspecting results.
- Choose an age-safe, muscle-specific normalization method (for example, standardized submaximal reference contractions) with position, duration, repetitions and peak/mean reference processing fixed; the choice must be justified under the CEDE framework.
- For IMU, specify axis sign conventions, resultant angular speed computation, artifact detection, validity of placement over active muscle, and valid-trial criteria.
- Record expected and observed sensor dropout, invalid epochs and participant-level usable-signal counts by arm.

No default EMG frequency band, normalization contractions, or IMU thresholds are asserted as the actual settings until the equipment-specific acquisition manual is confirmed. The six sensor positions alone do not guarantee valid measurement of center-of-mass or center-of-pressure motion.

7. Randomization, allocation concealment and masking

7.1 Sequence generation

An individual not enrolling children will generate a reproducible allocation list using R with the R Commander (Rcmdr) interface or documented R code. Generate independent 1:1 sequences within the three predefined athletic-background strata. Proposed procedure: randomly varied permuted block sizes (e.g., 4 and 6), with

sequence seed, R version, Rcmdr package version and code archived. The final block sizes and sequence generation method must be locked before recruitment. No participant may be reallocated based on performance or preference.

7.2 Concealment and implementation

The allocation list will be held by a person independent of eligibility screening and baseline outcome assessment. After baseline measurements are completed, the intervention administrator will request the next assignment through a controlled allocation system or sequentially numbered opaque sealed envelopes prepared per stratum. Store assignment and audit log separately from primary outcome measurements. Record allocation deviations and their reasons.

7.3 Masking

Participants cannot be blinded to wearing a headset versus not wearing a headset, and personnel administering the activities cannot be blinded. A distinct post-intervention outcome assessor and, if operationally feasible, a non-delivering investigator will remain unaware of individual assignments. To reduce accidental unmasking, the VR headset and other visible equipment should be removed before post-tests, allocation labels hidden from assessment forms and children asked not to disclose activities; safety information must never be concealed. Track each masking breach. Do not register participant masking for this design.

8. Safety, assent and child-specific safeguards

8.1 Permissions and youth participation

Provide plain-language written and verbal information to the guardian and child. Obtain guardian permission and affirmative child assent before study procedures. A child's refusal takes precedence over guardian permission. Use neutral recruitment procedures so coaches, teachers and club administrators do not exert undue pressure. The participation decision will not influence selection, team membership or clinical services.

8.2 Risks, stop criteria and management

Foreseeable risks include cybersickness, nausea, dizziness, headache, visual discomfort, distress, fatigue, stumbling or falling, and temporary skin irritation from sensor adhesives. Supervision, appropriate headset fitting and a cleared safe testing zone are required. Stop immediately for significant symptoms, pain, distress, loss of balance or child request. Conduct a brief adverse-event checklist after activity and at session close. Document onset, symptoms, suspected relationship, duration, action, resolution and whether treatment/referral was required.

For serious symptoms, stop research activity, use the site's clinical response plan and call local emergency services (112 in Romania) when indicated. The responsible clinician/on-site responder, incident reporting deadlines and emergency supplies remain TO FINALIZE with each approved testing site. No independent Data Monitoring Committee is currently specified; the investigator is responsible for continuous participant safety oversight and reporting to the ethics body under applicable rules.

8.3 Platform use and age restrictions

Participants aged 10–12 must use Meta Quest accounts allowed under the platform's parent-management requirements; age-appropriate Beat Saber content must be accessible under that account and region. Game telemetrics and account processing may occur independently of the research database. No child's name should be intentionally entered into game profiles for study use. The precise account/device configurations, hygiene procedures, privacy settings and international transfers require a documented device-data assessment before enrollment.

9. Statistical analysis plan (prespecified draft)

9.1 Sample size and power

The recruitment target of 360 corresponds to 120 children per athletic-background stratum and approximately 60 participants per intervention cell. This is a design target, not a completed power calculation. Before first enrollment, determine the smallest meaningful between-arm difference in adjusted median correct reaction time (ms), plausible residual SD and baseline/post correlation, acceptable power, type-I error and any dropout/invalid-

trial allowance. Simulate or calculate power for the two-degree-of-freedom interaction if it is intended as confirmatory, and revise the target with an ethics/registry amendment if needed. Do not describe this study as adequately powered until the written calculation exists.

9.2 Analysis population and data cleaning

Primary analysis will follow the randomized assignment (intention-to-treat principle) for participants with analyzable primary outcome information. Include all randomized participants in flow diagrams; report exclusions, missing baseline and post measures, invalid trials and reasons by randomized arm and stratum. The pre-specified data dictionary defines permitted values, units, transforms, timing and signal-validity flags before database lock. Analysts should work from coded datasets; a blinded arm label (A/B) is preferable until the analysis code is fixed.

9.3 Primary model

Fit an ANCOVA model with post-intervention median correct reaction time (ms) as the dependent variable, randomized arm as the main predictor, baseline median correct reaction time as a covariate, and athletic-background stratum as a fixed factor. The main effect is estimated as an adjusted VR-minus-control difference, with a 95% confidence interval. Age and sex may be considered as prespecified precision covariates if balance, overlap and model stability permit; do not select them post hoc based on P values. If multiple testing sites contribute, prespecify handling of site clustering, e.g., a site random effect or suitable cluster-robust sensitivity analysis when the number of sites permits.

9.4 Athletic-background interaction

For the effect-modification hypothesis, add intervention × athletic-background stratum to the primary ANCOVA and test its joint two-degree-of-freedom null. Report adjusted intervention contrasts separately for all three strata with CIs. Any pairwise differences in contrasts will be declared in advance and multiplicity-adjusted. Do not interpret a statistically significant effect in one stratum and a nonsignificant effect in another as evidence of heterogeneity without testing the interaction.

9.5 Multiplicity and confirmatory status

Provisional strategy: treat the overall treatment contrast and the intervention × stratum interaction as a family of two prespecified hypotheses, using Holm adjustment to maintain familywise two-sided $\alpha = 0.05$. The actual confirmatory designation of the interaction remains conditional upon a documented, interaction-specific power justification and signed SAP before enrollment. Secondary and other sensor-derived findings will be reported with effect sizes and CIs; unless an additional testing hierarchy is approved prospectively, their P values will be regarded as descriptive/exploratory. This avoids falsely presenting a large set of EMG tests as independent confirmatory outcomes.

9.6 Secondary and other outcomes

Apply baseline-adjusted linear models for sit-to-stand completion time and normalized sensor features when distributional assumptions permit. For balance-error counts, assess zero inflation and overdispersion, and consider a negative-binomial or other appropriate count model with baseline balance errors, arm and stratum. For choice-task accuracy, use a prespecified binomial model (correct/incorrect trials) or appropriate summarized accuracy model, explicitly allowing for ceiling performance. Repeat measures for six limb-specific channels require prespecified family-level multiplicity control, not unadjusted pointwise comparisons. Report estimates with units and 95% CIs.

9.7 Model checks, missing data and sensitivity analyses

Examine residuals, influential values, heteroskedasticity, and assumptions appropriate to each chosen model. Record score ranges and implausible reaction-time values against pre-set exclusion thresholds; do not delete values solely because they weaken results. Report the amount, pattern and reasons for missing data. Complete-case estimates are primary only if missingness is minimal and plausibly unrelated to outcome after conditioning; otherwise perform prespecified multiple-imputation or model-based sensitivity analyses under defensible assumptions and explore missing-not-at-random scenarios when warranted. Serious adverse events or incomplete interventions are not reasons to automatically exclude a child from the randomized analysis.

9.8 Reporting

For each outcome report randomized N, available baseline and post N, mean ± SD and/or median [IQR] where suitable, adjusted group contrasts, 95% CIs and exact P values. For F tests include numerator/denominator degrees of freedom; for other tests include the test statistic and effect size where informative. No claim of equivalence follows from a nonsignificant between-group result. Analyses may be performed in R (version to be recorded); Rcmdr may be used for allocation generation but scripted, reproducible analysis is preferred.

10. Data handling, monitoring, and quality assurance

10.1 Confidentiality and security

Each participant receives a pseudonymized code; names, guardian contacts and signed forms are maintained separately from the analytical files. Restrict access to authorized researchers; store raw signals, clean datasets and analysis code on approved encrypted storage with access logs and backups. Metadata and inadvertent identifiers in device exports must be assessed. Data are not fully anonymous while a code-to-identity key exists. Publications will use group-level data only unless separate permissions allow other uses.

10.2 GDPR, platform data and possible sharing

The legal data controller, Article 6 GDPR basis, relevant Article 9 condition (if special-category data are processed), retention period, data processors, cross-border transfers and platform privacy configuration require written institutional confirmation. A controlled-access approach to individual-level research-data requests may be considered after publication only if lawful and consistent with the signed permission/assent information and institutional governance. No open release of children's raw data is promised.

10.3 Quality control

Training of assessors will cover electrode placement, timing protocol, balance error definitions, randomized assignment concealment, adverse-event recording and blinded outcome assessment. Before the first participant, a non-enrolled feasibility rehearsal will establish measurement timing, technical synchronization and comparator reproducibility. Changes informed by this rehearsal must be documented and, when material, ethics-approved and registry-updated before recruitment. Monitor missingness, sensor-quality metrics and adverse events without using unblinded accumulating efficacy comparisons to revise hypotheses.

11. Ethics, registration and dissemination

The investigator reports that the study is covered by Babeș-Bolyai University Ethics Subcommittee reference 18.231/10.11.2025, dated 10 November 2025. The research team must verify that the approval and any needed amendment explicitly cover this complete version, including N = 360, the two randomization arms, acquisition and data processing, and the final parental consent and child assent documents. Site authorizations and GDPR obligations remain separate from protocol approval.

ClinicalTrials.gov record: protocol ID PED-VR-EMG-2026-01; NCT number not yet assigned in the information available here. Prospectively register the final primary outcome, interventions, masking, participant numbers, recruitment status and analysis plan before enrollment, and maintain version concordance. At publication, use CONSORT 2025 and its CONSORT-C 2026 pediatric extension, including a participant flow diagram, child-specific safety reporting and age-appropriate intervention considerations. No patient or public involvement activities have been reported to date; if none occur, this will be stated transparently.

Appendix A. Session checklist

- ☐ Guardian permission and child assent confirmed; eligibility, safety screening and study ID complete.
- ☐ Recruitment stratum verified against locked criteria; age and site recorded.
- ☐ Six sEMG/IMU sensors placed and checked; IMU/sEMG clock synchronization documented.
- ☐ Practice and reference contraction protocol completed as specified.
- ☐ Baseline reaction time (30 trials), 5xSTS and six stance trials obtained in fixed order.
- ☐ Allocation revealed only after baseline; intervention administrator documents assigned task.
- ☐ VR or active comparator duration, movement fidelity and symptoms recorded.
- ☐ Post-intervention reaction time, 5xSTS and balance in fixed order; start delays timestamped.
- ☐ Adverse-event check, equipment removal, child debrief and secure upload completed.

Appendix B. Minimum structured data dictionary

Variable	Type / units	Rule or purpose
study_id	Coded string	No full name in analytic export.
stratum	3-level category	Rhythmic / other competitive / non-athlete-low-active.
arm	2-level category	VR / active non-VR; derived from concealed allocation.
age, sex, site	Years / category / site ID	Prespecified baseline descriptors and cluster information.
training exposure	Years and hours/week	Document athletic-background characteristics.
RT_pre, RT_post	ms	Median of correct scored trials; record accuracy and valid trial count.
STS_pre, STS_post	s	Five complete chair rises; prespecified event triggers.
BAL_pre, BAL_post	Errors per trial	Mean across 6 × 20-s trials with raw trial scores retained.
EMG reference and RMS	% of within-visit reference	Muscle, side, task, processing version and valid epoch counts.
IMU variability	degrees/s	SD of resultant shank angular speed per trial.
timing/dose	Time stamps; s; minutes	Start/end of activity, post-test delays, task deviations.
safety/missingness	Categorical / free-text coded	Adverse event, severity, reason, disposition and outcome status.

Appendix C. Items to lock before first enrollment

- ☐ Power calculation: justify 360 against the primary treatment effect AND, if confirmatory, the 2-df interaction; specify alpha, power and meaningful RT difference.
- ☐ Athletic-stratum operational thresholds: gymnastics and other-sport competition/training; a measurable definition of inactive/sedentary participants.
- ☐ Precisely standardized VR song, runtime, settings, platform account arrangements and age-approved content.
- ☐ Complete matched non-VR cue/movement script and criteria for fidelity and comparable physical demand.
- ☐ Test hardware/software and reaction-time latency validation; RT trial rejection thresholds and stimulus schedule.
- ☐ Chair-height rule, timing triggers, balance-error adjudication, rest period and fixed order of legs.
- ☐ Six-sensor model and sampling, reference contraction positions, EMG filtering/RMS and IMU preprocessing.
- ☐ Allocation generator, sequence blocks, responsible sequence keeper, blinded assessment personnel and access controls.
- ☐ Approved sites, visit duration, safety escalation, emergency contact, incident notification and supplies.
- ☐ Responsible party, legal data controller, GDPR bases, retention, platform transfers, participant contact information and consent version.
- ☐ Exact confirmatory hypothesis family/multiplicity strategy, missing data methods and any cluster handling written into signed SAP.
- ☐ Ethics committee confirmation that protocol 1.0 and final consent documents are covered by approval 18.231/10.11.2025 or approved amendment.

Appendix D. Pediatric reporting crosswalk (CONSORT-C 2026)

Pediatric reporting issue	Where specified / what remains
Justification of enrolling children	Section 1; short exposure and age-specific sensorimotor questions.
Age/development eligibility	Section 3; 10–14 years, age-appropriate comprehension and safeguards.
Age-appropriate interventions	Sections 4, 8; headset/accounts/content, physical demands, adult supervision.
Outcome suitability	Section 5; practice, child-scale chair setup and simple balance; age effects considered.
Assent and parent permission	Section 8; separate plain-language forms and child refusal protection.
Child-specific harms	Section 8; cybersickness, balance, skin, adverse-event reporting.

Pediatric reporting issue	Where specified / what remains
Flow, analyzed N and age group	Sections 9 and 11; CONSORT flow and denominators at publication.
Interpretation, limitations, PPI	Sections 1, 11; confounding of sport background, brief exposure, report involvement honestly.

References and authoritative materials

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