STUDY PROTOCOL

Official Title: The Effect of a Sports-Based Cognitive Game Development Program on Attention Level and Prefrontal EEG Theta/Beta Ratio

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Ethics Approval: Düzce University Scientific Research and Publication Ethics Committee (No. E-78187535-050.04-426788)

Status of this document. This study was conducted between 20 December 2025 and 14 March 2026 and was registered retrospectively, after data collection had been completed. No protocol or statistical analysis plan was registered or time-stamped before data collection. Version 1.0 of this document was prepared retrospectively at the time of registration. Version 2.0 corrects errors in Version 1.0 that were identified during peer review and describes the study and analyses as they were actually conducted; the changes are listed in the revision history at the end of this document. This document should therefore not be regarded as a prospectively specified plan.

1. Background and Rationale

Attention is a core component of executive function and is considered important for sports performance, including the speed of decision making, motor planning and error correction. Interventions targeting executive functions can improve attention, although their effects vary considerably across intervention types. Sport-based cognitive game programs combine physical activity with cognitive demands, but controlled experimental studies examining their effects on both behavioral attention performance and neurophysiological measures in healthy active athletes are limited.

The frontal theta/beta ratio (TBR) is one of the most frequently studied EEG indices in attention research. Much of the evidence on TBR comes from clinical samples, particularly children and adolescents with ADHD, and its diagnostic specificity and interpretation have been questioned. In healthy adults, frontal TBR has been associated with self-reported attentional control and shows acceptable test–retest reliability, but it has not been validated as a biomarker of attention in healthy young athletes. In this study, resting Fz TBR is therefore treated as an exploratory neurophysiological measure.

2. Objectives and Hypotheses

Objective. To examine the effects of a 12-week sports-based cognitive game development program, compared with no intervention, on (1) selective attention performance, measured by the d2

Attention Test TN−E score, and (2) the resting EEG theta/beta ratio recorded from the Fz electrode, in active athletes.

Hypotheses.

- H1: Compared with the control group, the experimental group will show a greater increase in the d2 TN−E score from pre-test to post-test (Group × Time interaction).
- H2: Compared with the control group, the experimental group will show a greater decrease in the Fz theta/beta ratio from pre-test to post-test (Group × Time interaction).

3. Study Design

Randomized controlled trial with a pre-test–post-test control group design and two parallel arms (experimental: sports-based cognitive game program; control: no intervention), with 1:1 allocation.

Allocation: Randomized

Intervention model: Parallel assignment

Masking: None (open label); outcome assessors were aware of group allocation

Primary purpose: Basic science

4. Participants

Active athletes studying at Düzce University were recruited on a voluntary basis. A total of 100 participants were enrolled, completed the baseline assessments and were randomized (experimental: n = 50; control: n = 50). The participants were 18–23 years of age.

Inclusion criteria

- Being actively engaged in sports
- No neurological or psychiatric diagnosis in the past six months
- Voluntary participation with written informed consent

Exclusion criteria

- Neurological or psychiatric diagnosis within the past six months
- Withdrawal of informed consent

Adherence criterion (analysis)

Participants in the experimental group who were absent from more than two of the 24 sessions (i.e., attended fewer than 22 sessions) were excluded from the analysis. Five participants met this criterion; the analyzed sample therefore comprised 95 participants (experimental: n = 45; control: n = 50).

5. Randomization and Allocation

All participants were first enrolled and completed the baseline (pre-test) assessments of both outcomes. Only after baseline testing had been completed for the entire sample were participants randomized. Allocation was performed once, for the full list of 100 enrolled participants, by one

member of the research team using a computer-generated random allocation program (1:1 ratio). Baseline scores were not used in the allocation, and the allocation was not modified after it had been generated. Because the allocation was generated only after enrollment and baseline testing had been completed, the researchers who enrolled participants could not know or foresee group assignments. No independent third party was involved in generating or holding the allocation.

Blinding. Because of the nature of the intervention, participants and the instructor could not be blinded. Post-test assessments were conducted by members of the research team who were aware of group assignments. To limit assessor influence, the d2 test was administered with standardized instructions and scored with the standard templates, and the EEG theta/beta ratio was computed automatically by the software.

6. Interventions

Experimental group

Participants took part in a basketball-based sports cognitive game development program delivered twice weekly for 12 weeks (24 sessions of 45 minutes). The program followed a five-stage structure with progressively increasing cognitive load: (1) adaptation and basic cognitive infrastructure (weeks 1–2); (2) attention and reaction development (weeks 3–4); (3) decision making and strategy (weeks 5–8); (4) concentration and multitask performance (weeks 9–10); and (5) reinforcement and transfer to sport (weeks 11–12).

Each session had the same structure: greeting and orientation (3 min), warm-up (5 min), sport-based cognitive games (15 min), table-based cognitive games (15 min), and evaluation and closing (7 min). In sport-based cognitive games, participants responded to visual or verbal stimuli with predefined motor actions while moving with the ball; table-based cognitive games targeted working memory, inhibition and processing speed.

Progression of difficulty. Cognitive difficulty was increased according to a predefined phase-based plan by manipulating (a) the number of stimulus–response rules, (b) rule reversals and no-go signals, (c) working-memory load (e.g., from 10 to 16 card pairs and from 1-back to 2-back tasks), (d) time pressure, and (e) dual tasking. Within each session, each game began at the level reached in the previous session, and the group moved to the next level once most participants were performing the game without errors. Difficulty was adjusted for the whole group rather than individually; cognitive load was therefore standardized by protocol and was not measured individually. The weekly content, the core rules of the main games, the difficulty levels and the progression criteria are given in Appendix Tables 1 and 2 of the manuscript.

Delivery and fidelity. All sessions were delivered by the same PhD-level sport sciences researcher using the same equipment. Each session was documented with a structured session control form recording whether the session stages were fully implemented, whether the planned games were executed and whether the time schedule was followed. Attendance was recorded at every session.

Control group

The control group received no intervention. After allocation, participants continued their daily lives without any program, sessions or contact with the research team until the post-test measurements. Physical activity outside the study was neither prescribed nor recorded in either group. Consequently, in addition to the cognitive game content, the experimental group received structured physical activity, researcher contact and group interaction that the control group did not receive.

7. Outcome Measures

Primary outcome 1: d2 Attention Test – TN−E score

Selective attention was assessed with Brickenkamp's d2 Attention Test (Turkish adaptation). The test consists of 14 rows of 47 characters; participants mark the target character (the letter "d" with two dashes) among distractors, with 20 s per row. The following raw scores were obtained: TN (total number of items processed), E1 (errors of omission), E2 (errors of commission) and E (total errors = E1 + E2). The primary outcome was TN−E = TN − (E1 + E2), the standard overall performance index of the d2 test (higher scores indicate better performance). All test forms were scored manually with the standard scoring templates, and all scores were entered and checked against the original forms.

Primary outcome 2: Fz EEG theta/beta ratio (exploratory neurophysiological measure)

EEG was recorded from Fz (international 10–20 system) against a linked-earlobe reference (A1–A2) with the NeXus-10 Mk II amplifier (Mind Media B.V., Herten, the Netherlands) and BioTrace+ software, during a 10-min eyes-closed resting condition, with electrode impedance below 5 kΩ. Processing:

- Acquisition at 256 samples/s; no resampling (8,192 samples/s is only the maximum capacity of the device).
- The first and last 30 s of each recording were discarded, leaving 9 min of data.
- Automatic rejection of segments exceeding ±100 µV; muscle (EMG) contamination monitored in the 75–100 Hz band; at least 8 min of artifact-free data required per participant and session.
- FFT over 0–60 Hz using 2-s epochs (512 samples), a Hanning window and 75% overlap (frequency resolution 0.5 Hz).
- Absolute theta (4–8 Hz) and beta (13–21 Hz) power obtained by summing spectral power within each band.
- TBR = Pθ(4–8 Hz) / Pβ(13–21 Hz), averaged across artifact-free epochs (one value per participant and session). Only the ratio was recorded and exported; separate theta and beta values were not stored.

Lower values indicate a lower ratio of slow- to fast-wave activity at the frontal midline; the functional meaning of this measure in healthy athletes is considered exploratory.

Time frame

Both outcomes were assessed at baseline (before randomization) and after the 12-week intervention period.

8. Data Collection Procedures

The d2 test and the EEG recording were conducted on the same day in separate sessions, in a fixed order (d2 test first, then EEG), separated by a rest interval of at least 30 min. All measurements were scheduled at the same time of day. The d2 test was administered individually in a quiet room (5–8 min per participant). EEG recordings were obtained with participants seated comfortably with eyes closed, under constant lighting, noise and temperature conditions.

9. Sample Size

An a priori sample size calculation (G*Power 3.1; independent-samples t-test comparing post-test scores between groups; $d = 0.50$, $\alpha = .05$ two-tailed, power = .80) indicated that 128 participants (64 per group) were required. This calculation was based on a between-group comparison of post-test scores rather than on the Group × Time interaction of the primary analysis. Owing to participant availability within the study period, the target was not reached: 100 participants were randomized and 95 were analyzed (74% of the target). The minimum effect detectable with the achieved group sizes is reported in the Statistical Analysis Plan.

10. Statistical Methods (Summary)

The primary analysis was a 2 (Group) × 2 (Time) mixed-design ANOVA for each outcome, with the Group × Time interaction as the test of the hypotheses, followed by Bonferroni-corrected simple-effects comparisons (three comparisons per outcome; $\alpha = .0167$). Intervention effects are reported as between-group differences with 95% confidence intervals. Supplementary analyses (ANCOVAs adjusting for pre-test score and gender, and estimation of the TBR group effect at different baseline levels) were added after data inspection and in response to peer review. Full details are given in the Statistical Analysis Plan (Version 2.0).

11. Data Management

Data were entered into IBM SPSS Statistics 27.0. Following peer review, the original d2 test forms were re-examined; because the d2 outcome had initially been computed incorrectly, all forms were re-scored using the standard TN−E formula and the data were re-entered and checked against the original forms. The raw data are available from the authors on reasonable request.

12. Ethical Considerations

The study was approved by the Düzce University Scientific Research and Publication Ethics Committee (No. E-78187535-050.04-426788) and was conducted in accordance with local legislation and institutional requirements. All participants were informed about the purpose and procedures of the study and provided written informed consent before enrollment. No financial support was received, and the authors declare no conflicts of interest.

13. Trial Registration

The trial was registered retrospectively at ClinicalTrials.gov (NCT07749937) on 3 August 2026, after data collection had been completed. Consequently, the outcomes, hypotheses and analysis plan cannot be independently verified as pre-specified.

14. Revision History

Version	Date	Description
1.0	3 August 2026	Prepared retrospectively at the time of trial registration.
2.0	8 October 2026	Revised after peer review to correct errors and to describe the study as conducted (see changes below).

Changes in Version 2.0:

- NCT number added; status of the document as retrospectively prepared clarified.
- d2 outcome corrected from "TNE = TN − E2 (Total Net Error)" to the standard TN−E = TN − (E1 + E2); description of the target stimulus corrected; re-scoring of all test forms documented.
- Participant flow corrected: 100 randomized (50/50), five experimental participants excluded for non-adherence, 95 analyzed. The previous statement of 100% attendance was incorrect.
- Control condition corrected: the control group received no intervention and continued their daily lives (not regular sports training); the inclusion criterion on continuing a regular exercise program was removed; the adherence criterion (≤ 2 absences) was specified.
- Age range corrected to 18–23 years.
- Allocation procedure, timing of allocation and lack of assessor blinding described; the statement that baseline equivalence was "confirmed" was removed.
- EEG acquisition and processing described as a single pipeline; TBR presented as an exploratory measure.
- Intervention description extended (basketball-based materials, progression of difficulty, standardization of cognitive load).
- Sample size section revised (a priori target not reached; observed power removed).
- Hypotheses reformulated as between-group (Group × Time) comparisons.