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Computerized Cognitive Retraining for Home Training of Children with Disabilities

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***Abstract*—Cognitive training shows promise for improving memory, attention, and reasoning in children with developmental disabilities, yet prior studies frequently suffer from small samples, clinic-only delivery, short interventions, and limited transfer to daily life. We present COGNITRAIN, a home-based, adaptive cognitive retraining system delivered via web and mobile. COGNITRAIN combines game-based tasks that personalize difficulty in real time, built-in day/week progress analytics for caregivers, and optional, affordable EEG integration for engagement research. We also detail a pre-registered, parallel-group randomized controlled trial (RCT) with a minimum of 60 participants to evaluate efficacy on standardized cognitive and functional outcomes. Our contributions are: (1) a scalable, low-friction architecture for at-home cognitive training with caregiver dashboards and privacy-by-design data pipelines; (2) an adaptive learning engine that maintains target challenge by tracking accuracy and latency; and (3) an RCT protocol with outcomes, power rationale, and statistical analysis plan suitable for replication. We release an open implementation blueprint to facilitate reproducibility and real-world adoption.**

***Index Terms*—Cognitive training, developmental disabilities, adaptive games, tele-rehabilitation, learning analytics, real-time progress, EEG, randomized controlled trial.**

I. INTRODUCTION

Cognitive impairment commonly accompanies developmental conditions such as autism spectrum disorder (ASD), attention-deficit/hyperactivity disorder (ADHD), and intellectual developmental disorder (IDD). Computerized cognitive training (CCT) has potential to support improvements in domains like working memory, selective attention, processing speed, and cognitive flexibility. However, typical limitations in prior work include: (i) delivery constrained to clinic settings, (ii) small, underpowered samples, (iii) limited personalization to an individual's moment-to-moment performance, and (iv) sparse caregiver-facing feedback that hinders sustained engagement at home.

To address these gaps, we propose COGNITRAIN, a home-deployable CCT platform with adaptive, game-based modules designed for short, frequent sessions (10–15 minutes), accessible on commodity devices. Caregivers can review daily/weekly summaries, while clinicians and researchers (where applicable) can access de-identified aggregates. An optional, low-cost EEG stream may be used in research contexts to explore links between engagement and task performance. Finally, we specify an RCT protocol to evaluate COGNITRAIN against an active control, emphasizing real-world usage and generalization to daily functioning.

A. Design Goals

- **Accessibility at scale:** frictionless onboarding, low bandwidth usage, offline-friendly sessions, and cross-platform support.
- **Personalization:** adapt difficulty using accuracy, reaction time, and error profiles to maintain a desired challenge zone.
- **Actionable feedback:** caregiver and clinician dashboards emphasize trends, adherence, and progress toward individualized goals.
- **Privacy and safety:** data minimization, role-based access, encryption in transit/at rest, and clear consent flows.
- **Evaluability:** instrumentation for reliable telemetry and pre-specified outcomes to enable reproducible trials.

II. RELATED WORK

Cognitive training and neurodevelopmental conditions: Prior studies on CCT report mixed but encouraging effects on working memory and attention in pediatric populations, with heterogeneity attributable to sample size, task variety, and transfer measurement. Home-based digital interventions show improved adherence when parents receive clear progress feedback and schedules are flexible.

Adaptive difficulty and engagement: Dynamic difficulty adjustment (DDA) is well-studied in learning sciences and games research as a route to sustain engagement by keeping the user within a "challenge-skill" balance. In CCT, combining accuracy and latency signals helps estimate mastery and detect fatigue, enabling micro-adjustments to stimulus timing, set size, and interference levels.

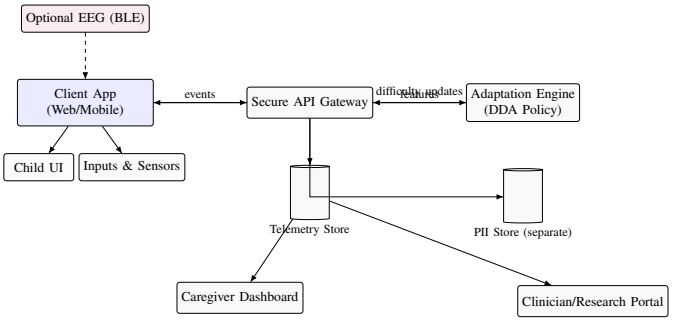

Fig. 1. System architecture

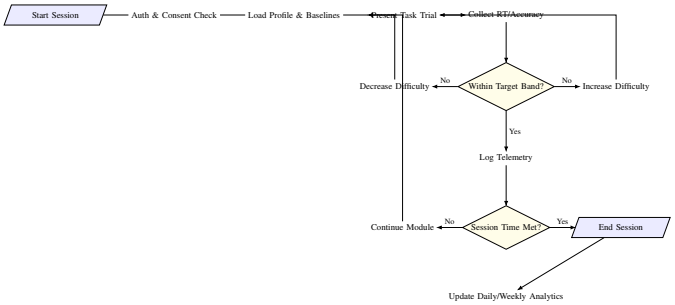

Fig. 2. End-to-end workflow

Tele-rehabilitation platforms: Telehealth solutions demonstrate feasibility for remote delivery, but many lack integrated caregiver dashboards, robust analytics, or clear trial protocols. Our work integrates these components and provides an RCT plan tailored to home settings.

III. System Overview

A. Architecture

Fig. 1 illustrates the modular, privacy-preserving architecture used by CogniTrain. TikZ is used so no external images are required.

B. Adaptive Game Modules

We include four core modules (examples):

- **WM-Span:** N-back / sequence recall with adaptive set size and inter-stimulus interval.
- **Focus-Shift:** Task-switching with congruent/incongruent trials; adjusts cue–target SOA and switch ratio.
- **Stop-Go:** Go/No-Go with adaptive stop-signal delay to maintain target inhibition rate.
- **Speed-Match:** Timed matching under distractors; increases item pool and visual interference.

C. Progress Analytics

Daily and weekly progress snapshots compute adherence, median latency, accuracy, and module mastery scores, highlighting actionable insights (e.g., "best time of day", "benefits from shorter sessions").

IV. Methods and Implementation

A. Workflow

The end-to-end workflow from session start to analytics is visualized in Fig. 2.

B. Personalization Policy

We adopt a target-band controller. Let p_t be smoothed accuracy at time t; the goal is $p^* \in [0.70, 0.85]$. The controller updates difficulty d_{t+1} using accuracy and response time (r_t):

$$d_{t+1} = d_t + \eta_1 \cdot \mathrm{sgn}(p^* - p_t) + \eta_2 \cdot \mathrm{sgn}(\tilde{r}_t - r_t), \quad (1)$$

where $\tilde{r}_t$ is a per-user latency baseline and $\eta_{1,2}$ are small step sizes. Limits prevent abrupt jumps.

C. Adherence Scheduling

Families choose a schedule (e.g., 5 days/week, 10–15 minutes). The system sends gentle reminders to caregivers, and missed sessions trigger non-punitive prompts. Streaks are celebrated to encourage habit formation.

D. Data and Privacy

We separate personally identifiable information (PII) from telemetry using different stores and keys. All data in transit use TLS, and at rest use AES-256. Access is role-based, and research exports are strictly de-identified. Consent and data retention are clearly communicated.

E. Optional EEG Stream

When enabled in an IRB-approved research study, lightweight EEG features (e.g., theta/beta ratio) are synchronized with task events. These signals are not used for clinical decision-making; they are solely for exploratory engagement analyses.

V. Randomized Controlled Trial (RCT) Protocol

A. Design

Parallel-group RCT with 1:1 allocation to CogniTrain or an *active control* (non-adaptive educational games). Minimum total sample size: $N \geq 60$ children (age band to be specified), stratified by site and baseline cognitive score.

B. Eligibility

Inclusion: confirmed developmental disability diagnosis (e.g., ASD/ADHD/IDD), caregiver support for home sessions, ability to use a tablet/computer. Exclusion: uncontrolled epilepsy, major vision/hearing impairments preventing task use, or concurrent intensive CCT.

C. Intervention and Control

CogniTrain: adaptive modules, 10–15 minutes/session, 5 days/week, for 8–12 weeks. Control: time- and device-matched non-adaptive games without targeted cognitive load progression.

D. Outcomes

Primary: change from baseline in standardized working-memory composite at post-intervention. **Secondary:** attention/processing speed, caregiver-reported executive function, adherence, and transfer to daily functioning (e.g., BRIEF subscales). Exploratory: associations between optional EEG engagement markers and performance.

E. Sample Size and Power

Power analysis targets detection of a small-to-moderate effect (e.g., $d = 0.40$) on the primary outcome at $\alpha = 0.05$, two-sided, with 80–90% power, allowing for 15–20% attrition. Exact numbers depend on chosen instruments; final calculation to be provided in the pre-registration.

F. Randomization and Blinding

Randomization is computer-generated with concealed allocation. Outcome assessors are blinded to group; families are briefed not to disclose allocation during assessments.

G. Statistical Analysis Plan

Primary analysis uses ANCOVA with baseline score as covariate. Secondary outcomes are analyzed with mixed-effects models to account for repeated measures. Missing data are handled via multiple imputation under MAR assumptions; sensitivity analyses will be reported.

H. Ethics and Safety

The protocol will be IRB/ethics-approved. Adverse events (e.g., cybersickness, frustration) are logged; a data safety monitor reviews incidents. Families may pause or withdraw at any time without penalty.

VI. Prototype Evaluation (Feasibility)

Prior to the RCT, we recommend a feasibility study to assess usability, adherence, and technical stability over 2–4 weeks with a small cohort (e.g., 10–15 families). Key metrics include session completion rate, median daily use, error reports per 100 sessions, and caregiver satisfaction. Results inform refinements to modules and dashboards.

VII. Discussion

CogniTrain is designed to balance personalization, caregiver visibility, and rigorous evaluation. By operating in the home, the platform addresses barriers to clinic attendance and supports learning in naturalistic contexts. The RCT protocol emphasizes clinically meaningful outcomes and transparent analysis. Limitations include reliance on device availability and potential variability in home environments; we mitigate these via offline support and robust telemetry.

VIII. Conclusion and Future Work

We presented the design of CogniTrain, an at-home adaptive cognitive retraining platform, along with a detailed RCT protocol. Future work will: (i) broaden language and accessibility supports, (ii) extend modules to target academic skills (e.g., numeracy under interference), (iii) incorporate federated learning to personalize models without centralizing raw data, and (iv) publish de-identified benchmarks to accelerate open research.

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