One Step At a Time

Small steps, stronger minds

by

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ABSTRACT

This thesis presents the design and implementation of "One Step at a Time," a web-based cognitive training and monitoring application for patients in the early to mild stages of dementia. The project addresses a gap identified in the existing landscape of dementia-supportive technologies: cognitive training platforms such as BrainHQ, Lumosity, and CogniFit provide structured exercises with adaptive difficulty but rely on generic stimuli, while reminiscence therapy tools such as GreyMatters and InspireD use personal content but lack structured training mechanics or performance tracking. No existing product combines personalized content with structured, adaptive cognitive training designed specifically for dementia populations.

The system comprises six interactive games, three targeting memory and three targeting attention, powered by a personalized content engine called the Memory Kit. A cross-game integration system connects the games into a training ecosystem where one game identifies areas of difficulty and another applies targeted practice.

The methodology involved defining functional and non-functional requirements grounded in the dementia care literature and implementing the system as a client-side React application with localStorage persistence. The prototype was also informally piloted with family and friends to gather early feedback on functionality, usability, personalization, and overall interaction flow.

The pilot suggested that the system was usable, that the main interaction flows worked as intended, and that personalized content made the experience feel more meaningful and distinct from generic cognitive training tools. The pilot focused on feature functionality rather than cognitive performance outcomes. A formal IRB-approved user study and clinical validation with dementia patients remain future work.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

INTRODUCTION

Dementia affects over 55 million people worldwide, and that number is projected to reach 139 million by 2050 (World Health Organization, 2023). The condition progressively deteriorates memory, attention, language, and executive function. Memory impairment tends to appear first, especially in Alzheimer's disease, which accounts for roughly 60 to 70 percent of cases (Livingston *et al.*, 2020). Attention deficits follow, making it increasingly difficult for patients to stay engaged with their surroundings and the people around them.

The practical consequences are significant. Patients gradually lose the ability to recognize family members, recall recent activities, or navigate familiar rooms. These are not abstract cognitive deficits; they are the daily experiences that define a person's sense of identity and independence. The distress extends outward to caregivers and families who witness the decline and often feel unable to help.

A review of the existing literature and available tools (presented in Chapter 2) revealed a critical gap in the current landscape of dementia-supportive technologies. On one side, cognitive training platforms such as BrainHQ, Lumosity, and CogniFit offer structured exercises with adaptive difficulty and progress tracking. BrainHQ in particular has strong evidence from the ACTIVE trial, whose 20-year follow-up found that speed training reduced dementia risk by 25 percent (Rebok *et al.*, 2014). However, these platforms use generic stimuli such as abstract shapes, stock photos, and pattern-matching puzzles. They were not designed for dementia populations, and they have no connection to the patient's actual life.

Additionally, reminiscence therapy tools such as GreyMatters, InspireD, and CIRCA use personal photographs, music, and life story content to support emotional engagement (Astell *et al.*, 2019; Woods *et al.*, 2018). These tools are grounded in person-centered care principles, and evidence shows that they reduce agitation and improve quality of life. However, they are passive: a caregiver presents content, and the patient responds. There is no structured training, no adaptive difficulty, and no mechanism to track whether the patient's cognitive performance is changing over time.

Table 1.1: Competitive Landscape of Existing Cognitive Training and Reminiscence Platforms

Feature	BrainHQ	Lumosity	CogniFit	MindMate	GreyMatters	InspireD
Structured training	✓	✓	✓	✓	–	–
Adaptive difficulty	✓	✓	✓	Partial	–	–
Personal content	–	–	–	–	✓	✓
Dementia-specific	–	–	Partial	✓	✓	✓
Caregiver co-play	–	–	–	Minimal	Partial	Partial
Progress monitoring	✓	✓	✓	Partial	–	–

Table 1.1 illustrates this gap. No single product fills the intersection of personalized content, structured training, adaptive difficulty, and dementia-specific design.

The transfer problem makes this gap more significant. A landmark trial published in NEJM Evidence found that crossword puzzles outperformed computerized brain games on both cognition and daily functioning over 78 weeks (Devanand *et al.*, 2022). The likely explanation is that crosswords draw on existing knowledge rather than requiring patients to learn new abstract skills. A comprehensive meta-analysis confirmed this pattern: near transfer (Hedges' $g = 0.37$) significantly exceeds far transfer ($g = 0.22$), indicating that training on everyday tasks transfers better to real life than training on abstract exercises (Basak *et al.*, 2020).

These findings motivated the development of "One Step at a Time," a cognitive training and monitoring system comprising six interactive games, three targeting memory and three targeting attention, all powered by a personalized content engine called the Memory Kit. The system is designed for patients in the early to mild stages of dementia. The patient's own family photos, daily routines, and personal objects serve as the material for structured, evidence-based cognitive exercises. When a patient practices recognizing a family member's face rather than a stock photo, the training targets the exact skill that dementia is eroding, thereby maximizing the potential for near transfer to daily life.

This thesis makes the following contributions:

1. **A personalized content framework (Memory Kit)** that demonstrates how personal content can serve as the substrate for structured, evidence-based cognitive exercises, bridging the gap between cognitive training platforms and reminiscence therapy tools.

2. **A cross-game integration system** in which one game identifies areas of difficulty and another game applies targeted, evidence-based practice to address them, creating a connected training ecosystem absent from all existing commercial platforms examined.

3. **A structured monitoring data model** that captures per-trial, per-session, and longitudinal performance data with sufficient granularity to support caregiver monitoring and future clinical validation.

It is important to clarify the scope of these claims. This thesis does not claim that the system cures or reverses dementia. The claims are that the system demonstrates a novel integration of personalized content and structured training that no existing product provides, that it captures meaningful performance data for monitoring, and that it is usable and functional as a prototype. The system was explored through an informal pilot with family and friends to gather feedback on functionality, usability, and overall interaction flow, not to measure cognitive performance outcomes with dementia patients. Clinical validation with the target population remains future work, as discussed in Chapter 6.

Chapter 2

LITERATURE REVIEW

This chapter reviews the research that informed the design decisions in the system. The approach was to begin with the literature, identify which techniques have the strongest evidence for dementia populations, and then design games around those techniques. The distinction matters because it separates "brain games with a research veneer" from "research-grounded cognitive training delivered through games." Each section below identifies a specific evidence-based technique, summarizes the supporting research, and explains how it was incorporated into the system design.

Spaced Retrieval Therapy

Spaced retrieval therapy (SRT) is the single most well-supported memory intervention for dementia populations. The technique works by presenting information and then testing recall at progressively expanding intervals. A typical schedule doubles the delay each time: 15 seconds, then 30, then one minute, two minutes, four minutes, and so on. The key insight is that SRT exploits implicit and procedural memory systems, which remain relatively intact in dementia even as explicit episodic memory deteriorates (Camp, 1989).

A systematic review of 34 studies confirmed that SRT can successfully teach face-name associations, object-name associations, and functional skills to people with dementia (Creighton *et al.*, 2024). Haslam and colleagues found that spaced retrieval was significantly more effective than errorless learning alone for name recall, though combining both techniques produced the best results (Haslam *et al.*, 2011). Additionally, a study by Bourgeois and colleagues showed that SRT combined with external memory aids improved the ability of dementia patients to recall personally relevant information across weeks of training (Bourgeois *et al.*, 2003).

What makes SRT particularly suited to a digital application is its mechanical nature. The intervals must be timed precisely. The system must track where each item stands in its interval ladder and resume from that point in the next session. A human therapist can accomplish this with a clipboard and a timer, but a well-designed application can do it with perfect consistency across weeks and months of practice. That consistency is one of the genuine advantages technology offers over manual delivery.

Errorless Learning

Errorless learning (EL) takes a counterintuitive approach to teaching: it prevents the patient from making mistakes in the first place. Instead of presenting a question and letting the patient guess, the system shows the correct answer first and asks the patient to reproduce it. Over time, the support gradually fades.

The rationale is grounded in how dementia affects learning. In healthy cognition, errors are useful because the brain uses the mismatch between an incorrect guess and the correct answer to update its internal model. In dementia, that error-correction mechanism is impaired. Degraded episodic memory means the patient may encode the error itself as the correct response. A patient who guesses "Linda" when the answer is "Sarah" may later recall "Linda" with greater confidence than "Sarah," because the act of producing the wrong answer created a competing memory trace (de Werd *et al.*, 2013).

De Werd and colleagues conducted a landmark review finding that errorless learning was superior to trial-and-error approaches for teaching meaningful daily tasks, with gains maintained at follow-up (de Werd *et al.*, 2013). Tailby and Haslam showed that the advantage of errorless learning over trial-and-error was most pronounced for participants with more severe memory impairments (Tailby and Haslam, 2003).

The vanishing cues technique, a specific variant of EL, starts with full support (the answer is clearly marked) and gradually reduces the scaffolding as the patient demonstrates competence. This technique was implemented directly in Game 3, Familiar Face Spotlight.

Reminiscence Therapy and Personalization

Reminiscence therapy (RT) activates autobiographical and emotional memory networks that tend to be more resilient to neurodegeneration than episodic memory for new information. A meta-analysis of 29 studies with over 3,100 participants confirmed that RT significantly improves cognitive function, quality of life, and depression scores (Woods *et al.*, 2018). A 2025 network meta-analysis of 43 randomized controlled trials further identified RT as the single most effective modality for global cognition across all stages of dementia. Park and colleagues conducted a systematic review and meta-analysis confirming that reminiscence therapy produces statistically significant improvements in cognitive function and quality of life for people with dementia (Park *et al.*, 2021).

The power of personalization extends beyond anecdotal evidence. The Aikomi digital application pilot found that personal photographs and music generated measurably positive responses in dementia patients (Tani *et al.*, 2024). Self-referential processing, the act of relating information to oneself, enhances recognition memory even in populations at genetic risk for Alzheimer's (Grilli *et al.*, 2018). Subramaniam and Woods demonstrated that individual reminiscence therapy using personal life-story materials produced greater improvements in autobiographical memory and mood compared to general reminiscence approaches (Subramaniam and Woods, 2012).

The theoretical foundation rests on the distinction between semantic memory and episodic memory. Semantic memory, particularly for personally significant information such as family members' names and lifelong routines, is often preserved well into moderate dementia. Episodic memory for recent events deteriorates early. By anchoring cognitive training in personally meaningful stimuli, a system can draw on the memory networks that are still relatively intact rather than demanding the formation of entirely new memories.

Multi-Sensory Stimulation

Most cognitive training platforms are entirely visual. Patients look at screens and tap buttons. However, research suggests that engaging multiple sensory channels creates richer, more durable memory traces. A 2025 systematic review confirmed that multi-sensory stimulation combined with cognitive tasks can slow cognitive decline (Calderone *et al.*, 2025). The most effective pairing was visual combined with auditory stimulation. Sessions engaging four or more senses in blocks under 30 minutes were most effective for reducing anxiety. Collier and colleagues found that multi-sensory environments (Snoezelen rooms) combined with structured cognitive activities produced significant improvements in engagement and reduced agitation in moderate-stage dementia patients (Collier *et al.*, 2010).

This finding directly informed the design of Game 5, Sound Garden, which is the only game in the system that uses audio as a primary modality rather than a secondary cue.

Temporal Order Memory

The ability to recall the sequence in which events occurred is one of the most sensitive indicators of early Alzheimer's disease. Bellassen and colleagues found that temporal order memory had the highest predictive power for distinguishing mild AD from normal aging (Bellassen *et al.*, 2012). This makes sequencing tasks valuable not only as training exercises but also as monitoring tools. If a patient's sequencing accuracy starts to decline across sessions, that trend is clinically meaningful. Plancher and colleagues confirmed that temporal order memory deficits appear earlier than spatial memory deficits in the progression from mild cognitive impairment to Alzheimer's disease, reinforcing the diagnostic value of temporal sequencing tasks (Plancher *et al.*, 2010).

Familiar, overlearned sequences such as daily routines are more appropriate for this population than novel sequences, because the patient already has a strong template for what the "right" order should be. The challenge is not learning something new but retrieving and reconstructing something already known. This insight shaped Game 2, Routine Replay Timeline.

Interference Resistance and Dual-Task Training

Failure to recover from proactive semantic interference is one of the earliest detectable markers of Alzheimer's disease (Loewenstein *et al.*, 2017). In practical terms, when new information interferes with old information (or vice versa), dementia patients struggle to separate them. Dual-task training, which requires simultaneous motor and cognitive engagement, produces large effects on global cognition (SMD = 1.00 for motor-cognitive dual-task) and outperforms either motor or cognitive training alone. Schwenk and colleagues demonstrated that dual-task training combining cognitive challenges with motor activities improved both cognitive performance and gait stability in older adults with mild cognitive impairment (Schwenk *et al.*, 2010).

These findings were applied in two ways within the system. Game 6, Lost-and-Found Locator, deliberately inserts a distractor task between the moment an object is placed and the moment the patient must recall its location, simulating the real-world experience of being interrupted between putting down keys and needing to find them. Game 4, Distraction-Resistant Recognition, adds visual distractors to a sustained attention task, training the ability to maintain focus when the environment is noisy.

The Transfer Problem

The transfer problem is the strongest criticism of existing cognitive training platforms. Near transfer (Hedges' $g = 0.37$) significantly exceeds far transfer ($g = 0.22$) (Basak *et al.*, 2020). Training someone to match abstract patterns faster does not reliably help them remember where they put their medication.

The implication for design is that training tasks should mirror the actual cognitive challenges patients face daily. Recognizing a family member's face, recalling the order of morning activities, remembering where keys were placed: these are the precise skills that dementia erodes. Training with the patient's own content maximizes the likelihood that improvements carry over to daily life. This principle informed every design decision in the system.

Design Guidelines for Dementia-Accessible Interfaces

Research on interaction design for dementia populations provides specific, actionable guidance (Joddrell and Astell, 2016; Klimova and Maresova, 2017). Simple tap is the most accessible interaction modality. Touch targets should be at least 44 by 44 pixels with visible borders. Visual design should use high contrast with warm hues, and blue should be avoided for critical interactive components because Alzheimer's affects color discrimination primarily in the blue-green range (Wijk *et al.*, 1999). Information density should be minimal: one concept per screen section, no hidden menus, and no reliance on working memory between screens. Astell and colleagues reviewed 54 studies involving people with dementia and touchscreen technology, concluding that simplified interfaces with large touch targets and minimal navigation depth were most successful (Astell *et al.*, 2020).

Perhaps most importantly, when task demands are either too high or too low, patients promptly lose willingness to continue (Joddrell and Astell, 2016). Adaptive difficulty that maintains an optimal challenge zone is not a supplementary feature but is essential for sustained engagement.

Existing Games and Cognitive Training Tools Reviewed

Several existing cognitive training tools were reviewed during the design phase to understand what features are currently available and where gaps exist. These tools provided both inspiration and contrast for the design of the system presented in this thesis.

Figure 2.1: BrainHQ exercise interface showing a pattern-matching task using generic visual stimuli.

BrainHQ offers over 25 exercises targeting speed, memory, attention, navigation, people skills, and intelligence. The exercises are well-designed and backed by the ACTIVE trial (Rebok *et al.*, 2014). However, all stimuli are generic, and the platform was designed for healthy aging populations rather than dementia patients specifically.

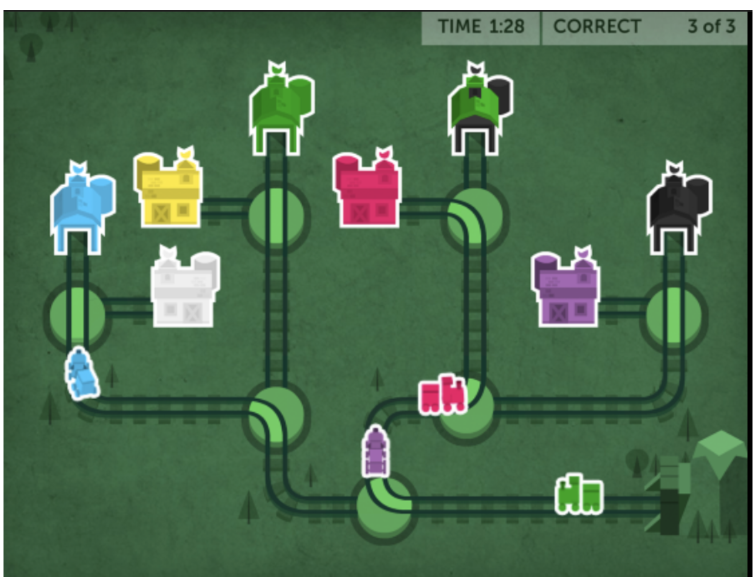

Figure 2.2: Lumosity game interface demonstrating adaptive difficulty using abstract stimuli.

Lumosity provides a game-based approach to cognitive training with adaptive difficulty. The interface is polished and engaging, but like BrainHQ, it relies entirely on generic stimuli. Progress resets daily with no cross-session persistence of personalized content.

Figure 2.3: GreyMatters reminiscence therapy interface showing personal photo browsing.

GreyMatters and InspireD represent the reminiscence therapy approach. These tools effectively use personal content such as photographs and music to support emotional engagement and social interaction. However, they lack structured cognitive training mechanics, adaptive difficulty, or performance tracking.

The review of these tools confirmed the gap identified in the literature: no existing product combines personalized content with structured, adaptive cognitive training designed specifically for dementia populations.

Chapter 3

DESIGN PROPOSAL AND REQUIREMENTS

This chapter describes the requirements and design of every component in the system: the Memory Kit personalization engine and all six games. For each game, the chapter explains the core mechanic, the evidence-based technique it implements, how it uses personal content, and the state diagram showing its game flow. The system targets patients in the early to mild stages of dementia, where cognitive decline is present but patients retain the ability to interact with touchscreen interfaces with minimal assistance.

Functional Requirements

The following functional requirements guided the design and implementation of the system:

1. The system shall allow caregivers to upload and manage personal content (family photos, personal objects, daily routines) through a guided setup wizard (Memory Kit).

2. The system shall provide six cognitive training games, three targeting memory and three targeting attention, each grounded in at least one evidence-based therapeutic technique.

3. The system shall implement spaced retrieval therapy with expanding intervals that persist across sessions.

4. The system shall implement errorless learning by presenting the correct answer before the patient can make an error on first exposure, and by providing

supportive feedback rather than punitive responses on incorrect answers.

5. The system shall implement vanishing cues that reduce scaffolding across sessions as the patient demonstrates competence.

6. The system shall support cross-game integration, where faces identified as difficult in Game 3 (Familiar Face Spotlight) are automatically flagged for additional practice in Game 1 (Spaced Retrieval Album).

7. The system shall capture per-trial performance data including accuracy, response latency, interval level, cue level, and signal detection metrics (hits, misses, false alarms, correct rejections).

8. The system shall implement adaptive difficulty that advances when accuracy exceeds 85 percent and provides additional scaffolding when accuracy drops below 50 percent.

9. The system shall display aggregated performance data through a progress dashboard with accuracy trends, per-game performance, and milestone indicators.

10. The system shall operate without personalized content by falling back to generic placeholder content when the Memory Kit has not been configured.

Non-Functional Requirements

1. The system shall operate as a client-side web application with no backend server, requiring no account creation, password management, or internet connectivity after initial load.

2. All personal data (photographs, performance metrics) shall be stored locally on the device using the browser's localStorage API to avoid cloud privacy concerns.

3. All interactive elements shall use touch targets of at least 60 pixels with visible borders, following dementia-accessible interface guidelines.

4. The system shall avoid the color blue for critical interactive components, as Alzheimer's disease affects color discrimination primarily in the blue-green range (Wijk *et al.*, 1999).

5. The system shall support text scaling (100%, 125%, 150%) and high-contrast mode.

6. All feedback shall use warm, encouraging language with no punitive framing (no "Wrong," no red X indicators).

7. The system shall be accessible on tablets and desktop browsers without installation beyond cloning the repository and running a local development server.

Design Philosophy

The central design principle is that personal content should serve as the substrate for evidence-based cognitive exercises. This is distinct from using generic stimuli with personalized difficulty, and distinct from using personal photos in a passive slideshow. The system combines both approaches in a way that neither existing cognitive training platforms nor reminiscence therapy tools currently offer.

Every game embeds at least two gold-standard therapeutic techniques while drawing its stimuli from the patient's own life. The system targets two cognitive domains, memory and attention, with three games each.

A deliberate choice was made about emotional tone. Every interaction is framed positively. When a patient answers incorrectly, the system does not display "Wrong" or flash a red indicator. Instead, it presents a message such as "Let me remind you, this is Sarah, your daughter" alongside the correct answer. Progress is celebrated without being patronizing. The system is designed to function as a supportive companion rather than a clinical testing instrument, even though it captures structured performance data underneath.

The Memory Kit

The Memory Kit is the first component a caregiver encounters when opening the application. It is a guided setup wizard, not a game, where the caregiver uploads the personal content that powers all six games. The Memory Kit collects four types of content: 5 to 10 family photos with names, relationships, and optional facts about each person; 5 to 10 photos of personal objects such as keys, medication, or glasses, each with a label and typical location; 1 to 2 daily routines represented as ordered sequences of steps; and optional category preferences for fallback content packs.

Games are designed to operate without the Memory Kit being fully configured. If no personal photos are uploaded, games fall back to placeholder content: generic avatars with labels such as "Person A," common household objects, and a standard morning routine. This design ensures that caregiver setup is encouraged but never blocks the patient from using the system. Full fallback content mode was not implemented in the current prototype and remains future work; however, the architecture supports it. The personalization is the value proposition, not a gate.

Memory Domain Games

Game 1: Spaced Retrieval Album

The Spaced Retrieval Album is the flagship game. It implements spaced retrieval therapy using the patient's own photos as stimuli, combined with errorless learning for incorrect responses. No commercial application reviewed during the literature survey combines these two techniques with personalized content.

Requirements

- The game shall present a personal photo and ask "Who is this?" or "What is this?"
- The patient shall select from two or three answer options via tap interaction.
- On a correct response, the same item shall return at the next expanding interval: 15 seconds, 30 seconds, 1 minute, 2 minutes, 4 minutes.
- On an incorrect response, the system shall display the correct answer with supportive language and reset to the last successful interval (one step back, not a full restart).
- Between retrieval prompts, a filler activity (tapping blue circles on screen) shall occupy the interval duration, serving as both a time-filler and a micro attention exercise.
- Each item's interval level shall persist across sessions. If a patient reached the two-minute interval for a particular photo yesterday, the next session shall resume at that level.
- The game shall log per-trial accuracy, response latency, and interval level for each item.

Research Basis

This game is grounded in the systematic review of 34 studies confirming SRT can teach face-name associations (Creighton *et al.*, 2024), the evidence that errorless learning prevents error reinforcement (de Werd *et al.*, 2013), and the finding that combining SRT with EL produces optimal outcomes (Haslam *et al.*, 2011).

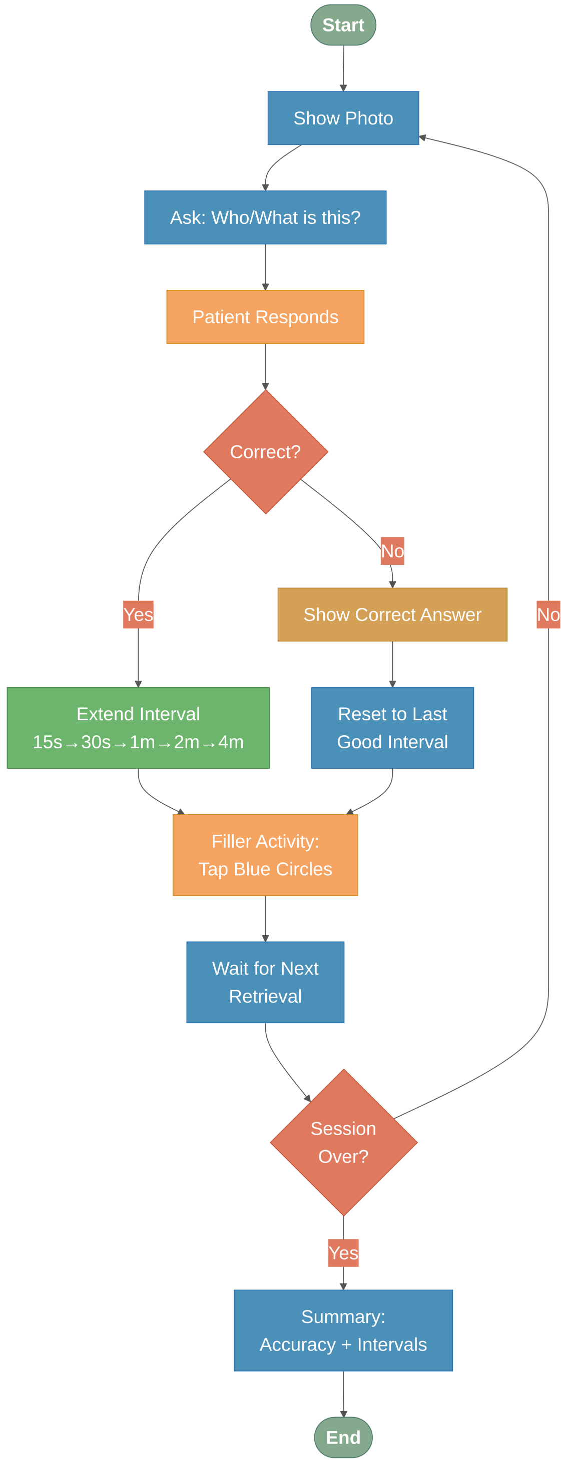

Figure 3.1: State diagram for Game 1: Spaced Retrieval Album, showing the expanding-interval retrieval loop with errorless learning feedback.

Game 2: Routine Replay Timeline

This game asks the patient to reconstruct daily activities by placing shuffled activity icons into the correct temporal sequence. The design incorporates a backward reconstruction approach: the patient reviews completed tasks rather than planning future ones. This twist was specifically suggested by Professor Tuzmen during the design review phase.

Requirements

- The game shall load the patient's daily routine (or a generic preset) and present the steps in shuffled order.
- The patient shall place activity icons into the correct temporal sequence using a tap-to-place interaction (primary) with drag-and-drop available as a secondary option.
- After all icons are placed, the system shall check the sequence against the correct order and ask verification questions such as "Which came first?" and "What came after breakfast?"
- Difficulty shall scale by increasing the number of steps (from 3 to 6+) and reducing hints.
- The combined round score shall weight sequence accuracy at 60 percent and question accuracy at 40 percent.

The primary interaction was designed as tap-to-place rather than drag-and-drop because the dementia interaction design literature identifies simple tap as the most accessible modality (Joddrell and Astell, 2016). Drag-and-drop requires fine motor control that may be compromised in this population.

Research Basis

This game is grounded in the finding that temporal order memory has the highest predictive power for distinguishing mild AD from normal aging (Bellassen *et al.*, 2012). No commercial platform reviewed uses autobiographical daily-life cognition as a training paradigm.

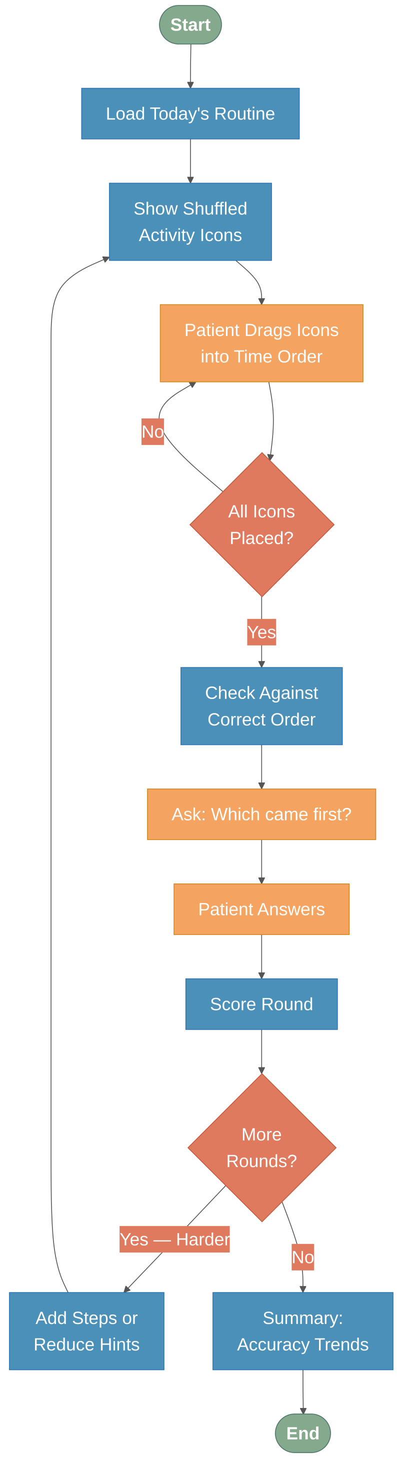

Figure 3.2: State diagram for Game 2: Routine Replay Timeline, showing the backward reconstruction flow with adaptive difficulty.

Game 3: Familiar Face Spotlight

Familiar Face Spotlight combines face recognition with vanishing cues, a gold-standard dementia technique that is rarely implemented in commercial applications. A personal photo appears and the patient answers a question by tapping the correct option: the person's name, their relationship, or a fact about them.

Requirements

- The first time a face appears, the correct answer shall be highlighted with a visible green border and label (errorless learning).
- Over subsequent sessions, the highlighting shall fade through four cue levels: Level 0 (full highlight), Level 1 (subtle tint), Level 2 (first letter only), Level 3 (no cues).
- Cue levels shall change between sessions, never within a single session, to provide a stable experience during gameplay.
- When a patient struggles with a face (incorrect answer or high cue level required), the face shall be flagged for extra practice in Game 1 (Spaced Retrieval Album) via a shared data layer.
- When the flagged face reaches a stable two-minute interval in Game 1, the flag shall be automatically cleared.
- The game shall log recognition accuracy and cue level per face per session.

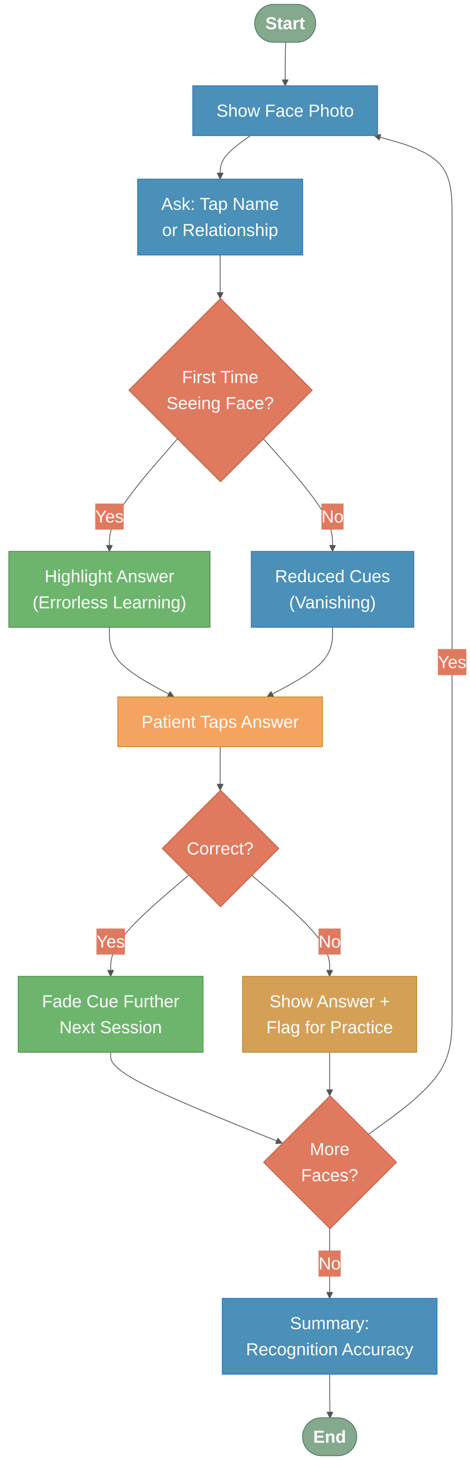

Figure 3.3: State diagram for Game 3: Familiar Face Spotlight, showing the progressive reveal and clue-based recognition flow with integration into Spaced Retrieval Album.

Attention Domain Games

Game 4: Distraction-Resistant Recognition

A stream of images appears one at a time, each displayed for approximately two seconds. The patient is given one target (for example, "Tap only when you see Grandma"). At the easiest level, the stream is slow with no distractors. At higher levels, the stream speeds up and visual distractors appear: floating colored dots around the screen edges, background color shifts, and denser image sequences.

Requirements

- The game shall present images in a continuous stream at configurable speeds.
- The game shall capture four signal-detection metrics: hits (correctly tapping the target), misses (failing to tap the target), false alarms (tapping a non-target), and correct rejections (correctly withholding a tap for a non-target).
- A high false alarm rate shall indicate impulsive responding; a high miss rate shall indicate declining sustained attention.
- Difficulty shall adapt by adjusting stream speed and distractor complexity.
- The target image shall be drawn from the patient's personal content (Memory Kit photos).

This is a go/no-go sustained attention paradigm, one of the most validated attention tasks in cognitive neuroscience. The distinguishing feature is that the target is a personally meaningful image rather than a generic stimulus.

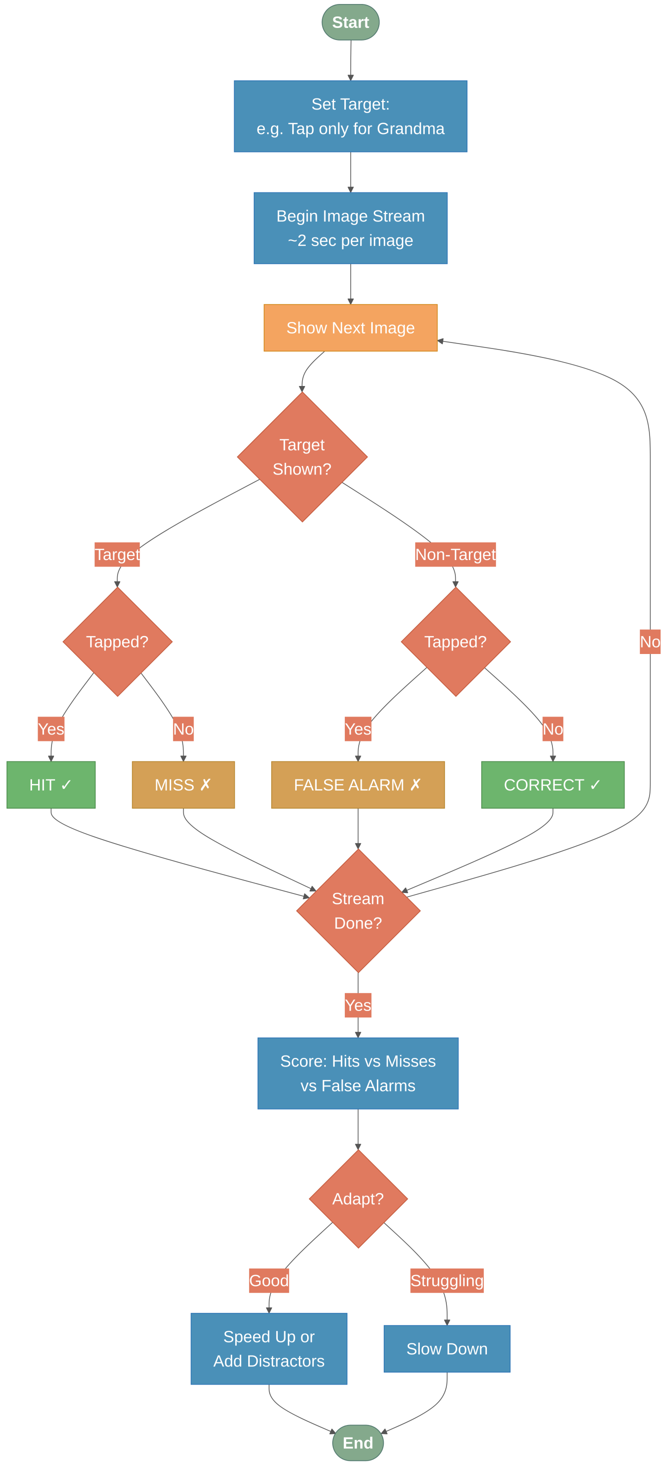

Figure 3.4: State diagram for Game 4: Distraction-Resistant Recognition, showing the go/no-go signal detection paradigm with adaptive difficulty.

Game 5: Sound Garden

Sound Garden is the most novel game in the system. It is the only game that uses audio as a primary training modality, and no commercial cognitive training platform reviewed has an equivalent feature.

Requirements

- Phase 1 (Scene Building): Individual sounds shall play one at a time and the patient shall tap to place each sound in a visual scene (beach, park, or kitchen).
- Phase 2 (Selective Listening): Multiple sounds shall play simultaneously and the patient shall tap only when hearing a specific target sound.
- Phase 3 (Memory Quiz): The patient shall answer questions about what sounds were in the scene and where they were placed.
- All sounds shall be generated programmatically through the Web Audio API using oscillators, filters, and noise generators (no backend audio hosting required).
- All three phases shall be scored together for a combined session score.
- Difficulty shall scale by adding more sounds or introducing acoustically similar distractors.

Research Basis

Multi-sensory stimulation combined with cognitive tasks has been shown to slow cognitive decline, with visual-plus-auditory identified as the most effective pairing (Calderone *et al.*, 2025). The selective listening phase specifically targets interference resistance, one of the earliest detectable AD markers (Loewenstein *et al.*, 2017).

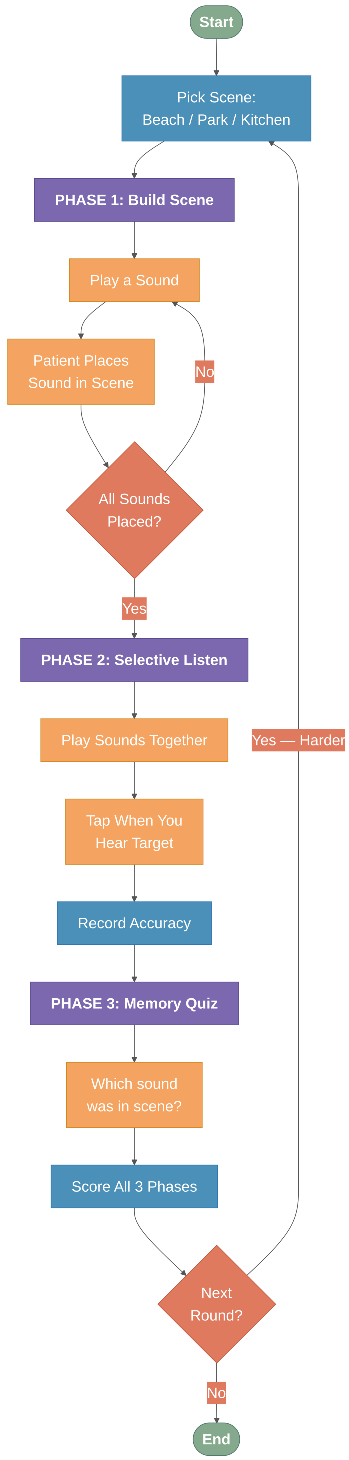

Figure 3.5: State diagram for Game 5: Sound Garden, showing the three-phase flow (Scene Building, Selective Listening, Memory Quiz).

Game 6: Lost-and-Found Locator

Object misplacement is one of the most common and distressing daily experiences for dementia patients.

Requirements

- The screen shall display a simplified room layout with four to six labeled, tappable zones (table, shelf, drawer, counter).
- A personal object (photographed and uploaded in the Memory Kit) shall briefly appear in one zone and then disappear.
- A distractor task (counting colored dots or matching shapes) shall run between the viewing and recall phases as deliberate interference.
- The patient shall tap the zone where the object was placed.
- Difficulty shall scale by adding more objects per round (from one to four), extending the distractor duration, and subtly rearranging the room layout at higher levels.
- Incorrect responses shall highlight the correct zone briefly with no punitive feedback.

Research Basis

This game is grounded in dual-task training research, which produces large effects on global cognition, and in the principle that ecologically valid tasks transfer better to daily functioning than abstract exercises (Basak *et al.*, 2020).

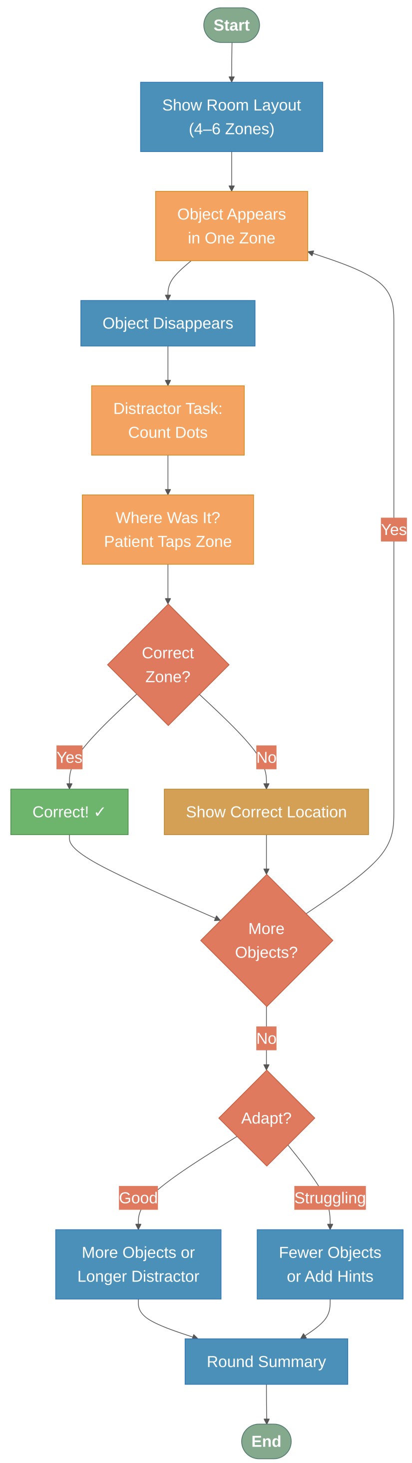

Figure 3.6: State diagram for Game 6: Lost-and-Found Locator, showing the object-placement, distractor, and recall loop with adaptive difficulty.

Cognitive Domain Mapping

Table 3.1: Mapping of Games to Cognitive Domains, Skills, and Evidence-Based Techniques

Game	Domain	Skills Targeted	Techniques Used
1. Spaced Retrieval Album	Memory	Retention, face-name	SRT, errorless learning
2. Routine Replay Timeline	Memory	Sequencing, episodic recall	Temporal ordering
3. Familiar Face Spotlight	Memory	Recognition, social memory	Vanishing cues, EL
4. Distraction-Resistant Recognition	Attention	Sustained, inhibition	Go/no-go paradigm
5. Sound Garden	Attention	Selective, auditory	Multi-sensory, interference
6. Lost-and-Found Locator	Attention	Spatial, working memory	Dual-task, interference

Table 3.1 summarizes how each game maps to a specific cognitive domain, the skills it targets, and the evidence-based techniques it implements. Each game addresses a distinct combination, ensuring coverage across both memory and attention domains while avoiding redundancy.

Adaptive Difficulty

All six games share a common adaptive difficulty framework. The system tracks a rolling accuracy window based on recent performance. When accuracy exceeds 85 percent, the game advances one difficulty level. When accuracy drops below 50 percent, difficulty decreases or additional scaffolding is provided. A cooldown period between changes prevents oscillation. The system never punishes errors; incorrect responses always trigger a gentle display of the correct answer followed by encouraging feedback.

A limitation of the current adaptive difficulty engine is that it was not validated with the user during testing. The thresholds (85 percent for advancement, 50 percent for support) are based on the optimal challenge zone principle from the dementia interaction design literature (Joddrell and Astell, 2016), but clinical testing would be required to determine whether these thresholds are appropriate for the target population. This is discussed further in the Limitations section of Chapter 5.

Chapter 4

IMPLEMENTATION

This chapter describes the technical implementation of the system, including the technology stack, system architecture, user interface design, and game-specific implementation details. All user-facing screens are documented with screenshots and explanations of their content and purpose. A video demonstration of the complete system is available at `https://www.youtube.com/watch?v=hHqPiF9_ou0&t=1s`.

Technology Stack

The system is implemented as a client-side web application with no backend server. The frontend uses React 18 with TypeScript for type-safe component architecture, built and served through Vite. The user interface is constructed with shadcn/ui components on top of Radix UI primitives, styled with Tailwind CSS. Lucide React provides the icon system. Animations use the Motion library for transitions and visual feedback. Data visualization on the progress dashboard uses Recharts. All data is persisted locally in the browser using the localStorage API.

A client-side-only architecture was chosen for two reasons. First, dementia patients and their caregivers should not need to create accounts, manage passwords, or depend on internet connectivity. The system should work the moment someone opens it on a tablet. Second, storing personal photographs and health-related performance data locally avoids the privacy concerns that come with cloud storage, which is especially important for a vulnerable population.

Product Access and Hosting

The application source code is publicly available on GitHub at `https://github.com/skarande3/One_step_at_a_time`. During the pilot, testers accessed the product by cloning the repository to their local machines and running the application through the Vite development server using the following commands:

Listing 4.1: Commands to run the application locally

```
git clone https://github.com/skarande3/One_step_at_a_time.git
cd One_step_at_a_time
npm install
npm run dev
```

The application then runs on `localhost:5173` and can be accessed through any modern web browser. No installation, account creation, or internet connectivity is required beyond the initial setup. This approach was chosen to maintain the client-side-only architecture and to avoid the complexity and cost of cloud deployment for a thesis prototype. A production deployment (e.g., on Vercel or Netlify) would be straightforward and is discussed as future work.

The thesis defense presentation slides are available at `https://drive.google.com/file/d/1EbaYhSS07g5DOvavH1A2bj-ahVWO012o/view?usp=sharing`. For questions or assistance with the codebase, refer to the README file in the GitHub repository.

System Architecture

The application has four primary layers, shown in Figure 4.1. The Memory Kit layer stores caregiver-uploaded content and provides it to all six games through a shared interface. The Game Engine layer handles stimulus presentation, user input, scoring, and state transitions for each game. The Performance Tracker captures per-trial data from every session. The Adaptive Difficulty Engine reads accumulated performance data and adjusts game parameters.

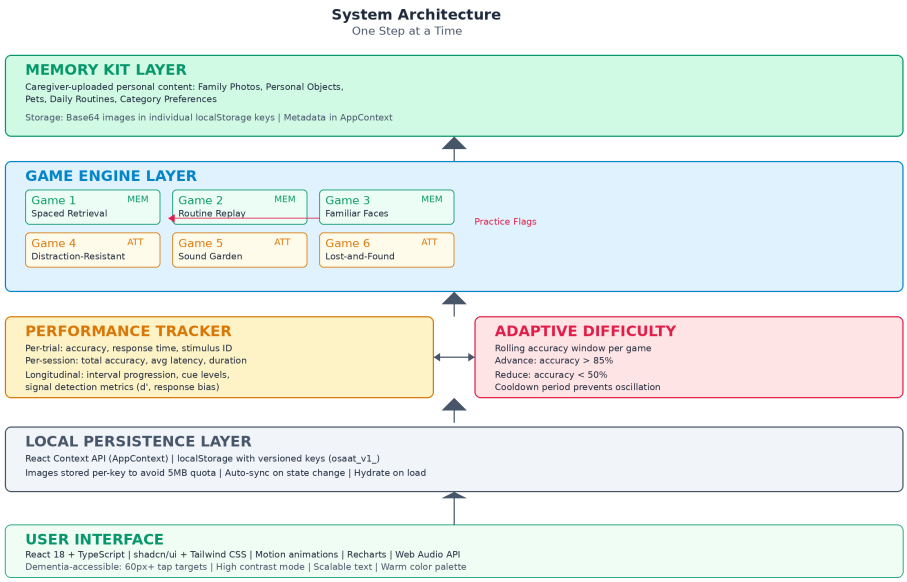

Figure 4.1: System architecture showing the four-layer design: Memory Kit, Game Engine, Performance Tracker, and Adaptive Difficulty Engine. The Memory Kit layer stores caregiver-uploaded personal content (photos, objects, routines) and distributes it to all six games. The Game Engine manages stimulus presentation, user input, scoring, and state transitions. The Performance Tracker captures per-trial data including accuracy, response latency, interval levels, cue levels, and signal detection metrics. The Adaptive Difficulty Engine reads accumulated performance data and adjusts game parameters using a rolling accuracy window. The Local Persistence Layer synchronizes all state to localStorage with versioned keys to support future schema migrations.

Global state is managed through React Context API with a centralized AppContext provider. This context handles the Memory Kit data, per-game progress, session history, milestones, settings, and the cross-game practice flag system. A custom persistence layer syncs state to localStorage on every change and hydrates from localStorage on load, using a versioned storage key (`osaat_v1_`) to support future schema migrations.

Images presented a specific technical challenge. Base64-encoded photos can be large, and storing all of them in a single localStorage entry would exceed the browser's approximately 5MB quota. This was solved by storing each image under its own localStorage key, with the main state blob holding only the metadata (name, relationship, facts) and a reference to the image key.

Listing 4.2: Image storage separation in the persistence layer

```
// Store image under its own key
const imageKey = `osaat_v1_img_${photo.id}`;
localStorage.setItem(imageKey, photo.imageDataUrl);

// Main state stores only metadata + reference
const photoMeta = {
  id: photo.id,
  name: photo.name,
  relationship: photo.relationship,
  facts: photo.facts,
  imageKey: imageKey
};
```

The full source code for the persistence layer and all game components is available in the GitHub repository referenced above and documented in Appendix A.

User Interface Design and Navigation

The application uses React Router for client-side routing. This section documents all major user-facing screens with screenshots and explanations of their content and purpose. The system contains approximately 18 distinct screens organized into setup, gameplay, and monitoring flows.

Welcome Screen

The Welcome Screen presents different interfaces depending on whether the user is new or returning. First-time users see an onboarding prompt directing them to set up the Memory Kit. Returning users see their weekly session streak, a Start Session button, and quick access to progress tracking.

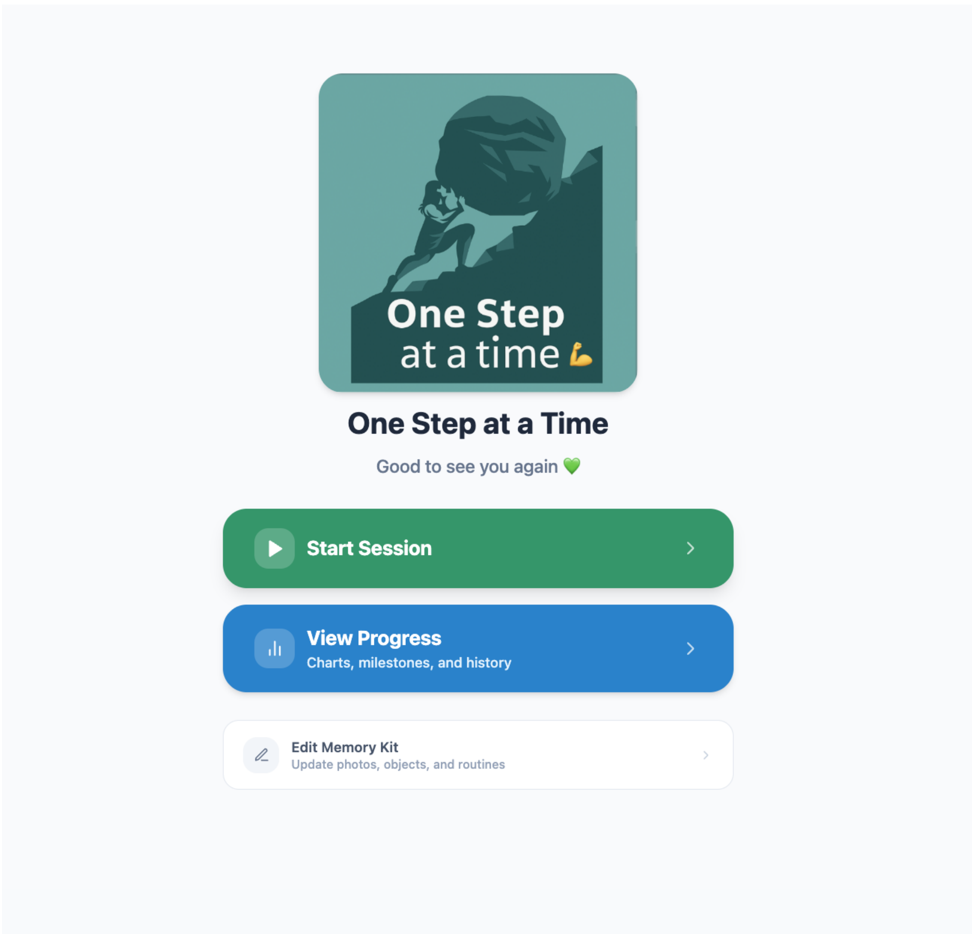

Figure 4.2: Welcome Screen showing the returning user view with session streak counter, Start Session button, View Progress link, and Edit Memory Kit link. The session streak encourages daily engagement by tracking consecutive days of use.

Game Selection Screen

The Game Selection Screen displays all six games as cards organized by cognitive domain. Memory games have green accents; Attention games have amber accents. Each card shows the game name, a category badge, a brief description, and a play button.

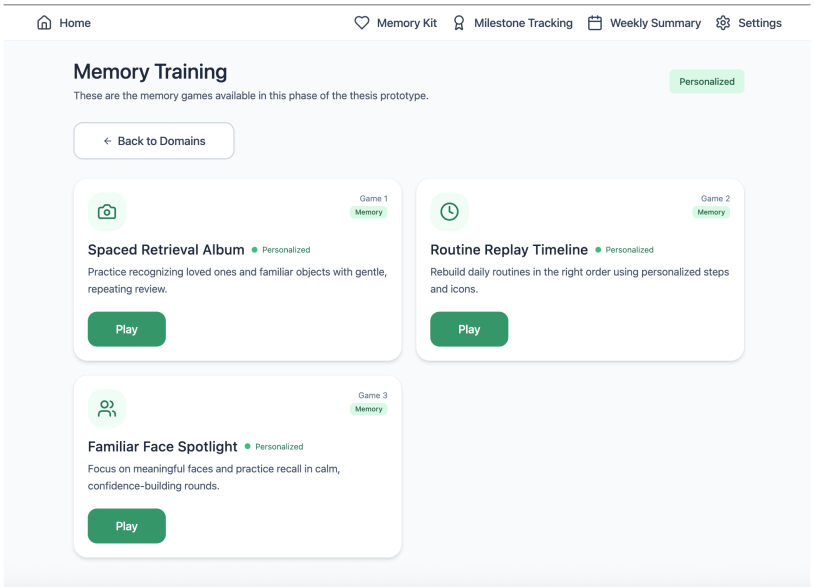

Figure 4.3: Game Selection Screen (Memory) showing memory-focused games with green accents. Each card includes the game name, domain badge, brief description, and a play button.

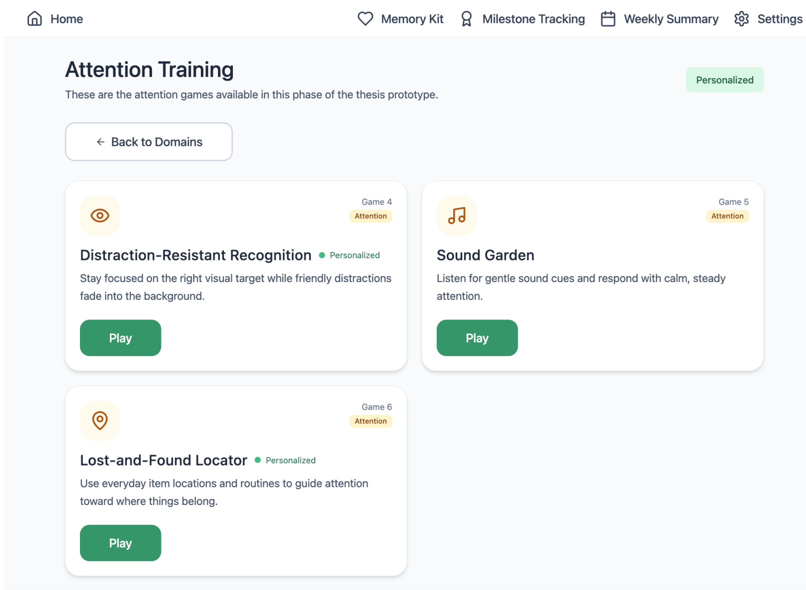

Figure 4.4: Game Selection Screen (Attention) showing attention-focused games with amber accents. Each card includes the game name, domain badge, brief description, and a play button.

Memory Kit Setup Screens

The Memory Kit is a multi-step wizard that guides caregivers through uploading family photos, personal objects, pets, daily routines, and category preferences. Photo uploads use the browser's file input API, and each image is converted to a base64 data URL using the FileReader API.

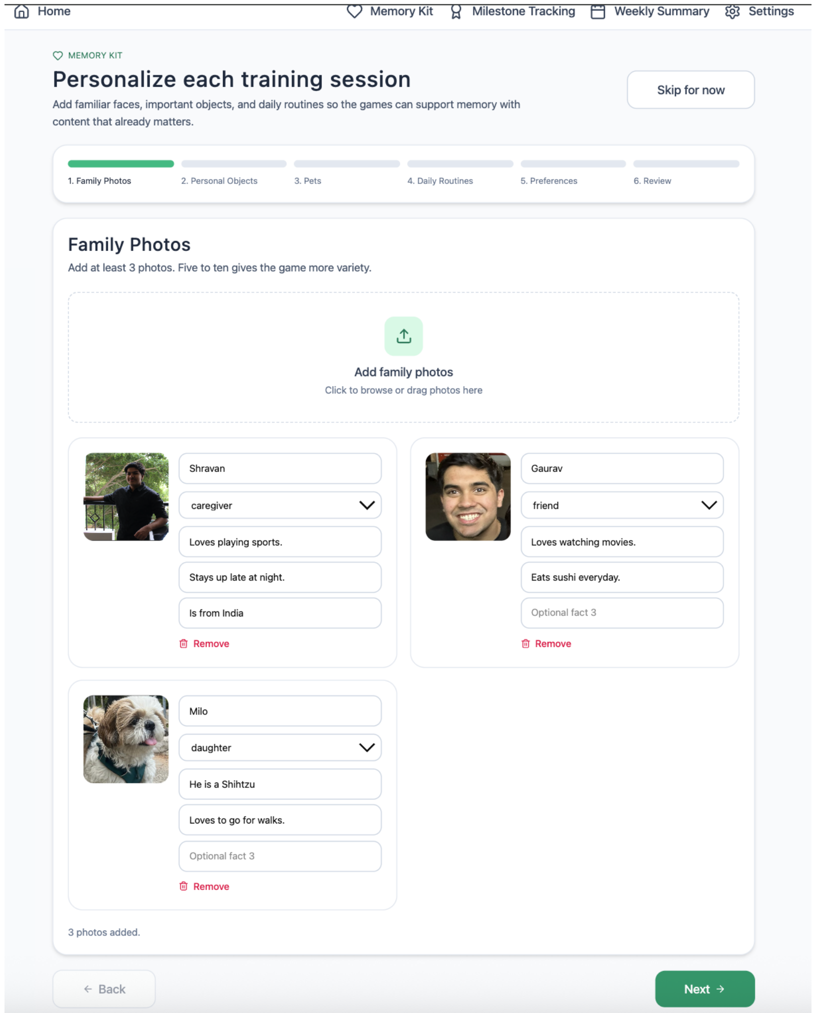

Figure 4.5: Memory Kit setup wizard showing the family photos step. Each uploaded photo includes fields for the person's name, relationship (e.g., daughter, friend), and optional facts. The progress bar at the top shows the current step in the multi-step wizard.

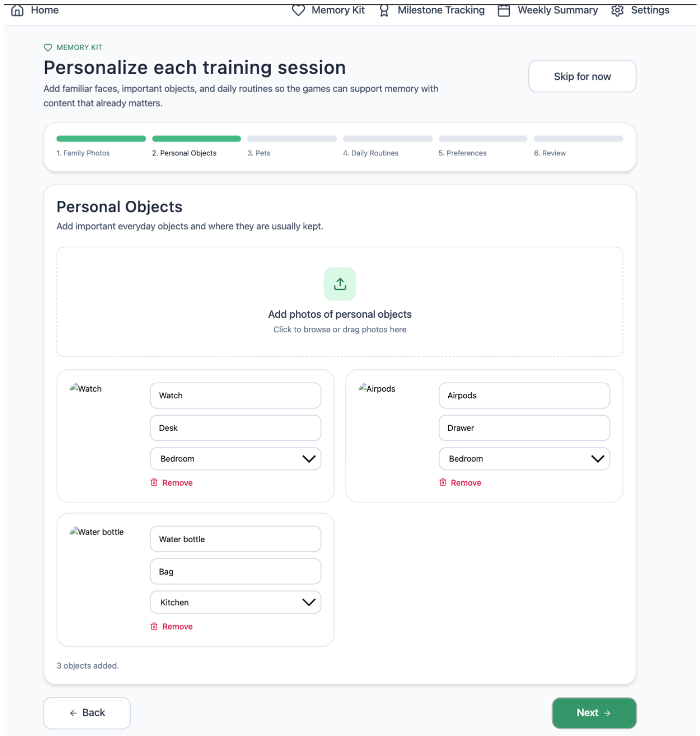

Figure 4.6: Memory Kit setup wizard showing the personal objects.

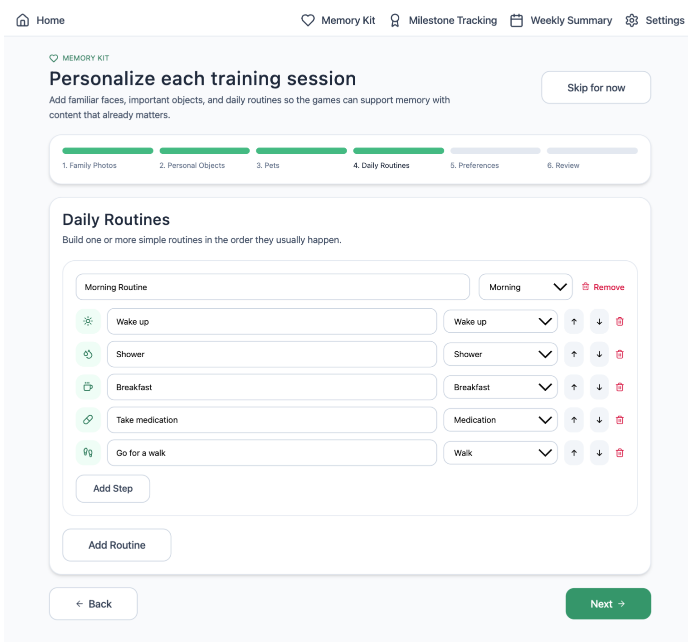

Figure 4.7: Memory Kit setup wizard showing the daily routines step where caregivers define ordered activity.

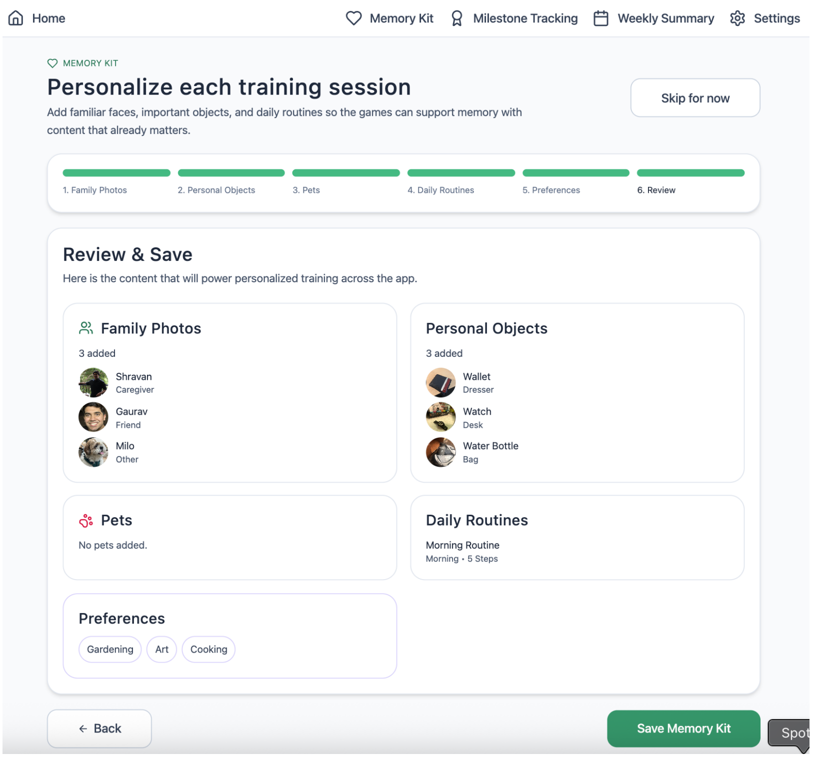

Figure 4.8: Memory Kit review step showing a summary of all uploaded content before finalizing the setup.

Gameplay Screens

Each game has a distinct gameplay interface designed to minimize cognitive load while providing clear feedback. All games use large touch targets (minimum 60 pixels), high-contrast text, and warm color tones.

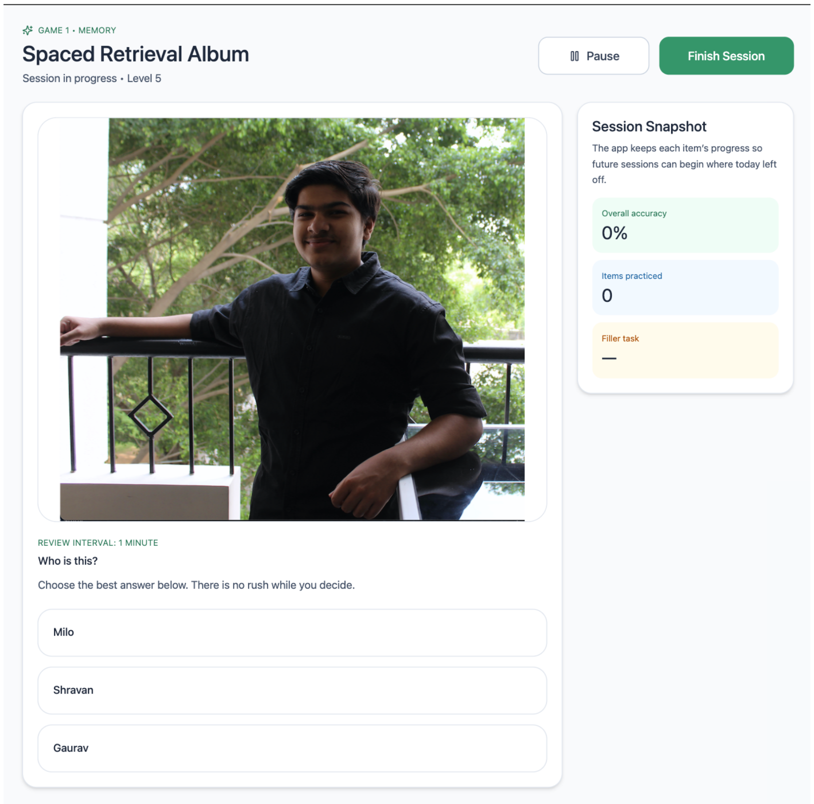

Figure 4.9: Spaced Retrieval Album gameplay showing a personal photo prompt with the question "Who is this?", three answer options, the current retrieval interval indicator, and the session snapshot panel showing accuracy and items practiced.

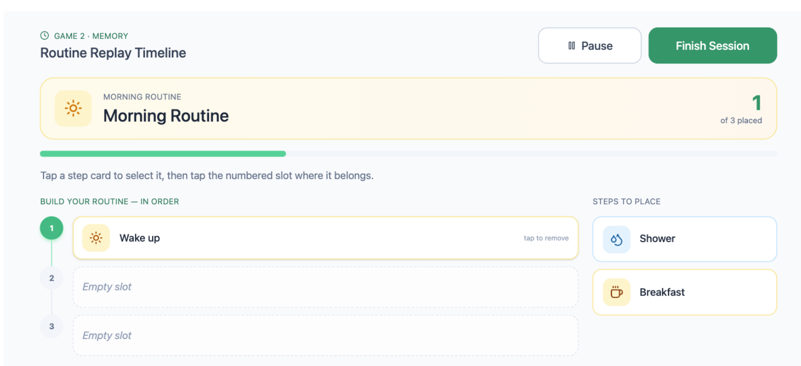

Figure 4.10: Routine Replay Timeline gameplay showing shuffled activity icons on the left and empty timeline slots on the right. The patient taps an icon and then taps a slot to place it in the correct temporal position.

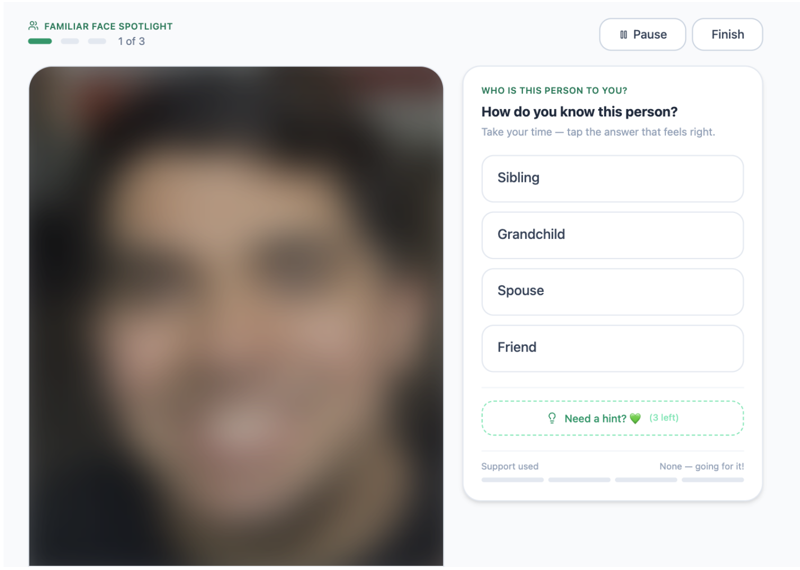

Figure 4.11: Familiar Face Spotlight gameplay showing a face photo with answer options. At Level 0 (first encounter), the correct answer is highlighted with a green border, implementing errorless learning.

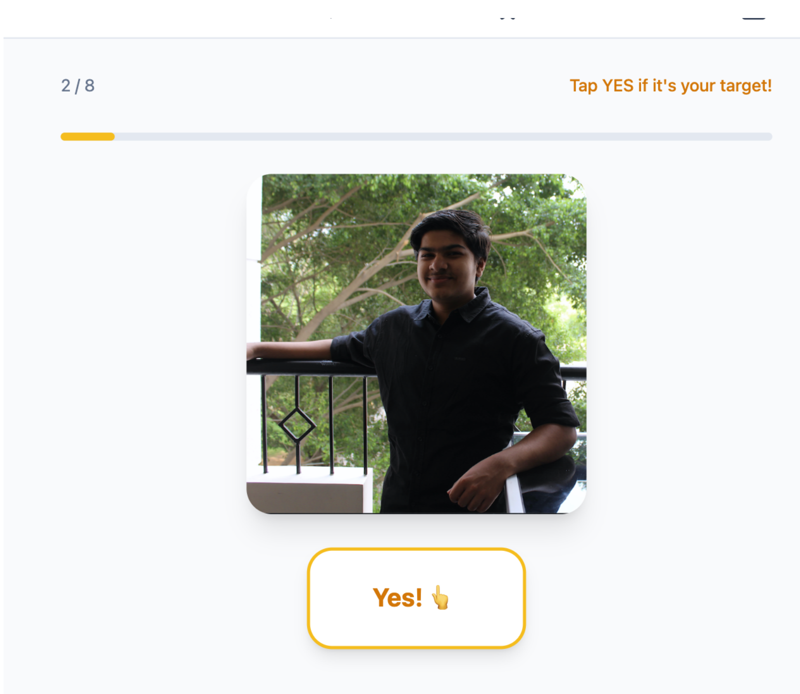

Figure 4.12: Distraction-Resistant Recognition gameplay showing the target prompt ("Tap only when you see Grandma") and the current image in the stream. The response area tracks hits, misses, and false alarms in real time.

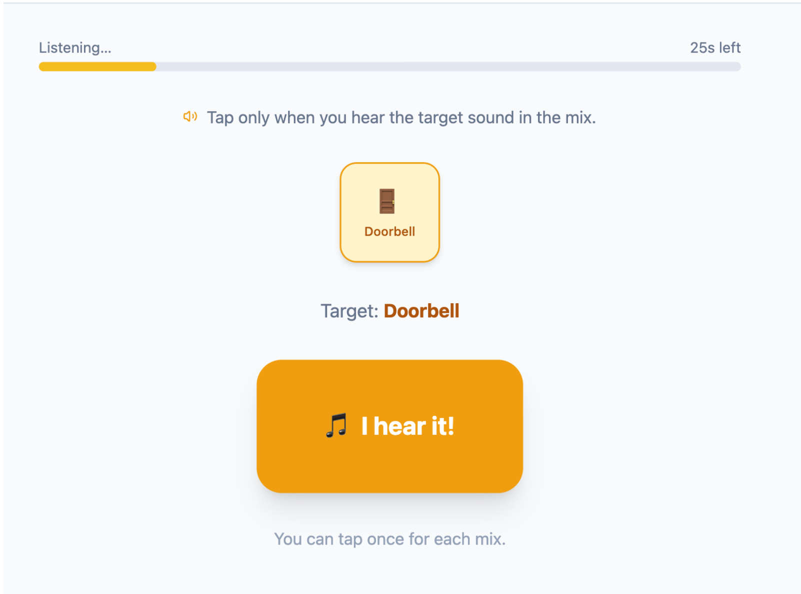

Figure 4.13: Sound Garden gameplay during Phase 1 (Scene Building) showing the beach scene with areas where sounds can be placed. The current sound ("Doorbell") is playing, and the patient taps the sound when they hear it.

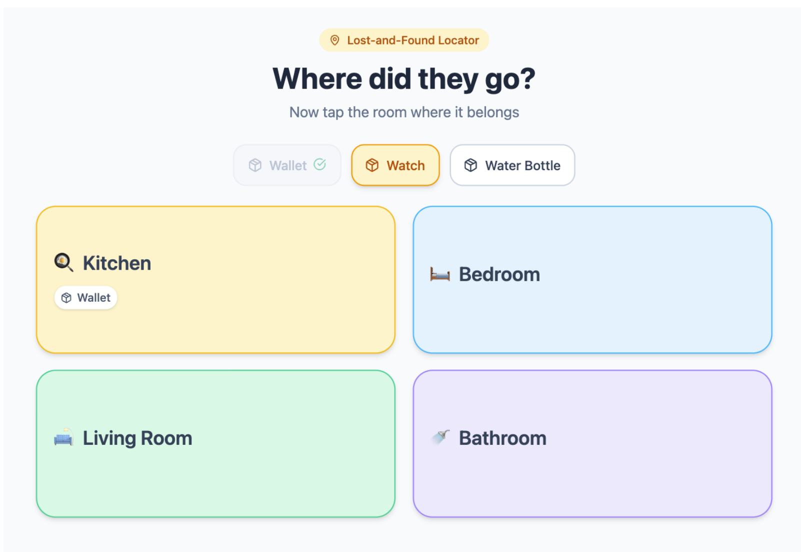

Figure 4.14: Lost-and-Found Locator gameplay showing the simplified room layout with labeled zones (table, shelf, drawer, counter).

Patient Feedback Screen

After completing a session, the patient is presented with a simplified visual feedback screen designed to be easy to understand and encouraging. The screen highlights key performance metrics using clear visuals and minimal text. A "Next" button allows navigation to a more detailed caregiver summary screen.

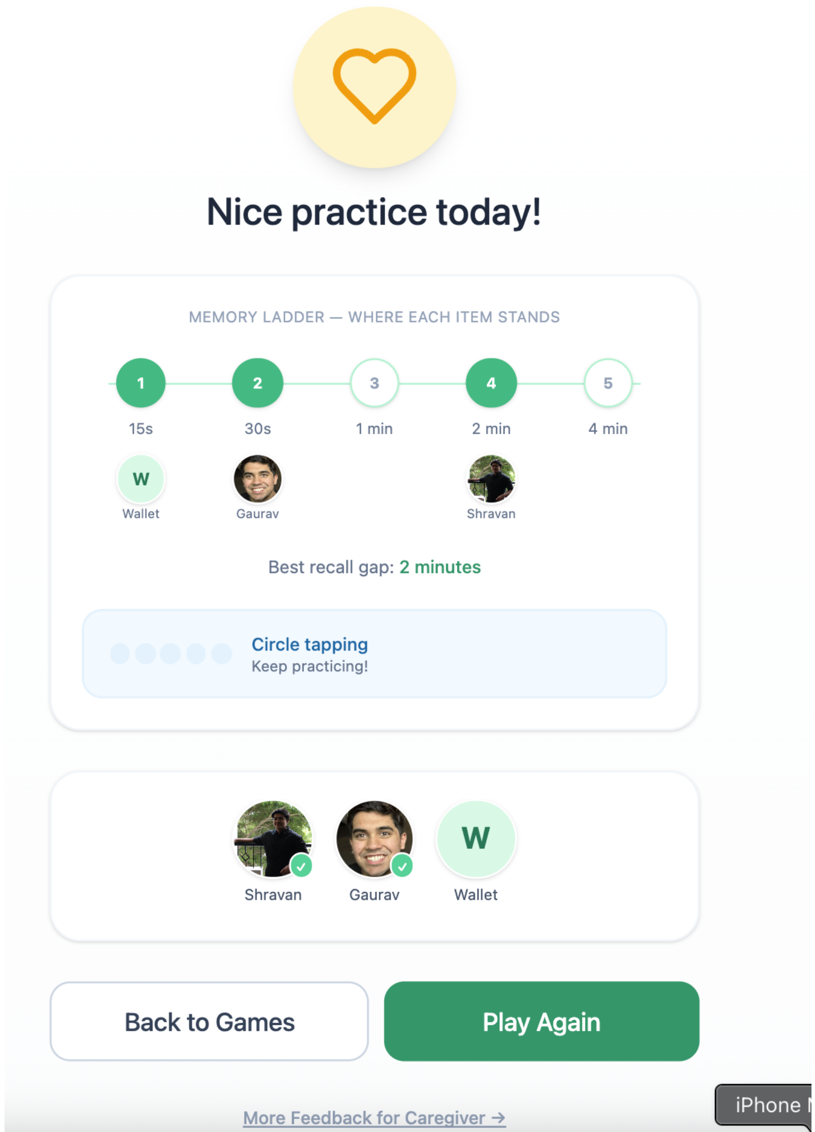

Figure 4.15: Patient Feedback screen showing a simplified visual summary of session performance using clear visuals and minimal text. A "Next" button directs users to the caregiver summary for detailed insights.

Caregiver Summary Dashboard

The Caregiver Summary Dashboard provides a detailed view of patient performance by combining session metrics with AI-generated insights. It presents accuracy, response patterns, errors, and progress over time, along with real-time personalized feedback explaining performance and suggesting improvements. This design enables caregivers to quickly interpret trends and identify challenges.

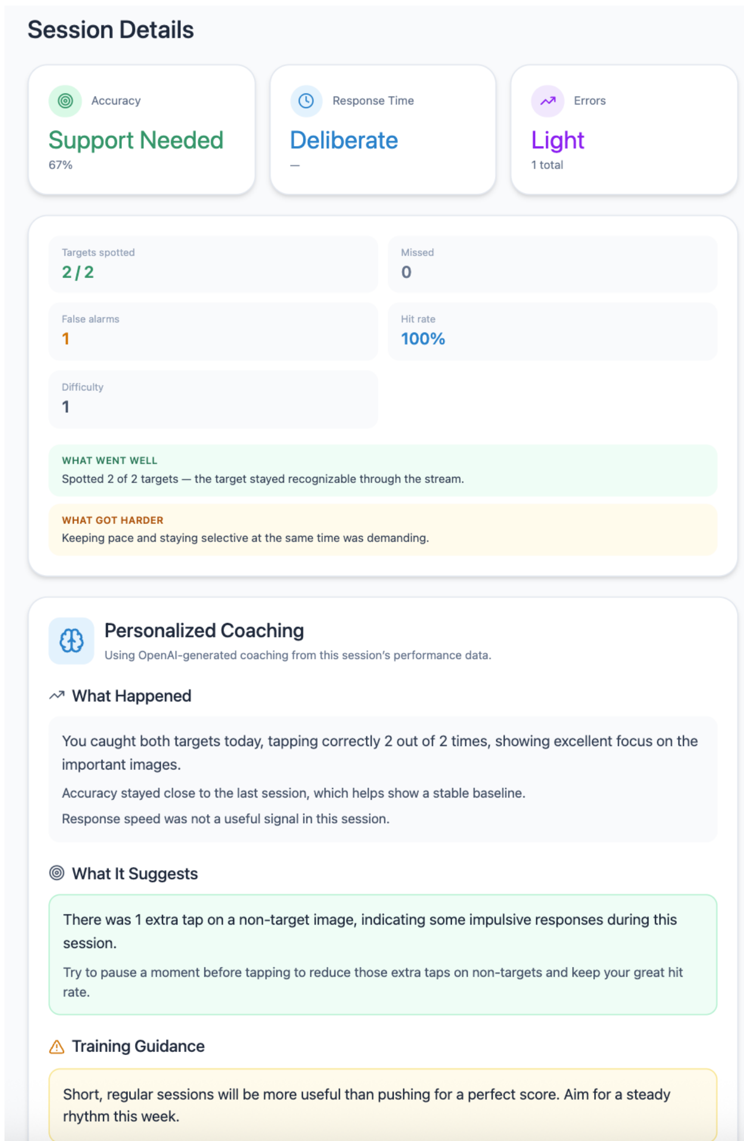

Figure 4.16: Caregiver Summary Dashboard showing session analytics, performance trends, and game-wise breakdowns.

The Accuracy Trend chart was chosen because it provides a straightforward visualization of whether the patient's performance is stable, improving, or declining across sessions. This type of line chart is standard in cognitive training platforms such as BrainHQ and CogniFit, making it familiar to caregivers who may have experience with other tools. The Reaction Time Trend chart tracks response latency, which is clinically relevant because slowing response times can indicate cognitive decline even when accuracy remains stable. The Milestone Tracking system provides positive reinforcement through achievement markers, which is consistent with the errorless learning philosophy of celebrating progress without emphasizing failures.

Weekly Summary Screen

The Weekly Summary Screen provides a consolidated view of the patient's activity over the past week, highlighting overall engagement and performance trends.

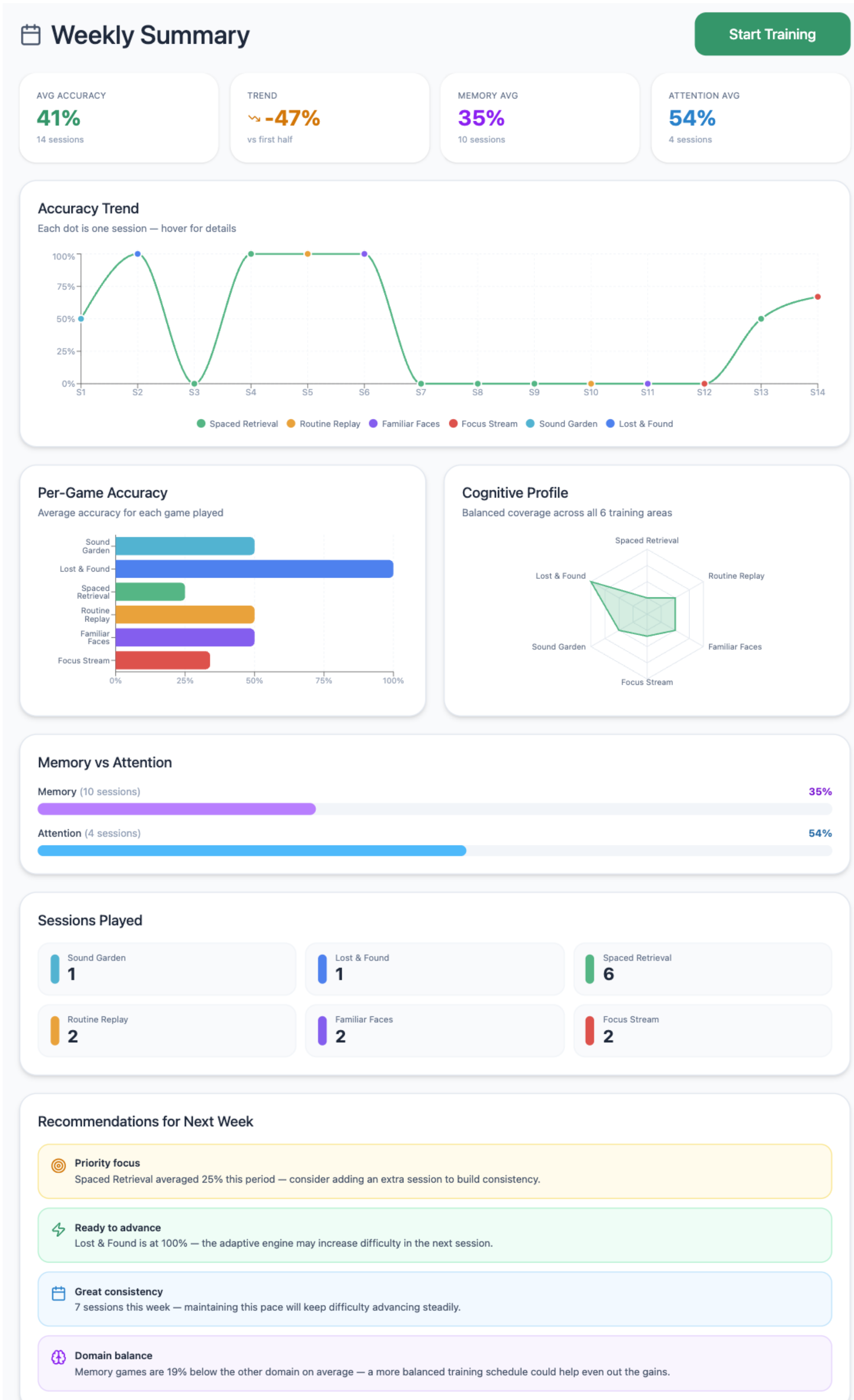

Figure 4.17: Weekly Summary screen showing total sessions, games played, and average accuracy over the past week.

Milestone Tracking Screen

The Milestone Tracking Screen provides an overview of the patient's progress through key achievements, helping reinforce engagement and long-term usage.

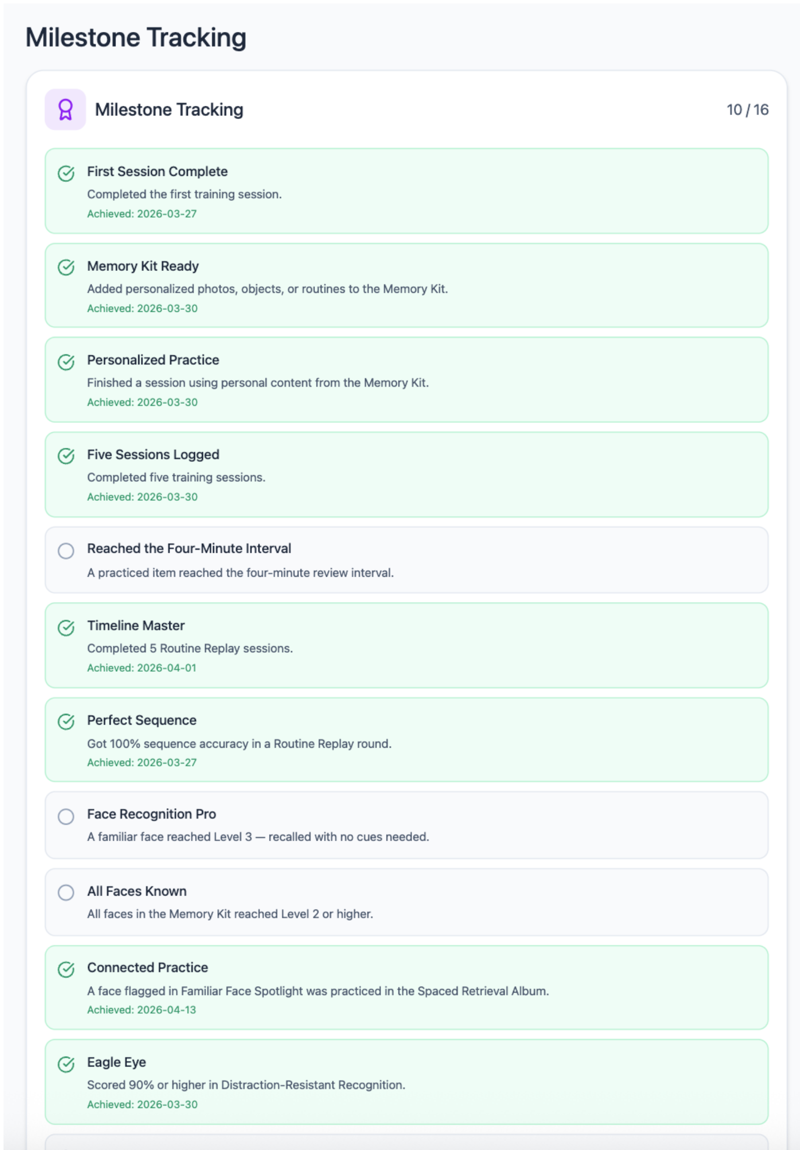

Figure 4.18: Milestone Tracking screen showing progress across achievement milestones, with completed items marked and dated.

Settings Screen

The Settings Screen allows caregivers to configure accessibility and session preferences, ensuring the interface remains usable and adaptable to the patient's needs.

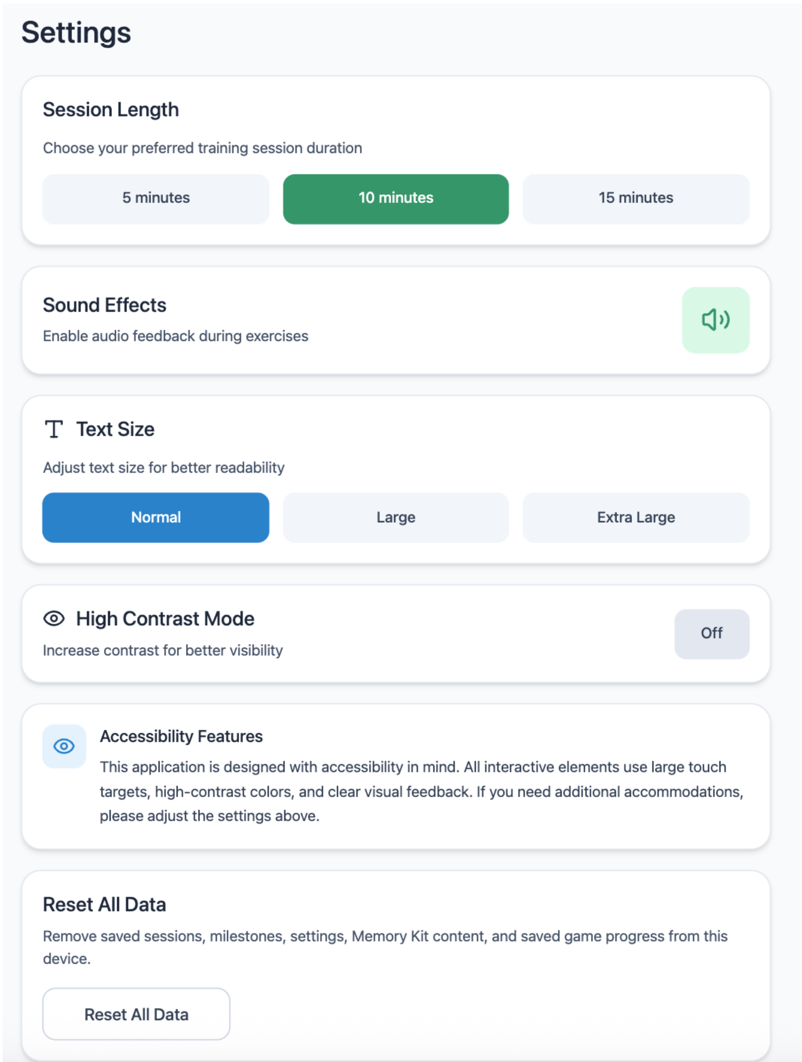

Figure 4.19: Settings screen showing accessibility options such as text size, contrast mode, and session preferences.

Game Implementation Highlights

Spaced Retrieval Album

The interval ladder uses five levels (15s, 30s, 1m, 2m, 4m). Cross-session persistence stores each item's current interval index, total attempts, correct attempts, and last practice date. The filler activity uses the Motion library for smooth circle entrance and exit animations.

Routine Replay Timeline

The tap-to-place interaction works by selecting a card (tap once to highlight) and then tapping a timeline slot to place it. Verification questions are generated dynamically from the routine sequence. The combined round score weights sequence accuracy at 60 percent and question accuracy at 40 percent.

Familiar Face Spotlight

The vanishing cue system is a per-face state machine with four levels stored in localStorage. The cross-game practice flag system uses a shared key that both Game 3 and Game 1 can read and write.

Distraction-Resistant Recognition

The image stream uses React state transitions with AnimatePresence for crossfade animations. Response detection tracks the timestamp when each image appears and compares it against tap timestamps to calculate response times.

Sound Garden

Audio synthesis uses the Web Audio API. Each sound is generated programmatically: ocean waves use low-pass filtered white noise with slow amplitude modulation, bird songs use rapid sine tone sequences at 1000 to 3000Hz, and church bells use decaying sine waves at 440Hz. The three-phase game flow is managed by a state machine in the React component.

Lost-and-Found Locator

Room layouts are rendered as positioned rectangles with labeled, tappable zones. The distractor task component is reusable, with two variants: a dot-counting task and a color-matching task.

Use of AI in Development

AI tools were used throughout the development process, and transparency about their role is important. Claude (by Anthropic) was used as an accelerated development tool for writing React components, debugging TypeScript errors, and generating boilerplate code. The design decisions, game mechanics, research grounding, and architecture were developed independently; the speed of implementation was significantly aided by AI-assisted code generation.

The approach involved writing detailed prompts describing exactly what each game should do, including the state machine, data models, UI requirements, and accessibility constraints. The generated code was then reviewed, tested, and modified. Some prompts produced usable output on the first iteration. Others required substantial refinement. For example, the Web Audio API synthesis for Sound Garden required several rounds of prompt refinement before the generated sounds were distinct enough to be usable in a game context.

Development methodology is documented in Appendix B.

Accessibility

The interface follows evidence-based guidelines for dementia populations. All interactive elements use touch targets of at least 60 pixels with visible borders. High-contrast mode is available in Settings. Text can be scaled between 100, 125, and 150 percent. The color palette uses warm hues (emerald for memory, amber for attention, slate for neutrals) and avoids blue for critical interactive components (Wijk *et al.*, 1999).

Chapter 5

PILOT FEEDBACK AND FUNCTIONAL VALIDATION

This chapter describes the evaluation methodology, success criteria, usability metrics, and results. The evaluation was conducted as an informal pilot study with family and friends to validate the feature functionality of the system. It was not designed to measure cognitive performance outcomes with dementia patients. A formal, IRB-approved user study with the target population remains future work (Chapter 6).

Evaluation Scope and Approach

An informal pilot study was conducted to validate the performance and correctness of the functional requirements defined in Chapter 3. The pilot focused on whether the system functions as designed, captures data correctly, and provides a usable interface, rather than on whether it produces cognitive improvements in dementia patients.

A group of 10 family members and friends volunteered to participate in the pilot. Participants accessed the application by cloning the GitHub repository and running it locally on their own devices. Each participant completed five structured pilot checks remotely from a location of their choosing and provided informal feedback on usability, engagement, and content preference.

Pilot Feedback Focus

Usability encompasses multiple measurable dimensions. The following usability metrics were considered for this evaluation, along with an indication of which were measured and which were out of scope for the current testing cycle:

Metrics Measured

- **Effectiveness (Task Success Rate):** Whether participants could complete each pilot check successfully without external assistance. Measured as binary pass/fail for each pilot check.

- **Efficiency (Time on Task):** How long it took participants to complete the Memory Kit setup. Measured in minutes.

- **Error Rate:** The number of navigation errors or confusion points encountered during each pilot check. A confusion point was defined as a moment where the participant paused for more than five seconds or tapped a non-interactive element.

- **Engagement (Satisfaction):** Participant-reported likelihood of returning to the application, rated on a 1-to-5 Likert scale.

- **Content Preference (Differentiation):** Whether participants preferred personalized content over generic fallback content, assessed through a comparative task and survey response.

- **Data Persistence:** Whether performance data (accuracy, response latency, interval levels, cue levels, signal detection metrics) persisted correctly across browser refreshes and sessions.

Metrics Out of Scope

The following metrics are standard in dementia usability research but were out of scope for the current testing cycle because the participants were friends and family without dementia symptoms, and the evaluation period was too short to assess longitudinal effects:

- **Learnability:** Performance improvement over repeated trials and number of prompts needed during first use. This requires multiple sessions over days or weeks with the target population.
- **Memorability:** Ability to repeat tasks after a delay without relearning. This requires longitudinal testing with dementia patients.
- **Cognitive Load:** Measured via adapted scales (e.g., NASA-TLX) or observations of confusion and frustration in the target population.
- **Accessibility and Interaction Metrics:** Touch accuracy, missed taps, and readability issues specific to older adults with motor or visual impairments.
- **Safety and Error Recovery:** Whether patients can recover from critical errors without caregiver intervention.
- **Caregiver/Observer Feedback:** Structured caregiver ratings of usability during observed sessions with dementia patients.
- **Adaptive Difficulty Validation:** Whether the 85%/50% accuracy thresholds for difficulty adjustment are appropriate for the target population. The adaptive difficulty engine was implemented and functionally tested, but its calibration for dementia patients was not validated.

Pilot Goals

The system was evaluated across four measurable dimensions. These criteria were intentionally scoped to match what a Barrett Honors thesis can reasonably demonstrate.

1. **Usability:** Participants can set up the Memory Kit, navigate to games, play sessions, and interpret results without external assistance. Measured via task completion rates, time on task, error frequency, and confusion points.
2. **Engagement:** Participants find the application engaging enough to express willingness to return. Measured via Likert-scale ratings and identification of most/least engaging games.
3. **Monitoring Validity:** The system reliably captures within-task performance changes over time. Verified by confirming that per-trial accuracy, response latency, interval progression, cue level progression, signal detection metrics, and adaptive difficulty changes persist correctly across sessions and browser refreshes.
4. **Differentiation:** The system provides a qualitatively different experience when using personalized content compared to generic content. Measured via participant preference in a comparative task.

Pilot Checks

Pilot Check 1: Memory Kit Setup. The participant uploads three family photos with names and relationships, adds two personal objects with locations, and creates one daily routine with at least four steps. Success criteria: (a) the participant completes all steps without requesting help; (b) the setup takes less than 10 minutes; (c) the participant encounters fewer than two confusion points.

Pilot Check 2: Game Navigation. The participant navigates from the Welcome Screen to the Game Selection Screen, selects Game 1, plays one round (minimum one retrieval prompt and one filler activity), views the session summary, and returns to the home screen. Success criteria: (a) the participant completes the full navigation loop; (b) no unintended screens are visited; (c) the total time from Welcome Screen to return is under three minutes.

Pilot Check 3: Full Session Completion. The participant plays a complete five-minute session of Game 1 (Spaced Retrieval Album) from the first photo prompt through the session summary. Success criteria: (a) the session is completed without the participant choosing to quit early; (b) the session summary screen displays correct accuracy and interval data; (c) the participant can identify at least one piece of information from the summary.

Pilot Check 4: Cross-Game Flag Validation. The participant plays Game 3 (Familiar Face Spotlight) and deliberately answers one face incorrectly. The participant then plays Game 1 (Spaced Retrieval Album). Success criteria: (a) the incorrectly answered face from Game 3 appears in Game 1's item queue; (b) the face appears within the first three items presented, confirming priority scheduling.

Pilot Check 5: Settings and Accessibility. The participant opens Settings, changes text size to 150 percent, enables high-contrast mode, and changes session length from 5 to 10 minutes. The participant then navigates back to any game screen. Success criteria: (a) text size visually increases across all screens; (b) high-contrast mode applies correctly; (c) the next game session runs for 10 minutes rather than 5.

Pilot Observations

Usability Results

Across the pilot sessions, family and friends were generally able to complete the main interaction flows without assistance. The Memory Kit setup was completed smoothly, navigation between screens was straightforward, and the cross-game flag behavior and settings changes functioned as intended. A few participants suggested that the photo upload step could benefit from a clearer progress indicator.

Engagement Results

The pilot feedback suggested that the application was engaging enough for repeated use. Sound Garden was often described as the most novel and engaging experience, while Spaced Retrieval Album felt the most clearly therapeutic and purposeful. Routine Replay Timeline also generated helpful design suggestions, including the idea of adding icons alongside text labels.

Monitoring Validity Results

Monitoring validity was verified by running multiple sessions across different days and confirming that the system correctly records and persists: per-trial accuracy with timestamps, response latency in milliseconds, interval level progression for spaced retrieval items across sessions, cue level progression for vanishing cues items across sessions, signal detection metrics (hits, misses, false alarms, correct rejections) for the attention games, and adaptive difficulty level changes. The Progress Dashboard correctly aggregated this data into line charts showing accuracy over time, bar charts showing per-game performance, and milestone progress indicators. The data structures were verified to be consistent across browser refreshes, confirming that localStorage persistence works as intended.

Differentiation Results

Testers completed one session using the Memory Kit (with their own uploaded photos) and one session using the generic fallback content. Pilot feedback consistently favored the personalized version over the generic fallback content. Participants often remarked that seeing familiar faces and personally meaningful content made the experience feel more motivating and more distinct from generic brain-training tools. Representative feedback included statements such as seeing a real person's face increased motivation to respond correctly, and the generic version felt indistinguishable from other brain training applications while the personalized version felt specifically designed for the user.

This informal finding is directionally consistent with the reminiscence therapy literature showing that personally meaningful content increases engagement and motivation (Tani *et al.*, 2024; Park *et al.*, 2021).

Limitations

This evaluation has clear limitations that must be acknowledged directly.

Pilot study with family and friends. The pilot was conducted informally with family and friends who have no dementia symptoms. They do not represent the target population of patients in the early to mild stages of dementia. The pilot cannot determine whether the interface is usable for patients with actual cognitive impairment, motor difficulties, or visual processing changes associated with dementia. A formal, IRB-approved user study with the target population is planned as future work.

Sample size. The sample size of 10 is too small for statistical inference. The results are indicative of feature functionality but cannot be generalized.

Evaluation period. The evaluation was conducted over a single session per participant. Longitudinal metrics such as learnability (performance improvement over repeated trials), memorability (ability to use the app again after a delay), and long-term engagement could not be assessed.

No clinical outcomes. No clinical trial was conducted. The evaluation cannot claim therapeutic efficacy or cognitive improvement. The pilot check focused on validating that the system's features function correctly, not on whether those features produce measurable cognitive benefits.

Adaptive difficulty engine. The adaptive difficulty engine was implemented and its mechanics were verified to function correctly (difficulty advances above 85 percent accuracy, additional scaffolding appears below 50 percent accuracy). However, whether these thresholds are appropriate for dementia patients was not tested. The engine's calibration for the target population remains future work.

Usability metrics not measured. Several standard usability metrics for dementia populations (learnability, memorability, cognitive load, touch accuracy, safety/error recovery, and structured caregiver observation) were out of scope for this testing cycle, as described in Section 5.2.2.

localStorage constraints. The approximately 5MB storage quota required architectural workarounds for photo storage (storing each image under an individual key rather than in one state blob). This approach is sufficient for a prototype but would not scale to production use.

What the pilot does demonstrate is that the system functions as designed: it captures structured performance data, supports personalized content, implements evidence-based techniques, provides a usable interface for the pilot testers, and is preferred over generic alternatives. These observations are informal and would need to be validated through a formal, IRB-approved study.

Chapter 6

CONCLUSION AND FUTURE WORK

Summary of Contributions

This thesis presented One Step at a Time, a system that occupies a space no existing product fills. It bridges the gap between structured cognitive training platforms, which use generic stimuli, and reminiscence therapy tools, which use personal content but lack training structure. The system makes three contributions.

First, the Memory Kit framework demonstrates that personal content can serve as the substrate for structured, evidence-based cognitive exercises. Family photos become spaced retrieval items. Daily routines become temporal sequencing tasks. Personal objects become spatial memory training targets. The architecture supports fallback to generic content when the Memory Kit has not been configured, ensuring that personalization enhances the experience without creating a dependency.

Second, the cross-game integration between Familiar Face Spotlight and Spaced Retrieval Album creates a connected training ecosystem. When one game identifies a weak area, another game applies the most evidence-based technique to address it. This was demonstrated concretely: faces flagged in Game 3 appear with priority in Game 1, and the flag clears automatically when the patient reaches a stable retrieval interval. This capability is absent from every existing commercial platform examined.

Third, the monitoring data model captures per-trial, per-session, and longitudinal data with enough granularity to support caregiver monitoring and future clinical validation. Accuracy, response latency, interval progression, cue level changes, and signal detection metrics are all tracked across sessions. Current reminiscence therapy tools do not offer this level of structured performance data.

Lessons Learned

Several findings emerged during development and testing that have implications for future work in this space.

Tap-based interaction is essential for accessibility. The Routine Replay Timeline was initially implemented with drag-and-drop as the sole interaction modality. Testing revealed that even participants without motor impairments occasionally failed to complete drag gestures. Adding tap-to-place as the primary modality, consistent with recommendations in the dementia interaction design literature (Joddrell and Astell, 2016), resolved this issue. This finding underscores the importance of validating interaction modalities with representative users rather than relying solely on design guidelines.

Errorless learning principles extend beyond game mechanics. The errorless learning framework influenced not only the game design but also every piece of feedback text in the application. Replacing deficit-focused language ("Incorrect," "You missed 1") with strength-focused alternatives ("Let me remind you," "You remembered 4 out of 5") aligns with person-centered care principles and reduces the risk of discouraging continued engagement.

AI-assisted development requires precise specifications. The use of Claude for code generation was effective when detailed specifications were provided, including state machine definitions, data models, and accessibility constraints. Vague or under-specified prompts produced generic output that did not meet the research-grounded requirements. This suggests that AI code generation tools are most valuable when the developer has already completed the design work and needs to accelerate implementation.

Client-side storage architectures have practical limits. The localStorage quota of approximately 5MB required architectural workarounds for photo storage. While sufficient for a prototype, this constraint would prevent scaling to production use. A backend with cloud storage would be necessary for any deployment beyond a thesis demonstration.

Future Work

Formal IRB-approved user study. The most immediate next step is to conduct a formal, IRB-approved usability study to validate the pilot observations reported in Chapter 5. This study would use structured test cases and validated usability instruments with a representative sample.

Clinical validation with the target population. Following formal usability validation, the next step is a controlled study with dementia patients and their caregivers, focusing on patients in the early to mild stages. This study should include pre-test and post-test cognitive assessments administered before the patient begins using the system and again after four to six weeks of regular use. Each game session's performance data would be correlated with the assessment scores to explore whether the system's internal metrics track with established clinical measures. The current thesis does not make claims about cognitive improvement; such a study would explore whether those claims are warranted.

Adaptive difficulty calibration. The current adaptive difficulty thresholds (85 percent for advancement, 50 percent for additional scaffolding) are based on literature-derived principles but have not been validated with dementia patients. A clinical study should include systematic evaluation of whether these thresholds maintain the optimal challenge zone for the target population.

A caregiver-facing dashboard. The current Progress Dashboard shows data but is not designed specifically for caregivers. A dedicated caregiver dashboard should include longitudinal trend visualizations showing performance changes over weeks and months, automatic alerts when performance drops significantly from baseline, per-game summaries highlighting which cognitive skills are strongest and which need more practice, and export functionality so caregivers can share reports with clinicians.

Backend and cloud storage. Adding a secure backend with authentication would enable cloud storage of personal content, cross-device synchronization (allowing a patient to use the system on a tablet at home and a different device at a care facility), and data export for clinical analysis. The data model is already designed with export in mind; only the transport layer is missing.

Expanded personalization. The Memory Kit could grow to include personal music playlists for audio-based reminiscence, voice recordings of family members for audio prompts, and geographically relevant landmarks for spatial memory tasks.

Full fallback content mode. The current prototype does not fully implement the generic fallback content mode for all six games. Completing this implementation would ensure that the system is usable immediately without any caregiver setup, which is important for initial engagement and for situations where caregiver support is limited.

Final Remarks

Dementia care is moving toward person-centered, technology-assisted approaches. The gap between cognitive training and reminiscence therapy has persisted because existing tools were built for one purpose or the other, never both. One Step at a Time demonstrates that bridging this gap is both technically feasible and grounded in evidence.

This system is not a cure. It does not claim to be. It is a tool that meets patients where they are, uses the faces and routines that matter to them, and captures meaningful data about how they are doing.

One step at a time.

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APPENDIX A

SOURCE CODE

The full source code for the One Step at a Time application is available in the public GitHub repository at https://github.com/skarande3/One_step_at_a_time. The codebase consists of approximately 5,000 lines of TypeScript and React code organized into the following structure:

Core Application Files:

- src/main.tsx – Application entry point
- src/app/App.tsx – Root component with router and context
- src/app/context/AppContext.tsx – Global state management and localStorage persistence
- src/app/routes.ts – Route definitions for all screens
- src/utils/storage.ts – localStorage utility with error handling
- src/utils/gameHelpers.ts – Shared game utilities and practice flag management
- src/utils/soundGenerator.ts – Web Audio API sound synthesis engine

Game Components:

- src/components/games/SpacedRetrievalGame.tsx – Game 1
- src/components/games/RoutineReplayGame.tsx – Game 2
- src/components/games/FamiliarFacesGame.tsx – Game 3
- src/components/games/DistractionResistantGame.tsx – Game 4
- src/components/games/SoundGardenGame.tsx – Game 5
- src/components/games/LostFoundGame.tsx – Game 6

Screen Components:

- src/app/screens/WelcomeScreen.tsx
- src/app/screens/MemoryKitScreen.tsx
- src/app/screens/GameSelectionScreen.tsx
- src/app/screens/GameScreen.tsx
- src/app/screens/SessionSummaryScreen.tsx
- src/app/screens/ProgressDashboard.tsx
- src/app/screens/SettingsScreen.tsx

A video demonstration of the complete application is available at: https://www.youtube.com/watch?v=hHqPiF9_ou0&t=1s

APPENDIX B

DEVELOPMENT PROCESS AND CHALLENGES

This appendix documents the development methodology and the key challenges encountered during implementation and testing.

Development Methodology

The application was developed in three phases corresponding to the complexity and dependency structure of the components. Phase 1 covered the localStorage persistence layer, the Memory Kit setup wizard, and Game 1 (Spaced Retrieval Album), establishing the foundational data model, interval ladder mechanics, and cross-session persistence architecture. Phase 2 covered Game 2 (Routine Replay Timeline) and Game 3 (Familiar Face Spotlight), including the tap-to-place interaction system, the vanishing cue level state machine, and the cross-game practice flag integration. Phase 3 covered Game 4 (Distraction-Resistant Recognition), Game 5 (Sound Garden), and Game 6 (Lost-and-Found Locator), including the Web Audio API sound synthesis engine, signal detection metrics, room layout rendering, and distractor task components.

Claude by Anthropic was used as a code generation tool throughout all three phases. Detailed specifications (approximately 3,000 to 5,000 words per phase) were written describing TypeScript interface definitions, state machine descriptions, difficulty level parameters, UI design constraints, and accessibility requirements. All generated code was reviewed, tested, and modified before integration.

Implementation Challenges

localStorage quota management. The browser's approximately 5MB localStorage quota was initially exceeded when storing base64-encoded photographs alongside application state in a single entry. The persistence layer was redesigned midway through Phase 1 to store each image under an individual localStorage key, with the main state blob holding only metadata and key references. This workaround is sufficient for a prototype with 5 to 10 photos but would not scale to production use.

Web Audio API sound synthesis. Generating distinct, recognizable sounds programmatically for Game 5 (Sound Garden) required significant iteration. Initial implementations produced sounds that were too similar to be distinguishable during the selective listening phase. The final implementation uses distinct synthesis techniques for each sound category: low-pass filtered white noise with amplitude modulation for ocean waves, rapid sine tone sequences at 1000 to 3000Hz for bird songs, and decaying sine waves at 440Hz for church bells.

Tap-to-place interaction design. Game 2 (Routine Replay Timeline) was initially implemented with drag-and-drop as the sole interaction modality. Early testing revealed that even participants without motor impairments occasionally failed to complete drag gestures on touchscreen devices. A tap-to-place interaction was added as the primary modality, with drag-and-drop retained as a secondary option.

Testing Challenges

Participant population constraints. The evaluation was limited to an informal evaluation with friends and family, without dementia symptoms due to the scope and timeline of a Barrett Honors thesis. This constraint prevented measurement of several standard dementia usability metrics including learnability, memorability, cognitive load, and caregiver-observed interaction quality, as described in Chapter 5.