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The *Timing Game* for Research on Temporal Perception

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This study presents a novel design and development for the *Timing Game*, a Serious Game for improving Temporal Perception Research. Often repetitive and time-consuming, traditional lab tasks are converted into engaging 2D mobile minigames through innovative design and compelling narratives. The game features two modes: Arcade, which focuses on specific temporal tasks, and Story, which integrates these tasks into a cohesive narrative. Enhancing user engagement improves data quality, providing deeper insights into temporal perception. The paper details the development process, including user feedback and expert consultations, and makes the game available for further research, demonstrating the potential of Serious Games in scientific applications.

Keywords: Temporal Perception, Serious Games, Game Design, User Engagement, Mobile Gaming, Human-Computer Interaction, Computational Neuroscience

1 Introduction

Estimating time is essential for a wide range of behaviours in humans and non-human animals [Paton and Buonomano, 2018]. Time intervals, particularly those in the range of hundreds of milliseconds, are essential for interacting with our environment [Merchant *et al*., 2008]. Temporal processing involves multiple skills, including estimating and reproducing time intervals, synchronizing actions with rhythms, and recognizing complex temporal patterns [Paton and Buonomano, 2018].

A central question in this field is whether and how these abilities are related to each other. To investigate these correlations, researchers must collect data from a large number of participants across various tasks. However, in laboratory settings, participants often struggle to engage with the repetitive and time-consuming tasks required for mapping these skills, posing a significant challenge to this type of research.

Digital games have long been recognized for their ability to enhance cognitive functions, memory, concentration, reaction time, problem-solving abilities, and motor coordination [Granic *et al*., 2014; Brandão *et al*., 2010; Brandão and Joselli, 2015; Paletta *et al*., 2020; Goldstein *et al*., 1997; Adachi and Willoughby, 2013]. Serious Games, in particular, are designed with objectives that extend beyond entertainment, aiming to influence behaviour, attitudes, health, understanding, and knowledge [Becker, 2021; Souza *et al*., 2022]. These games can serve as effective tools in educational and professional development contexts.

The *Timing Game*, as first designed by the authors by Santos *et al*. [2021], exemplifies the application of Serious Game principles to the field of Temporal Perception Research. This area of psychology and neuroscience investigates how organisms perceive and process time [Eagleman, 2008; Buonomano, 2017]. The initial prototype of *Timing Game* employed participatory design methods, engaging end-users, developers, and domain experts to contribute to the design process [Santa Rosa and Moraes, 2012]. However, it lacked comprehensive design and narrative elements essential for full game development and sustained user engagement.

Traditional studies on temporal perception often face challenges related to participant engagement due to repetitive and time-consuming task experiments [Crowston and Prestopnik, 2013]. By gamifying these assessments and embedding them in a 2D mobile game with a compelling time-travel narrative, the *Timing Game* aims to enhance user engagement and data quality.

This paper presents a novel design for the *Timing Game*, incorporating elements from the participatory design outlined by [Santos *et al*., 2021], focusing on the integration of engaging design and narrative elements to transform the initial prototype into a completely functional game. Enhanced user engagement is expected to yield more reliable data, contributing to a deeper understanding of temporal perception and its implications for neurological conditions such as Parkinson's and Huntington's diseases [Paton and Buonomano, 2018].

The main contributions of the present manuscript are threefold. First, we present a comprehensive redesign and development of the *Timing Game* [Santos *et al*., 2021], which integrates design elements and narrative structure to enhance user engagement. Second, we outline the development of the *Timing Game*, covering the creation of the initial prototype, the sequence of expert consultations, and the iterative update process. Third, we present a proposal for making player data available for use in temporal perception research.

Our version of the *Timing Game* has two modes: Arcade and Story. Arcade Mode allows players to engage in individual minigames focused on specific temporal perception tasks, such as Duration Discrimination, Temporal Attention, and Repetitive Tapping. Story Mode weaves these minigames into a cohesive narrative where the player assumes the role of a time traveller attempting to repair a malfunctioning time machine. Each minigame is carefully designed to be engaging and provide meaningful data on temporal perception, linking gameplay to key neuroscience concepts. The game leverages the principles of Serious Games to maintain user engagement and enhance the reliability of the collected data, thereby contributing insights into the study of temporal perception.

This paper is organized as follows. Section 2 briefly reviews the related work and its scientific applications for our purposes. Section 3 details the "analogical" temporal perception tests that we use as the basis to create our minigames. Section 4 outlines the initial design and storyline development of the first version of the prototype of the Timing Game [Santos *et al.*, 2021]. Section 5 describes the employed methodology. Section 6 discusses the changes made during design-alignment meetings. Section 7 describes the progression from the prototypes to the final version. Finally, Section 8 discusses the results and suggests directions for future work.

2 Related Work

In recent years, Serious Games have demonstrated significant potential in educational and therapeutic contexts, providing innovative solutions to complex challenges. In the domain of cognitive tasks, several initiatives have adopted this approach to both enhance participants' health and collect behavioural data that advances our understanding of cognition. For instance, *A Maze Game with Singing Interface to Fight Dementia* [Chaiwong *et al.*, 2021] integrates cognitive assessment into a maze navigation framework. This game uniquely combines a maze challenge with a singing minigame to improve cognitive and emotional well-being. Players receive navigational hints based on their singing performance, effectively blending cognitive load with interactive entertainment—much like the aims of the *Timing Game*.

Another noteworthy Serious Game is *Sea Hero Quest*, developed to collect data on spatial navigation and perception to aid dementia research [Hyde *et al.*, 2016]. The players navigate through oceanic mazes and solve navigation puzzles, generating data for scientific analysis. The game's dual focus on engagement and data collection parallels the objectives of the *Timing Game*, aiming to transform daily tasks into compelling gameplay that promotes extensive user participation and high-quality data acquisition.

Remember targets Alzheimer's caregivers, educating them, through gameplay, about non-pharmacological treatments to slow disease progression [da Silva Carreiro *et al.*, 2020]. The game immerses players in the daily challenges faced by Alzheimer's patients, fostering empathy and understanding. This aligns with the *Timing Game*'s approach of using engaging narratives to deepen user involvement and enhance the educational value of the gameplay experience.

Addressing childhood anxiety, *MindLight* employs game mechanics derived from clinical anxiety reduction techniques [Schoneveld *et al.*, 2020]. By integrating neurofeedback and exposure therapy within the game, *MindLight* provides an effective and enjoyable therapeutic tool. The *Timing Game* similarly seeks to embed scientific principles within its design, transforming cognitive assessments into engaging and meaningful activities.

MindMate offers tools designed to support individuals with Alzheimer's through daily activity tracking and cognitive training [McGoldrick *et al.*, 2021]. The application's focus on continuous data collection and user engagement through a mobile platform reflects the *Timing Game*'s strategy of utilizing mobile technology to facilitate ongoing participation and data collection.

Although not a serious game, *Among Us* has influenced the design of the current version of *Timing Game* with its engaging environment and task-based gameplay. In *Among Us*, players navigate a spaceship, completing tasks while identifying impostors. This design inspired the *Timing Game*'s time-travel narrative, where players complete temporal perception tasks to advance in the game, showing how elements from mainstream games can enhance the appeal and engagement of Serious Games.

Beyond the development of Serious Games for cognitive assessment and behavioural data collection, the field of neuroscience research faces significant challenges in the management, standardization, and sharing of experimental data [Braghetto *et al.*, 2018; Ruiz-Olazar *et al.*, 2016, 2022]. The principle of reproducible science necessitates that data be reliable and publicly accessible, accompanied by comprehensive provenance information. To address these challenges, initiatives such as the Neuroscience Experiments System (NES) and the NeuroMat Open Database (NeuroMat DB) [Ruiz-Olazar *et al.*, 2022; Braghetto *et al.*, 2018] emerged.

Similar to previous work in which their contributions rely on cognitive assessment and development, the *Timing Game* integrates and adapts key elements from these successful models to create a novel tool for assessing temporal perception. It incorporates a compelling narrative and dynamic gameplay inspired by *Among Us*, with two distinct modes (Story and Arcade) designed to increase user engagement and data quality. The game design aims to ensure that scientific tests are seamlessly embedded within the gameplay, guaranteeing the data collected is both valid and applicable to future research and potential medical interventions. In this context, scalable and structured data collection strategies can direct future infrastructure improvements to increase the robustness and accessibility of collected datasets.

3 Temporal Perception and Scientific Testing

Temporal processing is a central cognitive function that enables organisms to interact effectively with their environment. Time intervals—particularly those in the range of hundreds of milliseconds—are crucial for everyday activities such as anticipating the duration of events (e.g., when a traffic light will turn green), synchronizing movements with external rhythms (e.g., dancing to music), and reacting to rapidly unfolding stimuli (e.g., during a tennis match). Despite the importance of these abilities, whether they rely on shared or distinct cognitive mechanisms remains an open question [Merchant *et al.*, 2008].

Understanding how different timing abilities relate to one another is essential not only for basic cognitive science but also for clinical applications [Paton and Buonomano, 2018]. Examining the structure of temporal skills—both across individuals and within individuals over time—can bring insights into how timing functions are organized in the brain, how they develop, and how they are affected by neurological conditions. However, addressing these questions requires large-scale, high-quality data, which is difficult to obtain using traditional laboratory-based experiments. Such studies typically involve repetitive, time-consuming tasks that can lead to participant fatigue and reduced engagement.

To overcome these limitations, we developed a gamified platform that transforms scientifically validated timing tasks into engaging, interactive experiences. This approach aims to maintain experimental rigour while enabling long-term user engagement, encouraging participants to return and complete multiple sessions over time. In doing so, it supports robust data collection and broadens accessibility, allowing researchers to gather standardized performance data from diverse populations. Over time, this platform can help track intra-individual learning and variability, examine inter-task correlations, and contribute to developmental and diagnostic research by mapping how timing abilities evolve across the lifespan.

The timing tasks integrated into the game were selected based on theoretical frameworks that propose distinct types of temporal abilities. Specifically, task selection was guided by the taxonomy proposed by Breska and Ivry [2016], which builds on earlier work by Coull and Nobre [2008]. Each task was designed to target a specific facet of temporal processing, allowing for an investigation into how these abilities may be functionally related or dissociated. These tasks are described in detail below.

The *Duration Discrimination* task involves participants comparing a standard time interval and a comparison interval, adapted from the study by Merchant [Merchant *et al.*, 2008]. In this task, two stimuli are presented, with the second serving as the comparison interval, which may vary in length from the standard. This task assesses participants' ability to discriminate between different durations accurately.

The *Temporal Attention Driven by Cues* task is based on the work of Coull [Coull and Nobre, 1998]. Participants are shown central stimuli alongside peripheral boxes where a target may appear. They must quickly detect the target, aided by spatial and temporal cues that direct their attention. This task explores the mechanisms underlying temporal attention.

In the *Repetitive Tapping* task, participants synchronize their taps with a sensory stimulus and continue tapping after the stimulus ends, a design based on Merchant's study [Merchant *et al.*, 2008]. This task evaluates sensorimotor synchronization and the ability to maintain a rhythm without external cues, enhancing our understanding of timing and motor coordination.

The *Ready-Set-Go* task, adapted from Jazayeri's work [Jazayeri and Shadlen, 2010], asks participants to observe and reproduce specific time intervals marked by visual flashes. The task assesses temporal accuracy and consistency by asking participants to press a key to replicate a previously shown interval, offering insights into how individuals perceive and reproduce short temporal sequences.

Temporal Patterns - Reproduction requires participants to repeat sequences of key presses with varying intervals, following the design by Laje *et al.* [2011]. This task tests the ability to reproduce complex temporal patterns.

The *Temporal Patterns - Perception* task is similar to the reproduction task. However, it involves a match-to-sample procedure, where participants must indicate which of two temporal patterns matches the one they were previously shown. This task evaluates the ability to discriminate between temporal patterns.

In the *Isochrony Judgement* task, participants detect deviations in the duration of intervals within a sequence of evenly spaced tones [Grube *et al.*, 2010]. This task assesses rhythmic processing skills.

Temporal Attention Driven by Rhythms challenges participants to detect visual stimuli presented at varying intervals, based on the work of Breska [Breska and Ivry, 2018]. This task examines how predictable and random temporal patterns influence participants' ability to perceive and react to stimuli, shedding light on the effects of temporal predictability on visual detection.

Finally, the *Fixed-Duration Circular Movement* task involves participants drawing circles or moving a cursor in time with auditory cues, adapted from studies by Zelaznik and Merchant [Zelaznik *et al.*, 2002; Merchant *et al.*, 2008]. This task evaluates how well participants synchronize their motor actions with sensory stimuli, focusing on the precision and consistency of their movements.

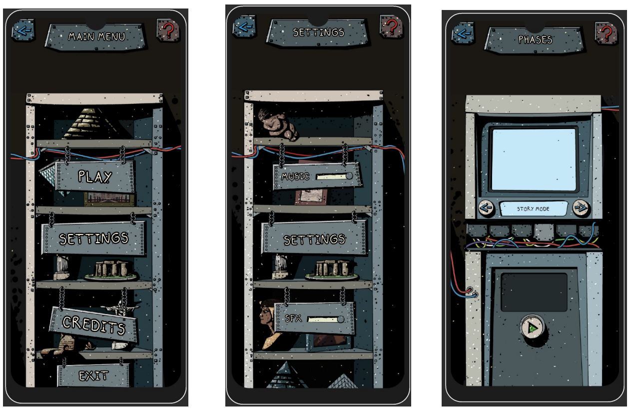
By transforming these tasks into engaging game formats, the *Timing Game* addresses the limitations of traditional laboratory settings, offering a more stimulating experience that enhances participant engagement and improves data quality. As a research tool, it is intended to be employed in ongoing studies conducted by the Timing Lab[1] at UFABC.

4 Art-Design Overview

The art for *Timing Game* is 2D, and the chosen illustration style is the hand-drawn cartoon, commonly seen in pop culture elements such as the animation Rick and Morty and the game *Among Us* [InnerSloth, 2020]. Although the original participatory design by Santos *et al.* [2021] opted for an 8-bit 2D style, this was changed to enhance narrative tools and gameplay attractiveness.

The user interface (UI) is a crucial aesthetic factor in game development. Although not detailed in the work of Santos *et al.* [2021], the UI acts as the modality of interaction between the application and the user, the main menu being the player's first contact. For our design, since the game environment takes place in a time machine, to evoke proper feelings, the main menu simulates a physical environment, like a warehouse containing items from different eras and places. Here, players can navigate shelves to access settings, credits, minigame selection, and Story mode menus (Fig. 1).

[1] `https://timing.pesquisa.ufabc.edu.br/` (accessed 25 August 2025)



(a) Initial Main Menu **(b)** Settings Menu **(c)** Play Menu

Figure 1. Main Menu Screens.

The *Play* selection menu, which allows players to choose between *Arcade Mode* and *Story Mode*, is inspired by a jukebox. In *Arcade Mode*, players can select from various minigames: *Circle Drawing*, *Rhythm-Induced Attention*, *Temporal Orientation*, *Duration Discrimination*, *Repetitive Tapping*, *Ready - Set - Go*, *Morse Code*, *In The Morse Code*, and *Isochronous Judgement*. In *Story Mode*, players can navigate the spaceship and interact with levels as they progress through the narrative (detailed in Sec. 7).

The UI maintains the aesthetic continuity of the main menu, with hanging signs displaying relevant information like fuel levels, scores, levels, and pause menus.

Animations were designed to be simple and lightweight for processing. Character movements, interface, and scenery use traditional frame-by-frame animation or are created directly in the Unity Game Engine.

To ensure the minigames' environments are not cluttered, some artwork was simplified. Animations, sounds, and images must not interfere with temporal tests, as users could use visual feedback to gauge speed, potentially invalidating scientific tests.

The prototype of Timing Game by Santos *et al.* [2021] lacked a complete storyline, only indicating that the character was in a time machine travelling between the past and future to collect fuel. To enhance this narrative, the new storyline involves the protagonist being trapped in a malfunctioning time machine, trying to return to their time. They must solve problems and capture crystal fuel to continue their journey. For the sake of comparison of the design styles, we present the nine minigames originally proposed [Santos *et al.*, 2021]:

1. *Rhythm Induced Attention* tasks the player with using a radar to locate functional crystals around the spaceship while navigating the environment. A large target displays lights moving toward the center, revealing either a perfect or defective crystal. The player chooses between retrieving or destroying the crystal (Fig. 2).
2. *Temporal Orientation* requires the player to identify briefly illuminated crystals to determine if they are intact or cracked. Based on this visual feedback, the player decides whether to keep or discard the crystal (Fig. 3).
3. *Isochronous Judgment* involves evaluating crystals retrieved by a claw. If a crystal flashes at regular intervals, it is validated; otherwise, it is discarded. This task assesses the player's ability in temporal judgment (Fig. 4).
4. *Ready-Set-Go* presents a sequence of lamps where the player must press a button when the last lamp is expected to light up. Timely responses result in blue lamps, near misses in dark blue, and significant errors in red (Fig. 5).
5. *Circle Drawing* requires the player to manually rotate gears to match the rhythm of the time machine, thereby increasing its fuel if performed correctly (Fig. 6).
6. *Repetitive Tapping* tasks the player with observing the exterior view of the time machine and tapping in sync with flashing lights to stabilize the machine and prevent destabilization in inter-temporal space (Fig. 7).
7. *Morse Code* challenges the player to replicate a Morse code message displayed on the screen by pressing a central button at correct intervals (Fig. 8).
8. *Duration Discrimination* involves determining which of two colors appeared for a shorter duration to adjust the time machine's speed, either accelerating or decelerating time accordingly (Fig. 9).
9. *In The Morse Code* requires decoding a message by comparing two sequences of flashes and selecting the correct one (Fig. 10).

The novel narrative we proposed connects all minigames through a cohesive storyline. The protagonist uses available materials to build a time machine, faces challenges while testing it, and must solve problems to continue their journey through the intertemporal space, ensuring that the machine functions correctly to reach its destination.

This narrative enhances the player's immersion by providing a clear path between actions and the story, making the transitions between minigames seamless and engaging. All actions occur within the time machine, allowing players to navigate between tasks within a unified environment.

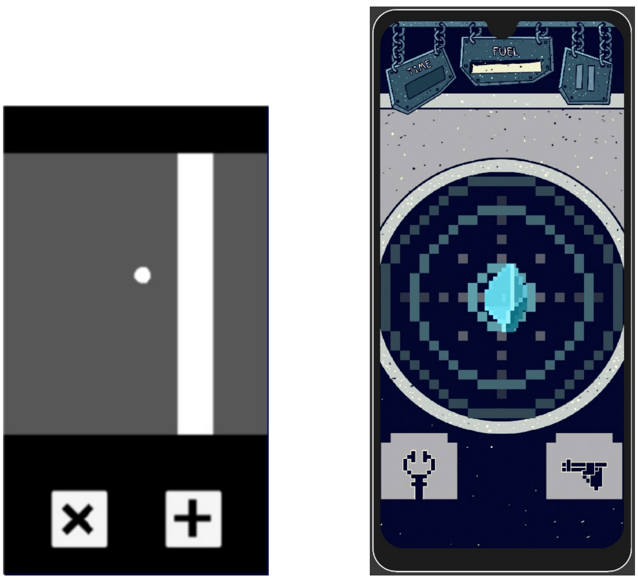


Figure 2. *Rhythm Induced Attention*: Initial Design by Santos *et al.* [2021] vs Final Design.

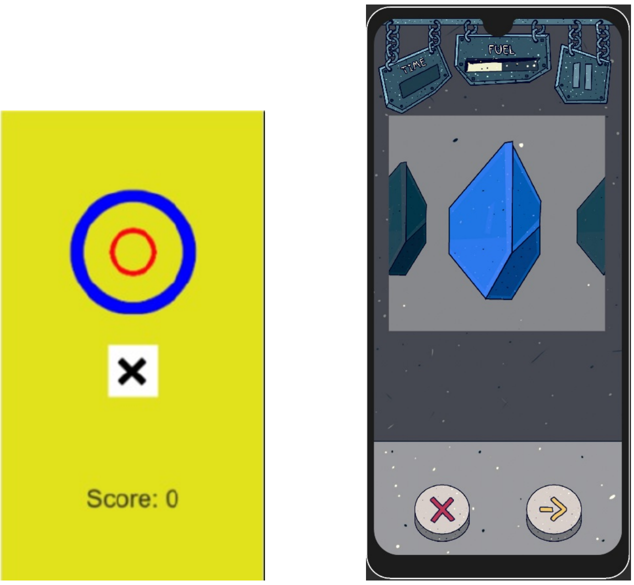


Figure 3. *Temporal Orientation*: Initial Design by Santos *et al*. [2021] vs Final Design.

Figure 4. *Isochronous Judgement*: Initial Design by Santos *et al*. [2021] vs Final Design.

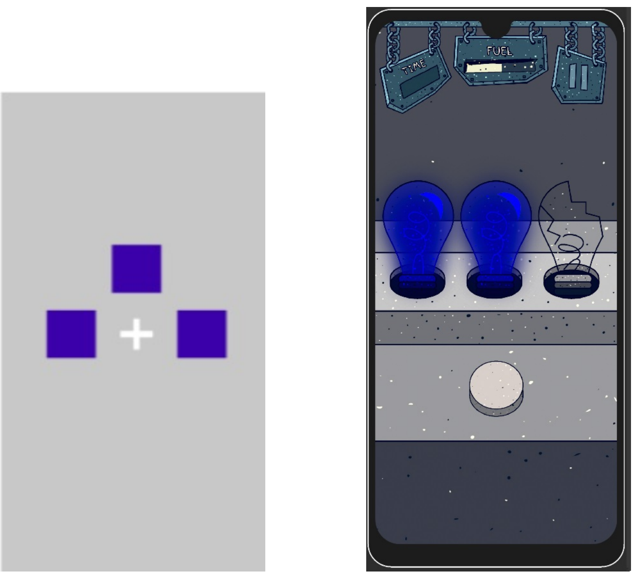


Figure 5. *Ready-Set-Go*: Initial Design by Santos *et al*. [2021] vs Final Design.

Figure 6. *Circle Drawing*: Initial Design by Santos *et al*. [2021] vs Final Design.

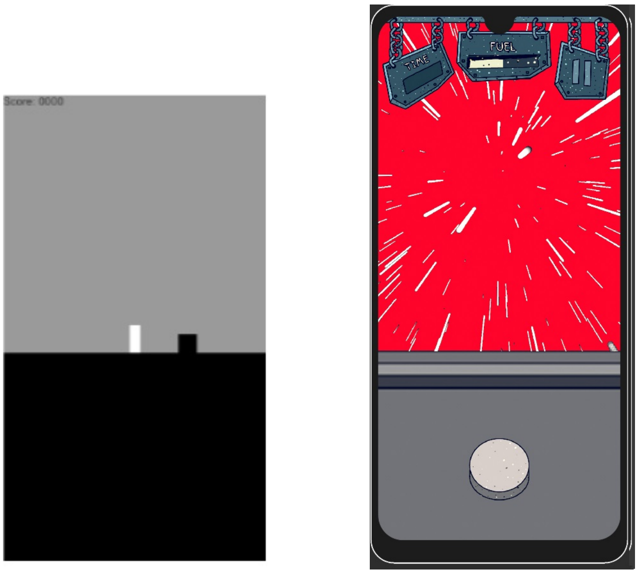


Figure 7. *Repetitive Tapping*: Initial Design by Santos *et al*. [2021] vs Final Design.

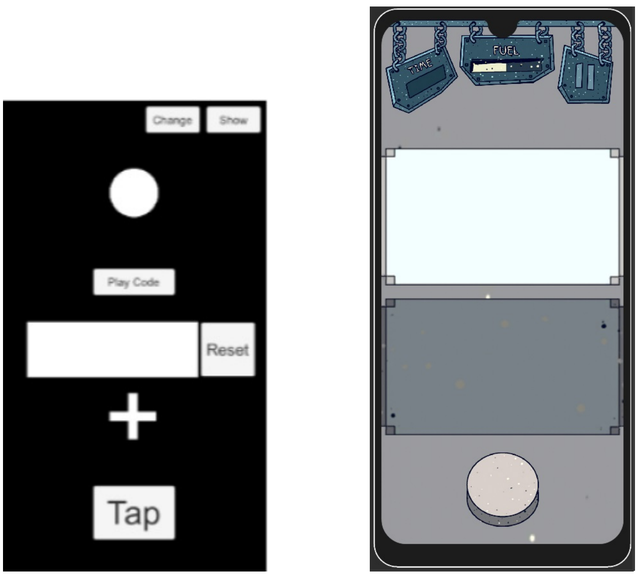


Figure 8. *Morse Code*: Initial Design by Santos *et al*. [2021] vs Final Design.

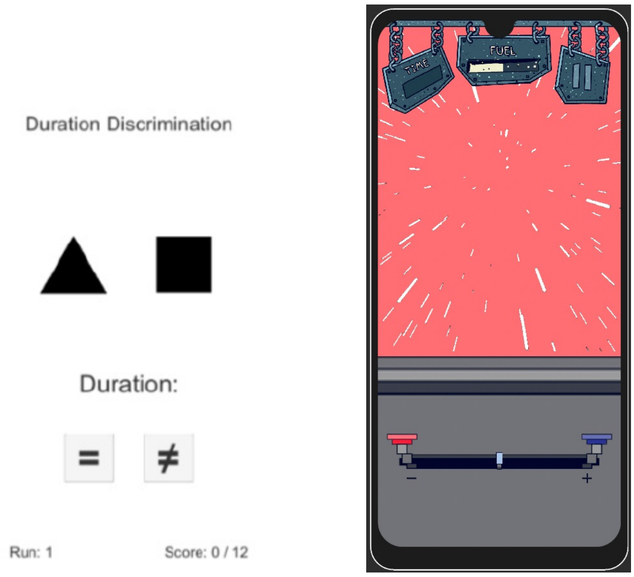


Figure 9. *Duration Discrimination*: Initial Design by Santos *et al.* [2021] vs Final Design.

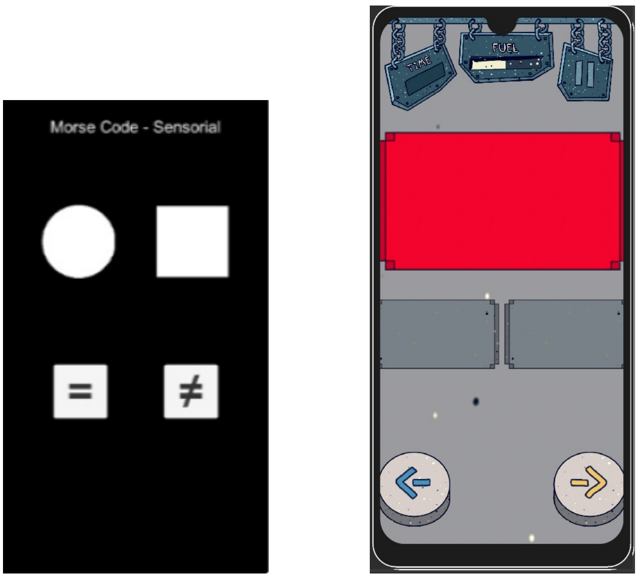


Figure 10. *In The Morse Code*: Initial Design by Santos *et al.* [2021] vs Final Design.

5 Methodology

The methodology employed in this study followed a structured and iterative process to ensure the development of a scientifically relevant and engaging game. The process began with the creation of the game narrative. This narrative framework defined the design and construction of the game environment, including the creation of menus, a time machine scene, and heads-up displays (HUDs).

Subsequently, a new design for each minigame was created considering the participatory design presented by Santos *et al.* [2021]. The minigames were subjected to preliminary testing conducted by the researcher to ensure functionality and alignment with the narrative. After these tests, the minigames were presented to a domain expert, who performed additional evaluations.

Based on the expert's feedback, the identified changes were implemented, leading to the generation of a new game construction. This process was repeated iteratively, starting with the environment's configuration and progressing through the stages of redesign, testing, feedback, and revision for each minigame until no further modifications were necessary.

Finally, elements common to all minigames, such as the scoring screen, data collection, and menu integration, were incorporated to ensure a cohesive user experience across the game. This approach ensured the scientific rigor and usability of the game, while also aligning with the study's goals.

6 Co-creation with Domain Expert

To preserve the original conception outlined in the participatory design that led to the initial prototype described by Santos *et al.* [2021] and to ensure scientific relevance, periodic alignment meetings were held. These meetings consisted of the game developer and a neuroscientist (PhD) specialist in temporal perception and co-author of this paper. Eight online meetings were conducted on Wednesdays throughout 2023, beginning in the second week of February and lasting between 2 to 4 hours each. The first three sessions were held at two-week intervals, the fourth and fifth were separated by four weeks, and the remaining meetings followed at two-week intervals. After each meeting, the developer and the neuroscientist generated and tested a new version of the game to verify if the discussed changes were effective.

An initial version of each minigame was developed based on the descriptions and the original prototype of the Timing Game [Santos *et al.*, 2021]. After completing this first development phase, all minigames underwent detailed inspections and adjustments, ranging from design and mechanical aspects like the frequency of element appearances on the screen to more complex aspects such as animations, sound effects, and data collection.

During this process, some minigames had to significantly update their narratives, while others remained almost unchanged. Moreover, the meetings explored ways to improve each minigame, identifying opportunities for enhancements in gameplay, functionality, and user experience. During this process, a limit of 60 attempts was set for the minigames: *Rhythm Induced Attention*, *Temporal Orientation*, *Isochronous Judgement*, *Ready-Set-Go*, *Duration Discrimination* and *In The Morse Code*.

In the first meeting, on February 8, 2023, modifications were defined for the minigames *Rhythm Induced Attention* and *Temporal Orientation*. For *Rhythm Induced Attention*, the intervals for each signal were adjusted to 500 or 900 milliseconds, with the interval for each target being the same as the cue 75% of the time. Two types of targets were introduced: Crystal and Broken Crystal. A scoring system with three categories was established: exceptional hit (100-300 ms), normal hit (301-600 ms), and error (above 600 ms), with corresponding points.

In *Temporal Orientation*, two crystal sizes representing 500 and 900 ms were defined, with 25% of the crystals showing a different value. The player could press the button as soon as the stimulus began, but pressing before the cue's presentation was considered an error, resulting in point loss. The scoring system mirrored *Rhythm Induced Attention*.

In the second meeting, on February 22, 2023, the following changes were made: In *Temporal Orientation*, instead of using two crystal sizes, distinct colors were employed. A waiting period was introduced before the start of the minigame to address the rapid transition between the last cue and the new stimulus. In *Isochronous Judgement*, a sequence of 6 intervals (500 or 900 ms) was defined, with a 50% chance for each crystal to be isochronous. The non-isochronous crystals had an interval extended by 20, 30, or 40%. Points were awarded for correctly identifying whether the crystal was isochronous or not, and deducted for incorrect responses.

The following modifications were defined during the third meeting, on March 8, 2023: In *Ready-Set-Go*, stimulus durations were fixed at 500 or 900 ms. The hit criteria depended on the percentage difference between the stimulus time and the player's response time: exceptional hit ($\pm 10\%$), normal hit ($\pm 20\%$), and error (above $\pm 20\%$), with the corresponding points. In *Circle Drawing*, a single circular movement time of 1 second (1Hz) was set. The player had 4 reference laps followed by 6 laps without reference, repeated 5 times.

In the fourth meeting, on April 5, 2023, the following changes were made: In *Ready-Set-Go*, the hit criteria were changed to exceptional hit ($\pm 15\%$), normal hit ($\pm 30\%$), and error (above $\pm 30\%$). In *Repetitive Tapping*, the number of times the user must follow the reference was adjusted to 5, with the visual references progressively fading. The player had to press the button six times without reference, with a single 700 ms interval between stimuli. The scoring criteria were based on response accuracy: exceptional hit ($\pm 15\%$), normal hit ($\pm 30\%$), and error (above $\pm 30\%$).

In the fifth meeting, on May 3, 2023, modifications were defined for *Morse Code*: The number of intervals was set to 6, with random values of 500 or 900 ms. Stimulus and response screens with specific colors and transitions were introduced. The scoring system was based on response accuracy: exceptional hit ($\pm 15\%$), normal hit ($\pm 30\%$), and error (above $\pm 30\%$).

In the sixth meeting, on May 17, 2023, the following changes were made: In *Morse Code*, the number of intervals was adjusted to 4, maintaining 2 of each time. In *Duration Discrimination*, two colors (blue and red) were assigned to the stimuli. The speed animation was disabled at the start of the minigame. Red stimuli times were set to 500 or 900 ms, randomly selected. The blue stimulus represented 60, 80, 90, 110, 120, or 140% of the red stimulus time.

In the seventh meeting, on May 31, 2023, changes were made to *In The Morse Code*: The number of intervals was set to 6, with random values of 500 or 900 ms. Two comparison sequences, one on the right and one on the left, were presented below the reference sequence. In one comparison sequence, an interval value was altered by 20, 40, or 60%. The player had to identify which comparison sequence matched the reference with points awarded for accuracy.

In the final meeting, on June 14, 2023, extensive changes were made in all minigames, with a specific modification for *In The Morse Code*: The number of intervals was adjusted to 4, maintaining 2 of each time. In addition, a fuel bar was introduced, starting at half capacity and varying according to the user score. An explanatory screen was added to demonstrate the required actions in each minigame, along with a final score screen.

7 Development of the *Timing Game*

The initial prototype was concise, focusing on functionality and determining the feasibility of implementing the time-based scientific tests through the minigames using Unity.

The narrative of the levels was not cohesive, with time travel as the primary theme. The minigames were created using the Unity Canvas, which limited some functionalities and made the game structure rigid.

To address these issues, the prototype was rewritten, and the narratives of most minigames were enhanced to provide a cohesive story. Complex animations that could interfere with the user's performance in the scientific tests were removed to maintain the validity of the results. Each minigame was designed with minimal animations to ensure a visually appealing gameplay experience while ensuring data reliability.

The game environment needed to appear both modern and crafted from everyday items, suggesting that the time machine was built in a garage. This aligns with the simple challenges and art style, creating a consistent experience for the player.

To achieve this, metal plates with screw marks hanging by chains display information and buttons. Simple shapes are used for buttons and other elements, and consistent crystal designs are maintained throughout the games (Fig. 11).

7.1 Game Controls and Mechanics

Controls and mechanics were simplified to remove potential barriers for different types of players. Screen touch controls the character within the time machine, with an interaction button available at the bottom of the interface when the character is in a position to interact with an element of the machine. Each minigame has its dynamics and tests different skills. All buttons and movements are explained in a tutorial

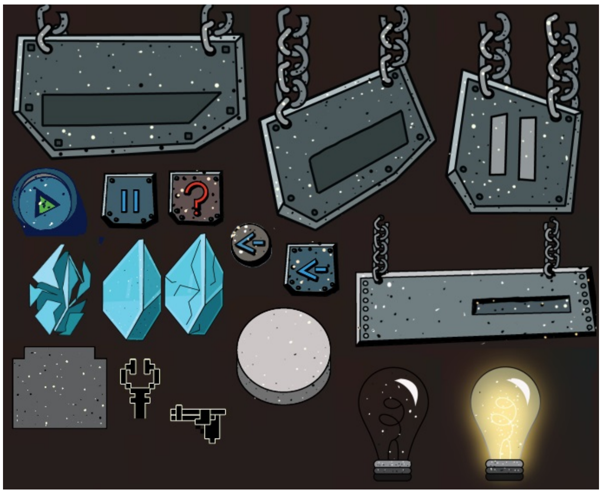


Figure 11. Example of game elements

image before each minigame begins, ensuring players are familiar with the game mechanics.

7.2 Menus

The initial game menu plays a crucial role in the player's experience, serving as the first point of contact and setting expectations. It reflects the visual identity and theme of the game, significantly contributing to its immersion. In the first version of the prototype, the initial menu was a list of nine buttons to select tests, which lacked immersion.

To create an immersive time travel menu, shelves with historical human artifacts and connecting cables were used, simulating various machines connected within the spaceship. The game's buttons are metal plates hanging by chains to represent an adaptive and rustic aspect (Fig. 1).

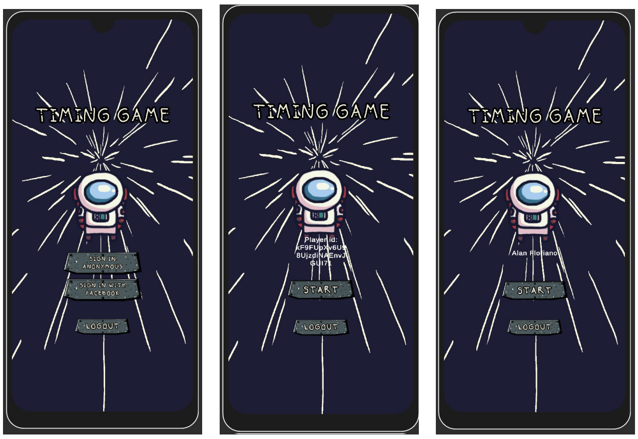
The main menu (Fig. 1) has a top information bar indicating the current menu section and six buttons: Back, Help, Play, Settings, Credits, and Exit. Each button leads to another menu, except for Exit, which closes the application. Constant animation between menus simulates a continuous physical environment.

In the pre-main menu, users can choose between an anonymous login and a Facebook login (Fig. 12). The anonymous login uses Unity's system, which provides a unique UID but no additional information. Facebook login allows the collection of more detailed user data.

7.3 Game Storyline

The initial concept included a theme of time travel but lacked a concrete story. The prototype considered storytelling scenes between minigames, but this approach was discarded into a more interactive game. A concise narrative was created in which the player assumed the role of the time traveler.

For the storyline of our *Timing Game*, *players assume the role of a renowned scientist who dreamed of building a time machine. Using intelligence and laboratory resources, the scientist creates an improvised time machine from everyday objects. Excited by the creation, the scientist embarks on the first-time travel journey, hoping to explore new eras and uncover mysteries of the past and future. During the journey, the time machine encounters unexpected problems, trapping the scientist in an unstable inter-temporal space. The scientist must resolve technical issues to survive and secure the time machine. Upon discovering powerful time crystals that can stabilize the machine, the scientist must collect them while addressing the machine's problems to return to the present.*



(a) Login Menu **(b)** Anonymous Login **(c)** Facebook Login

Figure 12. Login Menu Screens

7.4 Story Mode vs. Arcade Mode

Two game modes were created: *Story Mode* and *Arcade Mode*. In Story Mode, players follow a narrative, providing an immersive experience. In Arcade Mode, players can choose any minigame without the narrative complexity, making it dynamic and straightforward.

In the *Story Mode*, the character is in a time machine resembling a spaceship, addressing various issues to continue the journey (Fig. 13). The minigames are integrated into the narrative, such as collecting good crystals and destroying bad ones in *Rhythm-Induced Attention* (Fig. 14a), testing crystals in *Temporal Orientation* (Fig. 14b), and validating them in *Isochronous Judgement* (Fig. 15a).

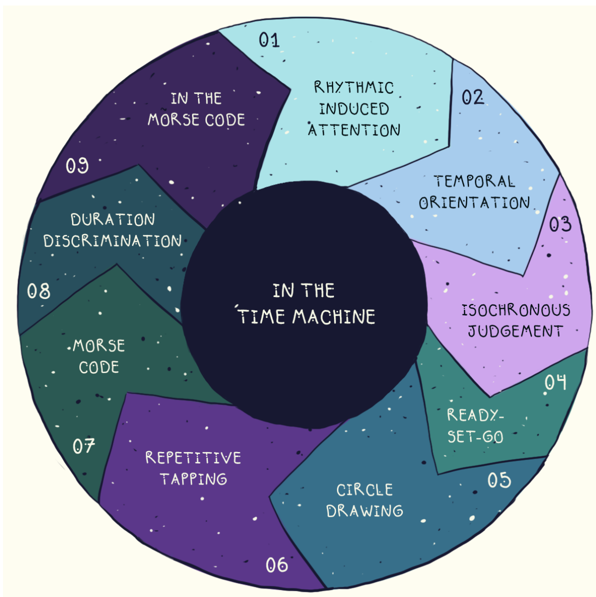


Figure 13. Diagram of Story Mode

(a) *Rhythm Induced Attention* **(b)** *Temporal Orientation*

Figure 14. Minigames Screens

In *Ready-Set-Go*, the player must press a button at the right time to start the machine (Fig. 15b), manually rotate gears in *Circle Drawing* (Fig. 16a), and stabilize the machine in *Repetitive Tapping* (Fig. 16b). The player receives and decodes messages in *Morse Code* (Fig. 17a), adjusts the machine's speed in *Duration Discrimination* (Fig. 17b), and transmits the response in *In The Morse Code* (Fig. 17c).

(a) *Isochronous Judgement* **(b)** *Ready-Set-Go*

Figure 15. Minigames Screens

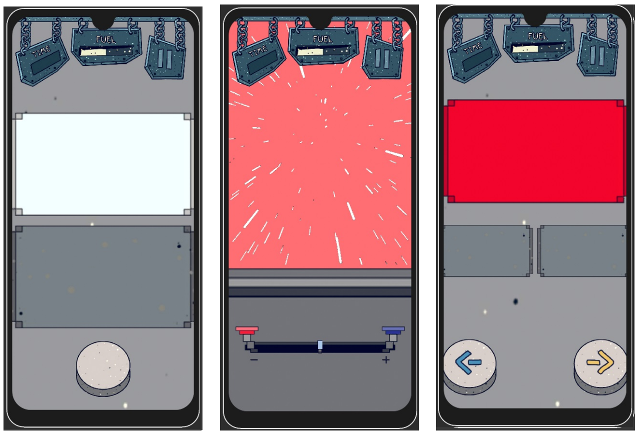
In Arcade Mode, all activities occur in the Play menu, where users can select any of the 9 available minigames (Fig. 18) returning to the menu after finishing the minigame.

7.5 Post-Development Minigames

Each completed minigame was analyzed from its prototype stage and then developed into an initial version that considered the game's narrative. This was followed by iterative im-

(a) *Circle Drawing* **(b)** *Repetitive Tapping*

Figure 16. Minigames Screens



(a) *Morse Code* **(b)** *Duration Discrimination* **(c)** *In The Morse Code*

Figure 17. Minigames Screens

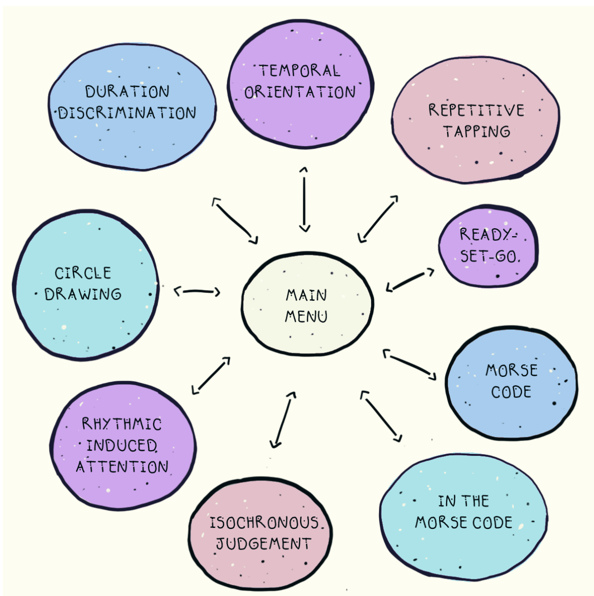


Figure 18. Diagram of Arcade Mode

provements through alignment meetings, as detailed in Section 6.

Although each task evaluates a different temporal skill, they share a common structure: all minigames begin with an introductory tutorial screen, feature a clear and minimalistic interface to avoid cognitive bias, and are integrated into the time machine environment, with access tied to specific locations. Each task provides feedback based on response accuracy, and players are scored according to precision, classified into tiers such as exceptional, normal, or error. Finally, a final version was created and presented here.

Minigame: Rhythm-Induced Attention

Based on the work of Breska and Ivry [2018], this minigame presents a series of visual stimuli followed by a target image. Rhythmic stimuli consist of four identical cues at fixed intervals (e.g., 500ms or 900ms), followed by a target (+ or X) which the user must quickly identify. Non-rhythmic conditions vary the interval between the last cue and the target. Initially, four visual cues (circles) appeared at fixed intervals, each lasting 100ms, followed by a target that the user had to identify within a given time.

The original prototype worked functionally but lacked thematic elements of participatory design [Santos *et al*., 2021]. To align more closely with the design, the game was revised to use a radar with concentric circles (Fig. 19a). Signals appear sequentially from the outermost to the innermost circle, each for 100ms, followed by a crystal that the user must capture or destroy based on its condition. This design maintains cue intervals at 500ms or 900ms, with a 600ms response window.

Minigame: Temporal Orientation

This minigame, based on work by Coull and Nobre [1998], involves presenting visual cues indicating when a target will appear on the screen. The user must respond as quickly as possible upon seeing the target. A brief visual cue (a blue or red circle) appears for 100ms, signaling whether the target will appear after 500 or 900 ms. In 70% of the trials, the cues are valid; in the remaining 30%, they are invalid, meaning the target appears at a different interval than indicated.

In the final version of the minigame, the user tests crystals previously captured in the *Rhythm-Induced Attention* stage. Crystals of different colors, representing 500ms or 900ms intervals, appear and light up. If the crystal remains intact, the user presses a forward button; if cracked, the user presses an "X" button to destroy it. A 600ms delay precedes the crystal's illumination (Fig. 19b).

Minigame: Isochronous Judgement

This minigame, based on Grube *et al*. [2010]'s work, involves presenting participants with a sequence of five stimuli, each lasting 100ms. The intervals between stimuli 1-2, 2-3, 3-4, and 4-5 are either 500ms or 900ms, depending on the experimental block, with one interval potentially altered in 50% of the trials. Participants must determine whether all intervals in the block are equal. In the initial prototype, a square stimulus appears, flashes according to the experimental block's interval, and may vary one interval. After the sequence, users press "yes" if they judge the block to be isochronous, or "no" if not, with feedback provided via happy or sad faces for correct or incorrect answers, respectively.

In the final version, the minigame integrates with the storyline by testing crystals collected in the intertemporal space. Crystals appear and flash five times at intervals of 500ms or 900ms, with one interval potentially 20%, 30%, or 40% longer. After observing the sequence, the players press the "X" button to destroy non-isochronous crystals or the "Okay" button to confirm good crystals (Fig. 19c). An evaluation meeting determined that a variation of 12% was too subtle, so the intervals were adjusted to longer variations, and the sequence increased to six stimuli. A different color indicates when the sequence ends.

Minigame: Ready-Set-Go

Based on Jazayeri and Shadlen [2010]'s work, this is an interval reproduction task. It involves presenting two brief visual stimuli in sequence, with an equal interval between them, which the participant must replicate by pressing a button to generate a third stimulus. The objective is to press the button when they perceive the interval between the second and third stimuli to be equal to the interval between the first two.

In the final version of the minigame, integrated into the storyline as a mechanism to activate the time machine, the user observes two lamps lighting up sequentially and must press a button when the third lamp, which is damaged, should light up. Initially, six different intervals were considered, but it was later simplified to two intervals: 500ms and 900ms. A successful button press within 15 of the target interval yields an excellent rating, turning the lamp light blue, while within 30 results in a normal rating with dark blue light (Fig. 19d). Presses outside this range are considered errors, and the lamp turns red.

Minigame: Circle Drawing

The *Circle Drawing* is a task derived from the studies of Merchant *et al*. [2008] and Zelaznik *et al*. [2002]. This task involves performing circular movements following a given rhythm. Initially, the user performs the movements with visual rhythm guidance, which is then removed, requiring the user to continue the movements independently. The task starts with a base rhythm presented for the first three cycles, after which the user must continue drawing the circle for five more cycles, maintaining the imposed rhythm. The cycle intervals are 500ms (2Hz) or 900ms (1.11Hz).

The final version, designed to align with the narrative, contextualizes the task within a clockwork theme. The user interacts with a red round lever within a gear-filled environment (Fig. 19e). When touched, the lever begins to move at a predetermined speed, and the user must match this rhythm with their finger movements. If the user lifts their finger or moves it outside the lever, the lever resets to the initial position, penalizing the user. Based on feedback from development review meetings, the interval was set at 900ms for better user manageability. The visual guide is shown for four cycles and then removed for the next six, leaving only a contour to help the user maintain accuracy.

Minigame: Repetitive Tapping

This task is based on Merchant *et al*. [2008]'s work. Participants tap a button in sync with a rhythmic stimulus on the screen. After five cycles, the stimulus stops, and the participant continues tapping at the same rhythm for four more cycles.

In the final minigame version (Fig. 19f), the user taps the button in sync with changing background colors indicating the rhythm. To enforce mandatory adherence to the rhythm, the screen freezes, waiting for the user's tap, and if they lose the rhythm before the initial 5 stimuli, the screen freezes again, and the count resets. Users must tap within 15% of the interval to earn maximum points and within 30% for a normal score. A single 700ms interval is used.

Minigame: Morse Code

This minigame, based on Laje *et al*. [2011]'s study, involves a sequence of exposure and testing phases. Participants observe a series of stimuli, tracking their temporal patterns and intervals. They then reproduce this pattern using a button interface. The prototype features a red square as stimuli and a reproduction button below. Patterns consist of 4 intervals, either 200-800 ms (mean 500 ms) or 360-1440 ms (mean 900 ms). Positive feedback (smiling emoji) is given for accurate reproductions.

The task was adapted smoothly to fit the design concept, resembling Morse code for user engagement. Dual stacked panels were implemented: one displaying the pattern and the other activated for reproduction upon button press. Initially, 6-stimuli exposure blocks were used, evenly distributed between fixed intervals of 500 ms and 900 ms. Development adjustments included reducing stimuli to 4 (2 per interval) and adding neutral color cues for start and end (Fig. 19g).

Minigame: Duration Discrimination

This task, based on Merchant *et al*. [2008]'s work, involves categorizing intervals as shorter or longer than a reference. In the prototype, a white square represents the reference stimulus, and a white circle serves as the comparison stimulus. Reference intervals are set at 500 ms or 900 ms, while comparison intervals vary between 250-1000 ms and 450-1800 ms, respectively.

Initially, a motion animation depicted time travel with changing light rays (red for reference and blue for comparison stimuli). In the final version of the minigame (Fig. 19h), the animations were paused during the stimulus display and resumed after user input, also the color was changed to be displayed in the background color (red or blue) for better visibility. The user pulls one of the two handles to indicate which color is visible longer in the background.

Minigame: In The Morse Code

This task, adapted from Laje *et al*. [2011]'s study, involves a match-to-sample task comparing two target sequences to a sample sequence. In the prototype, squares represent these sequences: red denotes the reference and blue is the test sequence, with intervals uniformly distributed between 200-800 ms (average 500 ms) or 360-1440 ms (average 900 ms). After the presentation, users indicate which of the two samples were similar to the sample.

The design evolved to present three panels: one large one for reference and two smaller ones for test sequences (Fig. 19i). The sequences consist of four stimuli with fixed intervals of 500 or 900 ms, randomized. One of the smaller panels contains a sequence equal to the reference, and the other contains a sequence with one of the intervals between stimuli 20%, 40%, or 80% of the reference value.

The Time Machine

The entire Story mode occurs within the time machine environment, resembling a spaceship (Fig. 20). A vortex animation suggests movement, and the machine's makeshift appearance is consistent with the narrative of being built from available materials.

A video presentation of the game is available on YouTube[2].

7.6 Collected Data

Data collection is a critical component of the *Timing Game*. To organize and store gameplay data, serialized data classes were created for each minigame, allowing flexible modeling of the relevant variables (Code 1). These structures can be updated as needed for future experimental requirements.

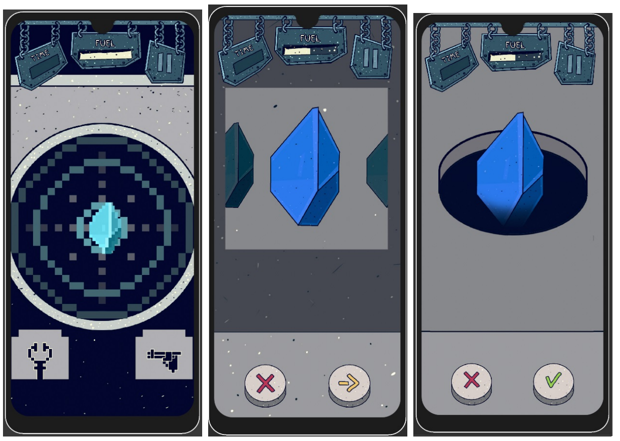
```
[Serializable]
public class readySetGoObj
{
    public float exampleTime;
    public float userTime;
    public float maxOffSet;
    public float minOffSet;

    public readySetGoObj(float exampleTime,
        float userTime, float maxOffSet,
        float minOffSet)
    {
        this.exampleTime = exampleTime;
        this.userTime = userTime;
        this.maxOffSet = maxOffSet;
        this.minOffSet = minOffSet;
    }
}
}
```

Code 1: Serialized Class from the *Ready-Set-Go* Minigame

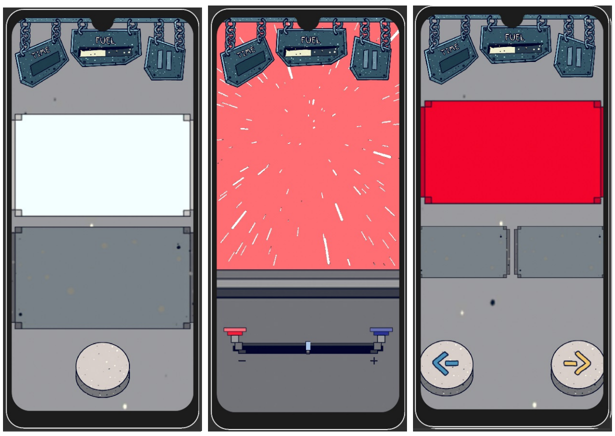
Although it is well established that temporal processing plays a critical role across virtually all aspects of human cog-

[2] https://www.youtube.com/watch?v=xBIwBxlBSZM (accessed 25 August 2025)



(a) Rhythm-Induced Attention **(b)** Temporal Orientation **(c)** Isochronous Judgement

(d) Ready-Set-Go **(e)** Circle Drawing **(f)** Repetitive Tapping



(g) Morse Code **(h)** Duration Discrimination **(i)** In The Morse Code

Figure 19. Final version of the minigames.

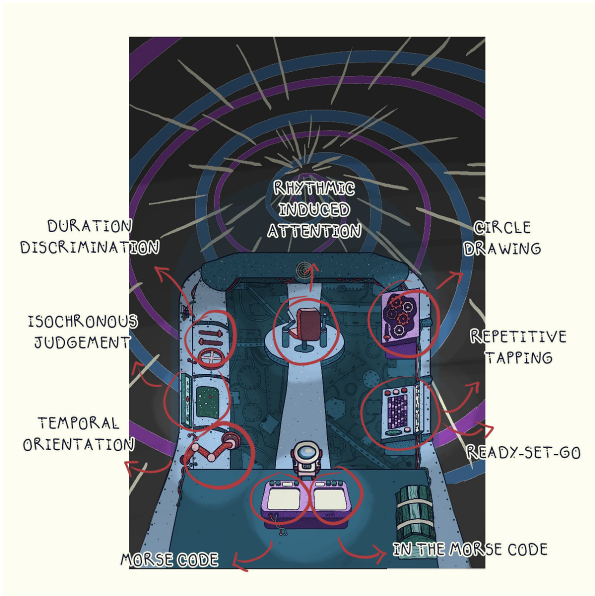


Figure 20. The Time Machine

nition, how different temporal abilities are interrelated remains poorly understood. By encouraging regular engagement with the game, we aim to build a large and standardized dataset that enables us to investigate these relationships at multiple levels. At the individual level, we can assess whether participants who do well in one timing task also tend to perform well in others, providing insight into shared underlying mechanisms. At the momentary level, we can examine how fluctuations in an individual's performance across tasks co-vary over time, shedding light on dynamic aspects of cognitive functioning.

Additionally, we can explore learning trajectories within each task and test whether learning effects generalize across different timing domains. In the long term, this platform holds the potential to track developmental and aging-related changes in temporal cognition, offering a unique window into how these abilities evolve across the lifespan. The use of standardized tasks and repeated measurements will be critical in supporting reliable, longitudinal analyses. The resulting data may have downstream implications for understanding and diagnosing conditions associated with impaired temporal processing, such as Parkinson's disease, Huntington's disease, Tourette syndrome, schizophrenia, and Attention-Deficit Hyperactivity Disorder [Paton and Buonomano, 2018; Coull and Giersch, 2022; Zheng *et al.*, 2022].

Initially, a shared Google Drive folder was adopted as the primary storage solution. This choice was motivated by the simplicity and ease of implementation, enabling quick deployment during the development phase. Each file is stored in JSON format and named using a standardized convention: the minigame name, the user's unique Unity authentication ID, and the date of the session. Individual gameplay attempts are stored as list entries within each file (Code 2).

To enhance scalability and enable broader application of the system, more robust and secure solutions such as Firebase, RESTful APIs, or Unity Cloud services are recommended for future versions. These technologies would support larger-scale deployments, automated data synchronization, and improved data integrity.

Configuration files already included in the system allow

```
{
  "Items": [
    {
      "exampleTime": 0.5,
      "userTime": 0.7004209756851196,
      "maxOffSet": 0.15000000596046448,
      "minOffSet": 0.07500000298023224
    },
    {
      "exampleTime": 0.8999999761581421,
      "userTime": 1.030975103378296,
      "maxOffSet": 0.27000001072883606,
      "minOffSet": 0.13500000536441803
    },
    {
      "exampleTime": 0.5,
      "userTime": 0.6826314926147461,
      "maxOffSet": 0.15000000596046448,
      "minOffSet": 0.07500000298023224
    }
  ]
}
```

Code 2: Example of collected data from the minigame *Ready-Set-Go*

real-time adjustment of difficulty levels and timing variables for each minigame. This feature enables researchers to tailor experiences according to participant profiles or research needs, allowing dynamic difficulty adjustment based on user performance.

7.7 Data and Code Accessibility

All gameplay data collected during user testing is collected anonymously. No personally identifiable information is stored at any point during gameplay sessions. Access to these data files is not publicly open by default, but they may be made available upon reasonable request. Requests must specify a valid research or educational purpose, and each case will be individually reviewed to ensure data use aligns with ethical standards and research goals.

Currently, the *Timing Game* application is stored on GitHub, but its access is restricted. Interested researchers may request access by providing a clear justification for its intended use. We plan to make the game available at Google Play Store.

This approach aims to balance transparency and reproducibility with ethical responsibility, supporting open science while safeguarding participant anonymity and data integrity.

7.8 Lesson Learned and Design

Throughout the development of the *Timing Game*, one of the main design challenges was balancing scientific rigor with engaging gameplay. A key concern was ensuring that visual and auditory feedback did not interfere with players' perception of time during the minigames. To maintain the integrity of the collected data, elements such as light flashes, animations, and sound cues were minimized to prevent players from using these as external time references rather than relying on internal temporal estimation.

This constraint, while scientifically necessary, made the design process more demanding. Creating minigames that were both immersive and scientifically valid required creative solutions to retain user engagement. One significant challenge identified early in testing was the repetitive nature of the tasks. As players are required to complete the same minigame multiple times to gather sufficient data, fatigue and disengagement can become common, reducing the overall enjoyment.

To address these issues, three main strategies were implemented: (1) strict control of sensory cues, (2) a motivational feedback system through a fuel bar, and (3) a hard cap of 60 attempts per minigame. In (1), minimizing visual and auditory cues ensured that users relied solely on their internal temporal perception, enhancing data quality. In (2), the fuel bar mechanic provided a sense of progress and accomplishment even within repetitive tasks, maintaining engagement. In (3), the 60-attempt cap ensured that no player would become stuck indefinitely due to a streak of errors, balancing the need for repeated data collection with player comfort. These strategies collectively enabled us to meet the dual goals of scientific reliability and user immersion.

Based on these lessons learned, we encourage future researchers developing Serious Games for experimental contexts to carefully balance scientific rigor with engaging gameplay, to anticipate issues of user fatigue in repetitive tasks, and to consider modular data collection systems that can evolve with project demands. Prioritizing user experience and data integrity in tandem is critical to achieving both valid results and broad participant engagement.

7.9 Future Improvements

Building on the current infrastructure, the system is well-positioned for scalable expansion. Integrating more sophisticated backend services would enable secure, efficient, and centralized data handling. This would allow the game to reach a more diverse user base, including remote studies and large-scale cognitive research.

Future versions of the game may implement authentication through platforms such as Google or Facebook. These login systems would facilitate the collection of basic demographic information—such as age or region—and support personalized tracking across sessions.

Additionally, a short pre-game questionnaire could be introduced to gather context about the player's physical or psychological characteristics, such as visual impairments or cognitive conditions. Mapping a player's profile [Carneiro *et al.*, 2022] is fundamental to improving the data quality acquisition. These data points would enable deeper analysis and more accurate interpretation of results, particularly for use in clinical or personalized research scenarios.

The combination of user authentication, contextual questionnaires, and flexible game configuration lays the groundwork for personalized gameplay experiences. These capabilities could support adaptive testing environments, enhance data quality, and facilitate longitudinal studies involving individuals with varied cognitive profiles.

Overall, these enhancements aim to reinforce the scientific robustness of the *Timing Game* while increasing its usability and accessibility across broader research and clinical domains.

8 Conclusion

This study presents the development of *Timing Game*, a 2D mobile game initially designed and prototyped by Santos *et al*. [2021]. The original prototype evaluated temporal perception through a series of scientific tests adapted into minigames, unified by the central theme of time travel. The work continues the original study by critically analyzing, presenting improvements, and implementing a complete novel game. Specifically, the proposed game introduces a broader narrative to integrate the min-games cohesively, enhancing immersion, seeking user engagement, and contributing to the quality and reliability of the collected data.

The interdisciplinary nature of this study posed significant challenges. Regular meetings with neuroscience professionals were crucial for validating the scientific integrity of the implemented minigames. Comprehending the scientific principles behind the tests was also important for developing and improving the minigames accurately. This collaboration aimed to ensure the game was scientifically valid and engaging for users.

Ensuring cohesion within the game was a major challenge, as the initial participatory design featured disconnected minigames linked only by the central theme of time travel. The narrative restructuring aimed to provide a unified storyline that motivated users to engage with the tasks.

Aesthetic enhancements, including improved art and animations, were also critical for maintaining user interest and enjoyment despite the repetitive nature of the tests. These improvements aimed to balance simplicity, necessary for scientific validity, with visual appeal and user engagement.

For future work, it is essential to enhance the data collection system by integrating additional user information, such as age and gender. Implementing a pre-game questionnaire to gather relevant user information and refining each minigame through rigorous testing will improve applicability and usability. Furthermore, expanding the scoring system, incorporating more animations and cut-scenes, and adding more scientific content will enhance user engagement and contribute to ongoing research in temporal perception neuroscience, promoting a stimulating and educational environment. Publishing the game on the Play Store will facilitate broader access and data collection.

Declarations

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Authors' Contributions

AFT: Data curation; Formal analysis; Methodology; Validation; Visualization;Writing – original draft; Writing – review & editing. ALB: Conceptualization; Investigation; Methodology; Supervision; Writing – review & editing. AKY: Software, Resources, Writing – review & editing. AC: Conceptualization; Formal analysis; Methodology; Writing – review & editing. JPG: Investigation; Methodology; Supervision; Visualization; Writing – review & editing. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

The project will be available at `https://github.com/Fiotz/ProjectTimingGame` (accessed 25 August 2025).

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