ESPECIAL

Recibido 14 Oct. 2024 ReCIBE, Año 13 No. 3, Dec.2024

Aceptado 15 Dec. 2024

Beat by Beat: Designing a Rhythm Game forScreening Dyslexia.

Paso a Paso: Diseñando un Juego de Ritmo para la Detección de la Dislexia

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Abstract. Dyslexia, a language-based disorder, affects children's reading, writing, and spelling abilities despite adequate classroom instruction. Early screening is crucial to mitigate the adverse effects of delayed detection. Dyslexia also impairs precise timing tasks, including rhythm skills essential for reading. This study explores the potential of serious games incorporating rhythms to screen for dyslexia, leveraging the natural synchronization of rhythm skills observed in body movements. Existing rhythm games fail to accurately address dyslexia-related difficulties, lacking relevant performance data and user-centred design. Our research aims to design a 2D sidescrolling platformer game, integrating established rhythmic activities to identify children at risk for dyslexia and engage them in gameplay. A multidisciplinary team collaborates on this initiative, including neuropsychologists, music therapists, and game designers. Using the Design Thinking Methodology, we focus on identifying effective music compositions, game mechanics, dynamics, and visual elements that enhance the gaming experience for children with dyslexia and support early dyslexia screening.

Keywords: screening dyslexia · rhythm video games · user-centered design

Resumen: La dislexia, un trastorno del lenguaje, afecta las habilidades de lectura, escritura y ortografía de los niños a pesar de una instrucción adecuada en el aula. La detección temprana es crucial para mitigar los efectos adversos de la detección tardía. La dislexia también afecta las tareas de sincronización precisa, incluidas las habilidades rítmicas esenciales para la lectura. Este estudio explora el potencial de los juegos serios que incorporan ritmos para detectar la dislexia, aprovechando la sincronización natural de las habilidades rítmicas observadas en los movimientos corporales. Los juegos de ritmo existentes no abordan con precisión las dificultades relacionadas con la dislexia, ya que carecen de datos de rendimiento relevantes y un diseño centrado en el usuario. Nuestra investigación tiene como objetivo diseñar un juego de plataformas de desplazamiento lateral en 2D, integrando actividades rítmicas establecidas para identificar a los niños en riesgo de dislexia e involucrarlos en el juego. Un equipo multidisciplinario colabora en esta iniciativa, que incluye neuropsicólogos, musicoterapeutas y diseñadores de juegos. Utilizando la metodología Design Thinking, nos centramos en identificar composiciones musicales efectivas, mecánicas de juego, dinámicas y elementos visuales que mejoren la experiencia de juego para los niños con dislexia y respalden la detección temprana de la dislexia.

Palabras clave: cribado de dislexia · videojuegos rítmicos · diseño centrado en el usuario

1 Introduction

Dyslexia manifests as a condition in children where, despite conventional classroom instruction, they struggle to achieve language skills in reading, writing, and spelling that match their intellectual capabilities [1]. Individuals with dyslexia face challenges with precise timing tasks, including rhythm skills that positively affect reading abilities. One of the reasons is that music and languages are common mechanisms, and thus, transfer effects from the former to the latter are expected to occur [2, 3]. Therefore, the lack of rhythm can indicate a dyslexia condition [4–6] characterized by difficulties in fluent reading. Several studies have shown a correlation between different rhythm tests and reading abilities [7–14, 18, 20, 21, 4]. Synchronization to a musical beat relies on a sophisticated neuronal network comprising perceptual regions, motor regions, and sensorimotor integration areas [22]. In the case of children with dyslexia, this disorder affects auditory-motor synchronization to a musical beat [22, 12], as well as other functions such as speech. Thus, researchers have proposed that music training could address these dyslexia timing issues [23].

In this context, serious games offer engaging, multisensory experiences to support therapies for children with neurodevelopmental disorders. With low cost and broad accessibility, they are well-suited for attending to diverse patient populations and environments. For instance, there are games to address auditory hyper-sensitivity using interactive virtual reality [24] and web-based games to screen dyslexia using music components [27], among others. While video games are used for early dyslexia screening, the potential of rhythm-based activities remains underexplored. Current rhythm games lack the necessary data to predict dyslexia risk and do not cater to the needs of therapists or psychologists. Understanding users' behavior is critical for creating design strategies that enhance and support dyslexia screening; furthermore, it is necessary to explore the use of rhythms for early detection. Therefore, based on the 2D sidescrolling platformer rhythms-based game *Jump'n'Rhythm* [28, 29], we propose a user-centred design focused on children with dyslexia. This initiative involves a multidisciplinary team comprising neuropsychologists, music therapists, and game designers. What is the most effective music composition for a video game, incorporating rhythms and rhythmic activities established in the literature, to identify children at potential risk for dyslexia and motivate them during the gameplay? Which game mechanisms and dynamics are needed to engage children with dyslexia? Which visual elements enhance the gaming experience for children with dyslexia? We used the ground theory and Design Thinking methodology to answer these questions.

2 Related Work

2.1 Dyslexia and Music

Tierney et al. [19] examine the role of rhythm processing in dyslexia, focusing on two factors: sequencing (perceiving and reproducing rhythmic patterns) and synchronization (maintaining consistent timing with stimuli). Sequencing is linked to reading ability and verbal memory, correlating with better performance in language and cognitive tasks. Meanwhile, synchronization relates to nonverbal auditory processing and phonological skills in preschoolers, school-aged children, and early adolescents [3, 12, 14]. The findings suggest rhythm perception, mainly through musical training, can enhance phonological processing, reading skills, and verbal memory [11]. Rhythmic priming may also support language processing, memory encoding [15], and grammaticality judgments [16]. [17] assessed the consistency of auditory brainstem responses across a recording session by measuring brainstem responses to speech syllables from normal-hearing children ages 6–13 years with a wide range of reading abilities. Results show that poor reader have significantly more variable auditory brainstem responses to speech than good readers, independent of resting neurophysiological noise levels. Overy [5] proposed that group music lessons focused on singing and rhythm games could serve as an effective multisensory support tool for dyslexic children by fostering the development of essential auditory, motor timing, and language skills. A research program was subsequently developed, which included the creation of group music lessons and musical tests tailored for dyslexic children, alongside three experimental studies. The findings revealed that classroom music lessons positively impacted phonological and spelling abilities but did not improve reading skills. Additionally, the results indicated dyslexic children struggled with musical timing skills but did not exhibit difficulties with pitch recognition.

2.2 Video Games for Dyslexia

Several digital tools are available for early dyslexia screening. *Dytective* [30] is a web-based game challenging players to accumulate points by solving linguistic problems within time-limited stages. Participants are presented with a target letter or non-word, displayed alongside similar-sounding distractors. *Diesel-X* [31] comprises three mini-games assessing skills associated with early dyslexia markers: distinguishing frequency-modulated tones, phonological awareness through word recognition, and letter knowledge. *Nessy* [32] is educational software. It focuses on core literacy skills such as phonemic awareness, phonics, spelling, and reading fluency. Interactive activities include matching sounds to letters, identifying syllables, word building, and sound categorization. An auditory game, *DysMusic* [27], adapted from the visual Memory game, aims to detect differences in sound perception between children with and without dyslexia. Players match musical elements hidden behind digital cards, varying tasks to test short-term memory.

2.3 Rhythm Video Games for Therapy

Bégel [22] and Dalla [10] evaluated games for training rhythmic and auditory-motor skills, considering factors like device precision and output modality. Of 27 games reviewed, none were suitable for rhythm rehabilitation - most focused on reacting to visual cues with background music rather than directly emphasizing rhythm. Poor device temporal precision also limited accurate rhythmic performance measurement. Bégel [25] then developed *Rhythm Workers*, a serious game explicitly targeting perceptual and sensorimotor rhythmic abilities. It involves constructing buildings using rhythmic patterns and musical stimuli, with versions for beat perception and synchronized tapping. Experiments showed it effectively improved rhythm skills in healthy adults after two weeks of training, suggesting potential for rehabilitating rhythm disorders. Vonthron's [26] *Mila- Learn* serious game for remote education was tested with over 5,800 children during COVID-19 lockdowns. Iterative feedback improved motivation and customization. While performance increased over time, particularly for older children and those with ADHD, progress was slower among children with dyslexia.

3 Methods

We are using the Design Thinking methodology [33], an iterative user-centred design methodology which consists of five stages as detailed below:

Stage 1: Empathize— This stage concentrates on understanding the user's needs. We garnered insights from the literature concerning the rhythm skills of children with dyslexia and their relationship to language. This literature review provided valuable context and foundational knowledge for our research. Subsequently, we conducted user research through seven semi-structured interviews involving three music therapists and four neuropsychologists. Each interview was recorded for analysis, amounting to 8.40 hoursof recorded material.

Stage 2: Define— We identified user needs and challenges in this stage. We analyzed the interview data using open and axial coding. During open coding, we segmented and analyzed the data of interest to identify concepts and categories. Subsequently, we systematically examined the data to determine relations between the categories and subcategories identified during the open coding phase. This qualitative analysis enabled us to generate our claims, assumptions, personas, and scenarios. Next, we will validate these scenarios with experts to ensure they address real user needs -three music therapists, three neuropsychologists, two music technologists, and one music pedagogies. These insights have become potential use cases for early dyslexia screening.

Stage 3: Ideate— With our scenarios finalized, we will engage therapists, neuropsychologists, and game designers in participatory design sessions. These sessions will serve as a platform for interdisciplinary collaboration, ensuring we challenge our initial assumptions and explore ideas. By incorporating the expertise of therapists and neuropsychologists, we will gain insights into the practical and clinical needs of early dyslexia screening. Meanwhile, the involvement of game designers will help us translate these insights into engaging and compelling game features. This collaborative effort aims to identify and develop the ideal features for an early dyslexia screening game.

Stage 4: Prototype— We will initiate the process by developing a prototype incorporating the main ideas generated during the ideation phase. This prototype will represent our concepts, enabling us to assess their feasibility and effectiveness. Initially, our team will share the prototype internally to gather preliminary feedback and make necessary refinements. Following this internal review, we will extend the testing to a small group of external experts, including therapists, neuropsychologists, and musicians. Their feedback will be crucial in identifying strengths and weaknesses and ensuring the prototype aligns with practical requirements and user expectations.

Stage 5: Test— After selecting the best solutions from prototyping, we will assess the final product through user experience and interaction evaluations. These evaluations will have two stages: formative assessments to refine usability and engagement and summative assessments to measure the tool's effectiveness in early dyslexia screening. While this marks the end of the initial five-stage process, design thinking is iterative. Any insights gained may lead to further refinements or identify new problems to address. This iterative approach ensures continuous improvement and maintains the tool's relevance and effectiveness over time.

4 Results

Based on the findings from Stages 1-3 of the Design Thinking methodology, we have created a list of design features for a 2D sidescrolling rhythm-based game [29] aimed at early dyslexia screening. Additionally, we have developed a game scenario using the storyboard technique. Our results are as follows.

4.1 Design Features

1. *Activities based on rhythm tests*: Our contextual research supports the integration of four rhythm tests, as proposed by Tierney [19], which focus on sequencing (perceiving and reproducing rhythmic patterns) and synchronization (maintaining consistent timing with stimuli). These tests are integral to our game design and are key tools for assessing rhythm processing in individuals with dyslexia. The game's mechanics are closely aligned with the rhythmic abilities targeted by these tests, which are often deficient in individuals with dyslexia:

- Synchronization with a metronome: The person taps in sync with auditory stimuli at a fixed tempo (metronome) at three speeds: 90, 120, and 180 bpm.
- Synchronization with a beat: The person taps while maintaining the tempo as auditory rhythmic sequences are played.
- Synchronization with rhythmic sequences: The person taps synchronously with auditory rhythmic sequences.
- Rhythm memory: The person listens to a rhythm sequence and then replicates the same sequence.

2. *Customization*: The video game design should prioritize children's autonomy by allowing them to personalize their experience by choosing the sequence of activities and selecting an avatar that resonates with their individual preferences and identity.
3. *Music*: Central to this project is the use of music, particularly rhythmic elements, to enhance children's motivation and engagement. Drawing from our contextual study, which included insights from music therapists, neuropsychologists, and music technologists, we focused on using percussion instruments. Experts emphasized the effectiveness of percussive elements in therapeutic settings, leading us to prioritize drums and rhythms in the composition of the game's music. This music is carefully designed to complement the visual elements, creating an engaging multisensory experience for children.

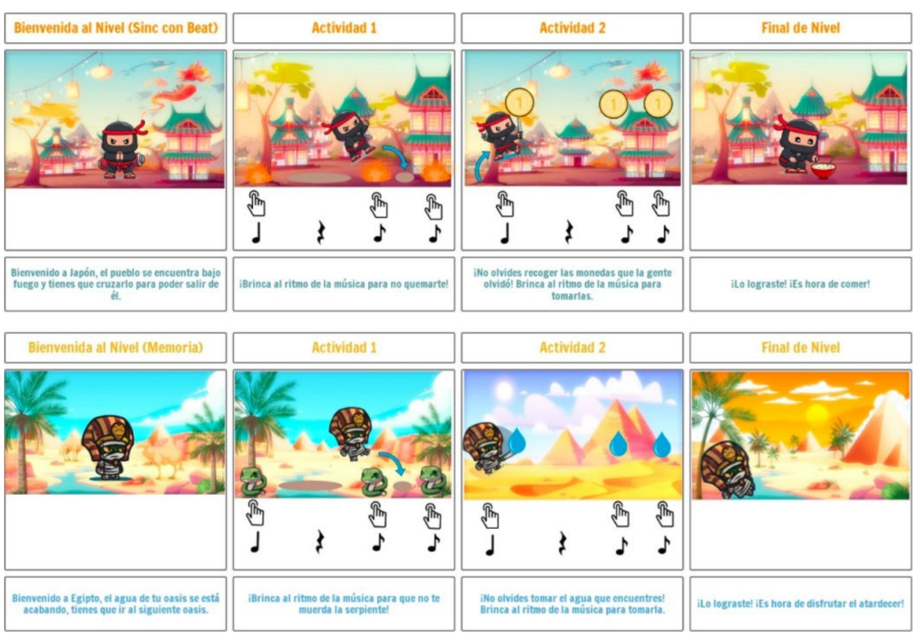

Fig. 1. A proposed game scenario. The figure shows a segment of the proposed story-board where the avatar jumps in sync with the rhythms, avoiding threats.

4. *Interface Design*: The visual elements of the game, including avatars and game worlds, are designed to be engaging and appropriate for children, with distinct scenarios for each activity or rhythm test. These visual design choices are informed by insights from our contextual study, where experts recommended a side-scrolling format. Consequently, the game was developed as a jump-and-run side-scrolling platformer.
5. *Instructions*: The video game should use audio for the tutorials and instructions because, as an early screening tool, the children may not know how to read and write. The audio for the tutorials and instructions will be agile, dynamic, and age-appropriate, without using condescending voices. Both children and therapists can skip the tutorials.
6. *Reinforcers*: The video game should include positive reinforcement. It should also incorporate partial reinforcers within each activity. Both partial and final reinforcers will be displayed on the screen through animations.
7. *Data Acquisition*: Our game incorporates rhythm tests adapted from the methodologies of Tierney [3, 19], who effectively distinguished between dyslexicand non-dyslexic participants to identify potential risks for having dyslexia. By recording the timing of user interactions, such as tapping in response to rhythmic stimuli, our game facilitates analysis akin to that utilized in the *Jump'n'Rhythm* game [28], which is the foundation for our design.

4.2 Initial Proposed Game Scenario

Inspired by our contextual study, we have developed ideas for a proposed game scenario using the storyboard technique, which will be showcased during our participatory design sessions. Figure 1 presents a segment of this storyboard tailored for our design sessions. With four rhythm tests [3] in mind, we have crafted unique scenes within a warrior-themed world. For example, we have chosen the Asia Kingdom setting for the synchronization test. Here, children are challenged to tap along with a metronome that changes tempo—shifting between 90 bpm, 120 bpm, and 180 bpm every forty beats. To represent the taps within the game, an avatar jumps when the children tap, synchronizing with the rhythm while navigating obstacles and avoiding traps. Similarly, we have envisioned a medieval kingdom for the test synchronizing with the beat. Children tap along with rhythmic music in this realm, guiding their avatar through challenges. Additionally, an Egyptian kingdom serves as the backdrop for the synchronizing with the rhythm test. Children tap in time with the music's rhythm, guiding their avatar's movements. Finally, the memory sequence test is set within a castle mission. Children listen to rhythmic musical sequences and then replicate them. Their avatar mirrors these sequences while navigating obstacles.

5 Conclusions and Future Work

This study explores integrating music and rhythm into serious games as a novel approach to screen for dyslexia. By leveraging the natural synchronization between rhythm skills and bodily movements, we designed a 2D side-scrolling platformer game. Our interdisciplinary collaboration and user-centred design approach aim to identify children at risk for dyslexia through engaging gameplay. Although our research is currently in Stage 3, preliminary results underscore the importance of customizable activities, compelling music compositions, visually attractive interfaces, and positive reinforcement. These features are crucial in creating an effective and enjoyable screening tool for early dyslexia detection.

Grounded in educational and cognitive theories emphasizing the significance of rhythm and timing in phonological and language skill development, particularly for individuals with dyslexia, our game's design reflects these principles. While formal studies with participants at Stage 5 have yet to be conducted, our contextual study, enriched by inputs from neuropsychologists, music therapists, and educators, confirms the appropriateness of the game's features for this stage. This alignment, coupled with the success of similar interventions in addressing Stage 5 needs, enhances our confidence in the game's potential efficacy.

The game's adaptability allows for modifications based on user feedback and continuous testing. As part of our iterative development process, we will conduct further evaluations with Stage 5 participants to refine and validate the game, ensuring it meets their specific needs.

Moving forward, our research will focus on several key areas to enhance the effectiveness and usability of the game for future work. We plan to conduct extensive user testing with both dyslexic and non-dyslexic children to gather detailed feedback on the gameplay experience, interface design, and the overall appeal of the game. This user testing will be accompanied by iterative design cycles, where we will incorporate the feedback into successive versions of the game, continuously refining its features.

Funding

First author is supported by Consejo Nacional de Humanidades Ciencia y Tecnologías (CONAHCYT) – Estancia Posdoctoral por México 2022(1)/M1/CVU 619441 in Mexico

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