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RESEARCH PAPER

Rhythm, Play, and Precision: Burger Beat as a Serious Game for Fine Motor Skill Training in Children

Ritmo, Juego y Precisión: Burger Beat como Juego Serio para el Entrenamiento de Habilidades Motrices Finas en Niños

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Resumen
Los sistemas de entrenamiento que promueven la coordinación motriz fina a través de medios interactivos se están volviendo accesibles gracias a los avances en visión por computadora y tecnologías de seguimiento del movimiento. Sin embargo, existen investigaciones limitadas sobre su diseño y eficacia para niños pequeños. Este estudio presenta Burger Beat, un juego interactivo basado en ritmo diseñado para fortalecer las habilidades motoras finas mediante la sincronización de gestos con estímulos musicales. En Burger Beat, los niños preparan hamburguesas virtuales realizando tres gestos —pinza, mano abierta y puño— detectados en tiempo real a través de un sistema de seguimiento basado en visión. Un estudio intrasujeto con 22 niños de 6 a 7 años comparó dos condiciones de juego: con y sin música rítmica. Los resultados mostraron que la versión guiada por ritmo redujo significativamente los errores gestuales y aumentó la competencia percibida y la autonomía, en comparación con la condición no rítmica. Las observaciones cualitativas revelaron mayor compromiso, concentración y persistencia cuando estaban presentes las señales rítmicas. Los juegos interactivos basados en ritmo como Burger Beat muestran potencial para mejorar la coordinación motriz y la motivación infantil mediante una retroalimentación multisensorial estructurada.

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Abstract
Training systems that promote fine-motor coordination through interactive media are becoming accessible due to advances in computer vision and motion-tracking technologies. However, there is limited research on their design and effectiveness for young children. This study introduces *Burger Beat*, a rhythm-based interactive game designed to strengthen fine motor skills through gesture synchronization with musical stimuli. In Burger Beat, children prepare virtual hamburgers by performing three gestures—pinch, open hand, and fist—detected in real time via a vision-based tracking system. A within-subjects study with 22 children aged 6–7 years compared two gameplay conditions: with and without rhythmic music. Results showed that the rhythm-guided version significantly reduced gesture errors and increased perceived competence and autonomy compared to the non-rhythmic condition. Qualitative observations revealed greater engagement, concentration, and persistence when rhythmic cues were present. Rhythm-based interactive games like *Burger Beat* show promise for enhancing children's motor coordination and motivation through structured multisensory feedback.

Keywords:
Fine Motor Skills, Serious Games, Rhythmic Interaction, Computer Vision, Child Development

1 Introduction
Fine motor skills play a fundamental role in child development, providing the foundation for daily activities ranging from buttoning clothes to writing [12]. Mastery of these skills in early childhood contributes not only to physical well-being but also substantially to cognitive and social development [2, 17]. Longitudinal studies have demonstrated, for example, that the level of fine motor proficiency in preschool can predict later school adjustment, including academic performance and social adaptation [14]. Conversely,

deficits in fine motor coordination are associated with educational and psychological difficulties; children with poor motor control tend to exhibit lower self-esteem, higher anxiety levels, and problems with peer integration [13, 18]. Thus, strengthening fine motor skills in neurotypical children is a priority for fostering healthy developmental trajectories [15].

Despite this importance, traditional interventions to improve fine motor abilities face limitations. Conventional occupational therapy approaches often rely on repetitive, monotonous exercises with simple materials (e.g., stacking blocks, tracing lines) that many children find unappealing [3, 19]. This lack of dynamism frequently leads to a decrease in the child's motivation and participation, reducing adherence to the treatment and, consequently, its effectiveness. In fact, parents and clinicians report that children often become bored with such mechanical motor rehabilitation tasks, which hinders the expected progress. In light of this, there is a need to explore new playful and interactive strategies that make these exercises more stimulating and accessible for young patients [4]. Gamification and multimedia technologies offer the possibility of transforming therapeutic exercises into game-like activities, thereby increasing the child's engagement and enjoyment during practice [16]. This work presents Burger Beat, an interactive game designed to enhance fine motor coordination in neurotypical children, incorporating rhythmic visual and auditory components to increase the efficacy and appeal of therapy. The system is designed for the child to perform sequences of hand movements (e.g., a pinch grasp, opening and closing the hand) in synchrony with musical stimuli, following on-screen visual patterns to the beat of a sound cue. These movements are detected in real time via a device's camera (computer or tablet) using computer vision techniques to recognize the user's hand gestures.

The goal is to turn traditionally static exercises into a rhythmic, multisensory experience, leveraging audio-motor synchronization to improve dexterity in a playful way. In the following, we review the most relevant works that support this approach, covering serious games for fine motor skill development, the use of sensors and computer vision in gesture detection, and the effect of rhythmic-musical stimuli on motor training.

2 Related work

The integration of computer vision technologies and gamification principles has been recognised as a promising approach to enhancing fine motor development in early childhood. By incorporating gesture recognition systems, multisensory stimuli, and game-based mechanics, interactive environments have been developed that reframe conventional therapeutic exercises into engaging and motivating experiences. These platforms have found application across a range of contexts, including early intervention, special education, and pediatric rehabilitation.

To contextualize these developments, the following subsections will outline the key interactive systems implemented for motor training, focusing on the technological strategies and therapeutic results highlighted in the research.

2.1 Interactive games for motor training

Interactive serious games that leverage motion sensors and depth cameras have been used to train hand and finger coordination in children. For example, [6] a Leap Motion–based 3D game implemented in Unity required participants (n = 28; 20 boys, 8 girls) to locate, grasp, move, and release virtual objects across progressively difficult levels. The game required children to perform the steps of locating, holding, moving, and releasing virtual objects to place them in boxes across three levels of increasing difficulty. User perception was measured through a 13-question survey using a Likert scale, which was validated by a multidisciplinary team and showed high internal consistency with a Cronbach's alpha of 0.83. The results indicated a highly positive perception among the children regarding hand grip and avatar movement within the game. Nevertheless, the system's performance was susceptible to environmental factors, requiring a preferably dark setting for optimal operation, and the evaluation was primarily based on user perception via a survey.

Another example, [7] there are studies that investigated the Gesture Interactive Game-based Learning (GIGL) approach using an ASUS Xtion PRO sensor to improve learning performance and motor skills in preschool children. The study involved a "The Goalkeeper" game, where children used body movements to catch virtual balls of different colors, simultaneously learning color names in English and training motor skills. A quasi-experiment was conducted with 105 preschoolers (average age 5.5), who were divided into an experimental group (GIGL) and a control group (traditional game-based learning). The results showed that the experimental group demonstrated significantly better learning performance. However, the authors explicitly note the relatively short timeframe of the experiment and its small, exploratory scale, which limits the generalizability of the findings and suggests a need for longitudinal studies with larger, more diverse populations.

A larger controlled intervention involving 202 fourth-grade students [22] investigated whether a digital fine motor skills game could yield broader cognitive and academic benefits. In this study, the authors aimed to test the benefits of digital training of fine motor skills for children's fine motor skills as well as for their reading and writing skills and graphomotor skills. Results indicated improvements in a targeted fine motor skill, spelling, graphomotor performance, and a specific executive function relative to an active control group. Nonetheless, gains did not extend to broader literacy domains such as reading comprehension, and the absence of correlations among improvements limited inferences about transfer mechanisms.

Together, these studies illustrate the promise of sensor-driven play for motor skill acquisition but also point to recurring issues: modest sample sizes, reliance on subjective usability measures, and sensitivity to environmental factors.

2.2 Vision-based gesture detection for Accessible training

There is evidence supporting the use of digital platforms, such as video game–based systems, designed to promote cognitive and fine motor development in children with special needs.

[8] Studies exemplify this approach by utilizing the Leap Motion Controller, a vision-based sensor, to create a serious game system for upper limb rehabilitation in Parkinson's disease patients. The system's core is its markerless, vision-based hand tracking, which detects fine motor gestures like pinching, grabbing, and individual

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finger movements without requiring users to wear any sensors. This technology enables an accessible training platform where patients interact with therapeutic games through natural gestures. The feasibility study confirmed that this vision-based approach was not only effective in improving motor skills but also highly usable, providing a practical and engaging tool that can be deployed in clinical or potentially home-based settings to make rehabilitation more accessible.

Another example, [9] there are studies that investigated appropriate hand gestures for controlling video games in a rehabilitation exergaming system to improve adherence to therapies for musculoskeletal disorders. The system uses gesture recognition, integrated with Python's library OpenCV, and a web-based maze video game. Ten gestures were selected from thirty-two, forming best and second-best groups, evaluated for usability and accuracy with 15 university students in a controlled environment, using SUS and UEQ scales. The results showed that the best gesture group offered greater accessibility, higher game scores, and recognition accuracy. However, the study had limitations. Environmental factors like lighting and distance affected accuracy, and no rehabilitation experts were involved, suggesting improvements in design and future evaluations.

Also, [23] additional research proposed a lightweight graph convolutional network for real-time hand gesture recognition supporting an interactive rehabilitation game. In a small usability test (n = 4), most participants improved their passing rate—successfully writing the prompted characters—across consecutive rounds and described the experience as smooth and interesting. However, the extremely limited sample size, sparse demographic information, and technical limitations—such as the difficulty of air-writing and imperfect third-party character recognition—restrict the generalizability of the results and highlight the need for broader clinical validation

2.3 Adaptive rhythm-based games for motor skills

The potential of rhythm-based serious games represents a promising direction for motor rehabilitation and skill training. For instance, [10] previous work has explored the use of a Leap Motion–based rhythm game designed to automate fine motor rehabilitation exercises for individuals with stroke or Parkinson's disease. The Guitar Hero-inspired game requires players to perform hand gestures synchronized with on-screen notes. A key innovation is an adaptive calibration algorithm that customizes gameplay sensitivity to an individual's range of motion for fist opening or wrist extension exercises. In a pilot study with 14 impaired and 14 non-impaired participants, no statistically significant performance difference was found, demonstrating the system's accessibility. A second study with 8 impaired participants confirmed that calibrated gameplay yielded significantly higher scores than non-calibrated gameplay. However, the authors note the preliminary nature of these small-scale studies, which focused on establishing usability rather than functional recovery, and recommend future longitudinal studies with larger cohorts.

Similarly, a pilot study evaluating a rhythmic game for Parkinson's disease [21] involved 33 patients with Parkinson's disease (6 women; mean age 68.40), who trained finger tapping to musical beats. Compared with an active control group (Tetris) and a no-intervention group, the rhythmic training group achieved significant improvements in rhythmic performance for orofacial and manual tasks, as well as rhythm perception. However, improvements did not extend to gait, and the intervention's effectiveness depended on consistent engagement, which was challenging for some participants.

In addition, [24] a study examining the integration of tactile stimulation into a rhythmic serious game for children aged 6–12 (N = 25) demonstrated that combining tactile and audiovisual cues significantly improved sensorimotor synchronization and produced greater activation in prefrontal, temporal, and motor regions compared with audiovisual-only gameplay. These findings highlight the value of multisensory rhythmic training in enhancing motor coordination and cognitive engagement, particularly for learners and clinical populations with developmental or therapeutic needs.

Collectively, rhythm-based approaches suggest that temporal cues can scaffold motor timing and engagement, yet evidence remains preliminary, frequently derived from small cohorts and short interventions.

3 Designing Burger Beat

We followed an iterative user-centered design approach to develop *Burger Beat*, a rhythm-based game for improving fine motor coordination in children. Experts in physiotherapy, music, and interaction design guided the refinement of gestures, rhythm cues, and feedback to ensure an engaging and effective experience.

3.1 Design process

A qualitative, user-centered design methodology was followed for 2 months to develop *Burger Beat*, a serious game aimed at strengthening fine motor coordination in neurotypical children through rhythmic visual and auditory interaction. During the study, 14 semi-structured interviews were conducted with 7 experts, including 2 physiotherapists, 3 music producers, and 2 designer(s) (Total duration = 13.4 hours; μ = 45 min; SD = 12.7 min). Each participant gave informed consent to be recorded via audio and to have their contributions documented.

The interview protocol comprised 22 open-ended questions addressing: (1) the main causes and manifestations of fine motor difficulties in children, (2) musical and rhythmic considerations for designing interactive rhythm-based games, and (3) children's preferences regarding game mechanics, feedback, and rewards. All interviews were transcribed verbatim, and a thematic microanalysis was performed to extract recurrent concepts and usability requirements. This process allowed the research team to synthesize the findings into thematic categories and to define key design principles for *Burger Beat*.

To ensure expert participation in the design process, the interviews were complemented by 6 collaborative design sessions. These sessions were attended by rehabilitation specialists, music producers, Human-Computer Interaction (HCI) experts, and educational game designers (Total duration = 9.4 hours; μ = 94 min; SD = 12 min). The sessions followed a participatory design dynamic: first, participants were introduced to the study context

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and objectives; subsequently, brainstorming activities were carried out to propose potential game mechanics and visual-auditory feedback strategies. As a result, 2 low-fidelity prototypes were created, which were evaluated collectively. The participants discussed their advantages and disadvantages and selected the prototype that best supported fine motor training through rhythmic interaction.

3.2 Design Considerations of a Rhythm-Based Videogame for Fine Motor Skill Development in Children

The contextual analysis, expert interviews, and iterative design sessions conducted during the development of *Burger Beat* allowed us to identify a set of key design considerations for rhythm-based serious games aimed at enhancing fine motor coordination in children. These considerations can guide future researchers and developers in creating interactive systems that combine music, movement, and play for therapeutic or educational purposes.

3.2.1. Provide an engaging narrative context that supports motor learning

Previous research has shown that embedding meaningful narratives within learning environments enhances children's motivation, engagement, and skill acquisition [16]. In *Burger Beat*, a restaurant-themed narrative was incorporated to contextualize the fine motor tasks within a playful and goal-oriented setting. Throughout the game, children assist in preparing hamburgers for various customers, transforming repetitive gesture-based exercises into an engaging culinary activity.

"When children feel part of a story, they forget that they are exercising. They just want to help the character, and that's what keeps them moving." [Motor therapist, P1]

Through this narrative framework, *Burger Beat* encourages engagement and persistence, promoting fine motor learning through play.

3. 3.2.2. Integrate multimodal feedback for motor awareness and learning

Motor learning research emphasizes the importance of multimodal feedback, combining visual and auditory cues to enhance perception and coordination. In *Burger Beat*, each gesture is accompanied by synchronized visual and rhythmic feedback to reinforce movement awareness.

Before an ingredient reaches the chopping board, the game produces a distinct rhythmic sound corresponding to the gesture required: *pinch* for tomatoes and lettuce, *open hand* for the bread bun, and *closed fist* for the meat patty. This anticipatory cue helps children prepare and synchronize their actions with the beat of the music.

"Auditory cues are essential. Some children react faster to sound than to visual signals, especially when they're focused on movement." [Motor therapist, P1]

This cross-modal feedback design strengthens the child's sensorimotor coupling, ensuring that gestures are learned through both perception and timing.

3.2.3. Employ rhythmic synchronization to promote temporal precision

Rhythmic synchronization has been shown to improve timing, coordination, and cognitive focus in children. To achieve this, *Burger Beat* integrates a rhythm extraction algorithm that detects beats per minute (BPM). Each beat corresponds to an ingredient's motion on the conveyor belt, ensuring that gestures align with consistent musical timing.

"The rhythm helps children anticipate the gesture. They start to expect the sound — they know when the next move is coming even before they see it." [Music producer, P3]

Through rhythmic training, *Burger Beat* enhances fine motor timing, attention, and fluency of movement.

3.3 Narrative design

Before developing the game and implementing the hand-tracking system, a narrative was created to establish the emotional and motivational foundation of *Burger Beat*. The story centers around Max, an enthusiastic little dog who dreams of running his own restaurant, introduced in the game's startup screen, shown in Figure 1. Max has recently opened a small burger shop called "PawBurger", where customers line up eagerly to taste his delicious creations. However, as the day progresses, more and more customers arrive, and Max must prepare a specific number of hamburgers to keep everyone happy and provide excellent service.

Each customer places a different order, meaning no two hamburgers are the same. Some may be simple — for example, bread, meat, bread — while others are more elaborate, such as bread, meat, lettuce, bread, or even include extra layers and ingredients. The player's task is to help Max assemble each unique burger correctly and on time, following the rhythm of the music.

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Figure 1."Burger Beat" transforms therapeutic gestures into a rhythm-based burger assembly task where players help to complete customer orders through hand gestures.

3. 4 Game Mechanics and Features

Burger Beat employs a rule-based interaction structure in which motor precision and temporal synchronization determine the player's performance. Each ingredient in the burger corresponds to a specific therapeutic gesture guided by a rhythmic cue. As shown in Figure 2, the tomato and lettuce are sliced with the pinch gesture, the bread bun is grabbed with an open-hand gesture, and the meat patty is flattened using a closed fist. These actions help Max, the puppy chef, keep up with the rhythm of the kitchen, combining musical beats with fine motor movements. The game's narrative and mechanics are designed to make children feel part of Max's restaurant crew, turning therapeutic exercises into an engaging culinary adventure full of colors, music, and fun.

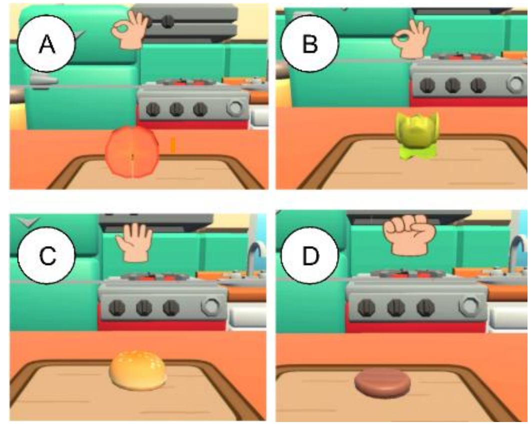

Figure 2. Therapeutic gesture mapping for ingredient preparation in Burger Beat: A. Tomato - pinch gesture, B. Lettuce - pinch gesture, C. Bread bun - open-hand gesture, D. Meat patty - closed-fist gesture.

Each level consists of a short session lasting a few minutes, where different ingredients appear at varying tempos and intensities. The gestures are associated with specific motor functions recommended by a physiotherapist. Visual cues (icons of the hands and ingredient motion) and rhythmic sound cues guide the player through the exercise.

When a gesture is correctly performed at the right time, the system provides visual rewards (spark effects, points, or smiles from Max) and auditory feedback (confirmation tones or rhythmic reinforcement). This immediate feedback loop encourages attention, timing, and precision. As the player progresses, the rhythm becomes more complex, stimulating coordination and temporal synchronization.

3.4.1 Point system

The scoring system provides immediate feedback based on both temporal and spatial accuracy. Children must perform the corresponding gesture precisely when the ingredient reaches the cutting board, where the system detects the movement and assigns a score depending on how accurately the gesture was executed. As illustrated in Figure 3, a correct gesture receives 3 points, a partially correct gesture receives 2 points, and an incorrect or mismatched gesture receives 1 point.

As shown in Figure 4, each gesture is evaluated within a defined temporal window corresponding to its rhythmic cue. The purple marker indicates the anticipatory signal that alerts the player to the upcoming movement, while the green zone represents the optimal timing interval in which a gesture is registered as correct. Gestures performed too early or too late fall into the red error zone, resulting in a missed score. Once all required gestures within a sequence are completed, the final assembled burger is displayed as visual feedback, summarizing task success immediately and intuitively.

3.4.2 Rhythmic Cue Design and Temporal Synchronization

One of the key features of *Burger Beat* is the integration of rhythmic sound cues that guide the player's movements and enhance their temporal awareness during gameplay. This rhythmic system was developed to provide an auditory scaffold that complements the visual guidance on screen, helping children anticipate when and what gesture to perform.

Before each ingredient reaches the cutting board, the game emits a distinct rhythmic sound that signals the upcoming gesture. Each ingredient—bread, meat, tomato, and lettuce— is assigned to a unique auditory cue that corresponds to its respective motor action.

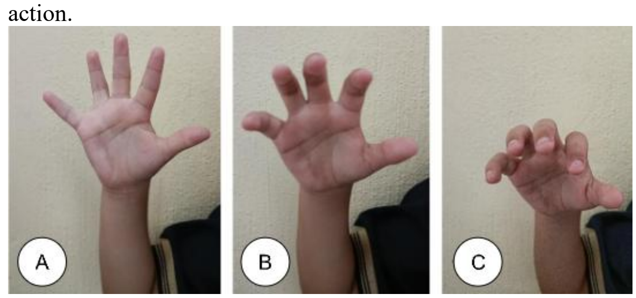

Figure 3. Real hand gestures and scoring in Burger Beat, showing open hand evaluated as A. correct (3 pts), B. partial (2 pts), or C. incorrect (1 pt).

These sounds are short, percussive, and aligned with the beat of the background music, allowing players to associate specific tones with specific gestures. As the conveyor belt moves, the rhythmic cues occur slightly before the ingredient appears in the action zone, giving the player time to prepare and synchronize their movement.

A rhythm extraction algorithm analyzes the background track to estimate tempo (beats per minute) and identify periodic accents corresponding to a 4/4 meter. From these data, a sequence of timestamps is generated to define when each ingredient enters the

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visual field and when its corresponding auditory cue should occur. Each food item (bread, meat, tomato, lettuce) is paired with a distinctive percussive tone that precedes its on-screen appearance by a fixed offset, allowing players a brief anticipatory window to prepare their gestures.

By combining rhythmic sound cues with visual movement and real-time feedback, *Burger Beat* helps children develop a stronger sense of timing and coordination. This synchronization between music, gesture, and action reinforces fine motor control and transforms the exercise into a rhythmic, multisensory experience that is both educational and engaging.

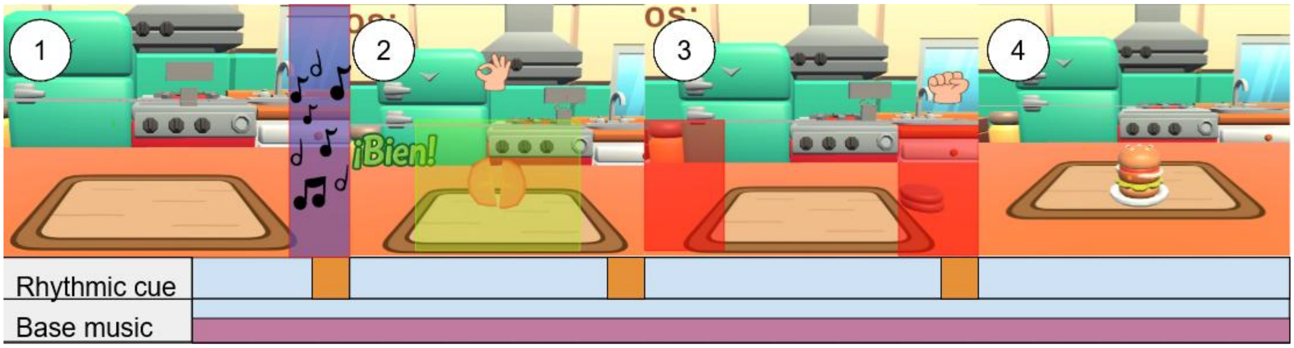

Figure 4. Scoring and feedback timeline in the rhythm-guided version of Burger Beat. (1) Rhythmic cue, (2) correct zone, (3) error zone, (4) final burger as feedback.

3.5 Developing Burger Beat

Burger Beat is built upon a three-component architecture designed to support fine motor training through rhythmic interaction. As shown in Figure 5, the system comprises a Camera Sensor, a Processing Host for hand-tracking, and a Unity Game Engine, forming a closed interaction loop that captures, processes, and visualizes user movements in real time.

The Camera Sensor—a high-definition webcam—acquires continuous video input of the child's hand gestures. This stream is handled by the Processing Host, implemented in Python, which executes a neural-based hand-tracking algorithm capable of detecting up to two hands per frame and extracting twenty-one anatomical key points per hand. These spatial coordinates are transmitted to the Unity environment via a low-latency User Datagram Protocol (UDP), ensuring synchronized and responsive communication.

Within the Unity Game Engine, the incoming data is interpreted to trigger gesture-specific events such as pinch, open hand, or closed fist. The engine renders these movements in synchrony with rhythmic stimuli, providing immediate visual and auditory feedback. This integration between sensing, processing, and presentation enables a seamless feedback loop that reinforces timing, coordination, and engagement during motor training.

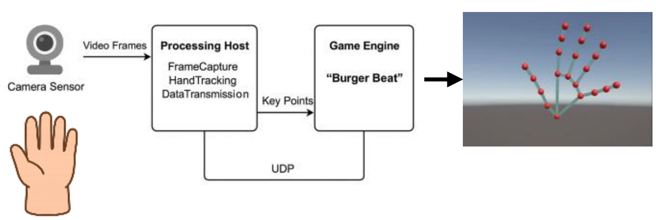

Figure 5. System Architecture. A three-component framework for motor training: a Camera Sensor, a Processing Host for hand-tracking, and a Unity Game Engine, forming a closed interaction loop.

4 Evaluation study

We evaluated *Burger Beat* to:

- Determine whether rhythmic musical synchronization effectively supports the practice of fine-motor gestures in children.
- Assess the system's ability to enhance task accuracy and consistency during gameplay.
- Examine its impact on perceived user experience, including competence and autonomy.

We hypothesized that children who played the rhythm-guided version of *Burger Beat* would demonstrate improved fine-motor performance, reflected in higher accuracy scores and fewer gesture errors, compared to the non-rhythmic version. We also hypothesized that the inclusion of musical rhythm would positively influence the user experience, increasing engagement, perceived competence, and autonomy during play.

4.1 Participants

Twenty-two children (N = 22) aged between 6 and 7 years (M = 6.60, SD = 0.49) participated in the study. Participants were recruited from a local primary school and exhibited typical cognitive and motor development according to school records and parent reports. All children were right-handed for writing and had no known motor impairments or prior experience with motor training systems. Testing sessions were conducted individually in a quiet classroom adapted for the study to minimize distractions. Each session lasted approximately 20 minutes, including familiarization with the game mechanics and a short practice phase. Written informed consent was obtained from parents or legal guardians, and verbal assent was obtained from each child before participation. The study followed ethical guidelines for research with minors and was approved by the institution's human research ethics committee.

4.2 Procedure

We conducted a within-subjects study in which each child completed both experimental conditions in separate sessions. To control potential order effects and mitigate learnability and fatigue, participants were randomly assigned to one of two counterbalanced groups: eleven children experienced Burger Beat under the rhythm-guided gameplay condition first, followed by the non-rhythmic condition, while the remaining children experienced the non-rhythmic gameplay condition first, followed by the rhythm-guided condition. Figure 6 illustrates how each session began with a 120-second narrative introduction, during which the facilitator presented the game's storyline and characters to foster engagement and contextual understanding. This was immediately followed by a 120-second interactive tutorial that demonstrated the three target gestures (pinch, open hand, and closed fist) and allowed children to practice each movement while receiving real-time feedback from the system. After the tutorial, participants completed a 70-second gameplay block, during which they independently played Burger Beat according to their assigned condition (with or without rhythmic accompaniment). To minimize fatigue and maintain attention, a 15-second rest period was provided between gameplay blocks. This cycle of play and rest was repeated four times, resulting in approximately six minutes of active gameplay per condition. During gameplay, the system automatically logged gesture detections (type, timestamp, and confidence) and synchronized these with the appearance of on-screen target. The narrative introduction was included in both conditions.

Rhythm-guided condition (with music): Each child interacted with the full version of Burger Beat. In this condition, each child used a set of headphones to hear the music. Children were instructed to perform one of three fine-motor gestures—pinch, open hand, and closed fist—at the exact moment the corresponding ingredient reached the target area on the screen. Correctly timed gestures caused the ingredient to be "captured," contributing to the virtual preparation of a hamburger. The session lasted six minutes and included continuous musical accompaniment to maintain rhythmic engagement. Both conditions were administered individually in the same classroom space. The instructor sat beside the participant to ensure safety and provide minimal prompts if needed (e.g., "Show your pinch," or "Try to open your hand more"). The ambient lighting and setup were maintained at a constant level across all sessions.

Non-rhythmic condition (without music): In this version, participants played an otherwise identical game; however, the rhythmic cues were removed. Children were instructed to perform the same gestures when each ingredient reached the target zone. The duration and scoring structure were identical to those of the rhythm condition.

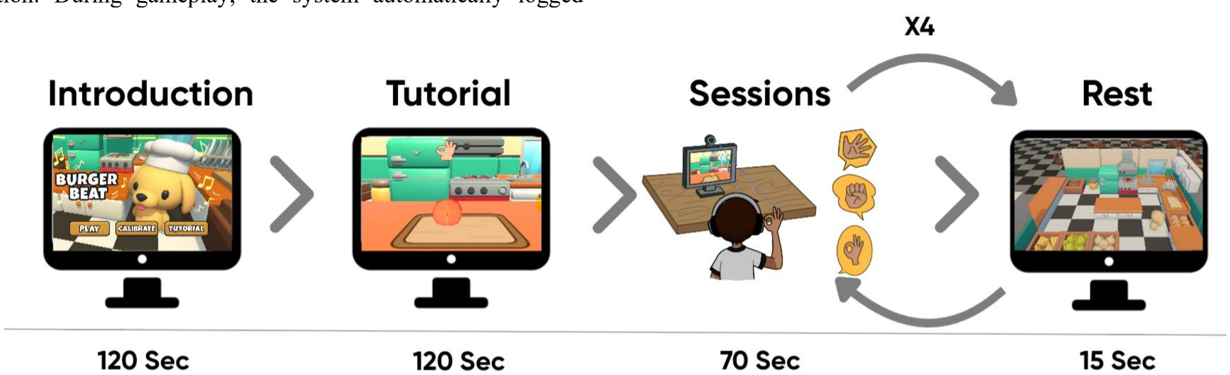

Figure 6. Each session consisted of a 60-second narrative introduction, a 60-second gesture tutorial, four 70-second gameplay blocks (with or without rhythmic music), and 15- second rest intervals between blocks.

4.3 Materials

To evaluate *Burger Beat*, a pictorial version of the Player Experience of Need Satisfaction (PENS) scale was administered after each session [11]. From the original five dimensions, we selected competence, autonomy, and intuitive controls, as they best captured the player's motor performance, sense of agency, and ease of gesture execution—key factors for assessing interaction quality in a rhythm-based motor training game. Participants rated their agreement on a 7-point Likert scale (1 = Do Not Agree, 7 = Strongly Agree), supported by a facial expression scale to facilitate comprehension and accurate scoring for children.

During gameplay, the system automatically logged gesture detections (type, timestamp, and confidence) and synchronized them with rhythmic targets. Each event was categorized as correct, partially correct, or incorrect, capturing spatial and temporal precision. The scoring data—recorded as total points per session, block, and gesture following Section 3.4.1—were later analyzed to compare motor performance across conditions.

Additionally, semi-structured interviews were conducted after each condition (with and without rhythm) to explore children's perceptions of enjoyment, ease, and motivation. These qualitative insights complemented the quantitative data, enabling a more comprehensive understanding of user experience and engagement.

4.4 Data analysis

Behavioral data were analyzed through descriptive statistics to summarize children's performance across conditions. Normality of the data was verified using the Shapiro–Wilk test, which indicated non-normal distributions ($p < 0.05$ across all variables). Therefore, the Wilcoxon signed-rank test was applied as the appropriate non-parametric method for within-subject comparisons between the rhythmic and non-rhythmic conditions.

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During gameplay, gesture detections (type, timestamp, confidence) were automatically logged and synchronized with the rhythmic targets. Each interaction was classified as correct, partially correct, or incorrect following the scoring criteria outlined in Section 3.4.1.

In addition, PENS scores (competence, autonomy, and intuitive controls) were computed for each participant to evaluate perceived performance and ease of interaction. Semi-structured interviews conducted after each condition were transcribed and thematically coded to identify patterns in children's perceptions of difficulty, engagement, and preference for rhythm-guided play.

5 Results

5.1 Effect of Musical Rhythm on Fine-Motor Performance

The results indicate that the rhythm-guided version of *Burger Beat* significantly enhanced children's fine motor performance compared to the non-rhythmic version (See Figure 7). Overall, participants achieved higher total performance scores when musical rhythm was present, as confirmed by the Wilcoxon signed-rank test ($W = 58$, $p = 0.017$, see Figure 7 for boxplot comparison). This finding demonstrates that rhythmic accompaniment improved both task accuracy and consistency, suggesting that synchronized auditory cues provided a stable temporal framework that helped children anticipate and coordinate their actions more effectively.

When examining performance by gesture type, a more nuanced pattern emerged. Significant improvements were observed in the pinch ($W = 39$, $p = 0.0063$) and open-hand gestures ($W = 19$, $p = 0.0063$*), while the fist gesture showed a positive but non-significant trend ($W = 55$, $p = 0.0637$). These results suggest that rhythmic cues were particularly beneficial for fine, high-precision movements —those requiring delicate timing and refined motor control —whereas broader, less temporally dependent gestures benefited less from rhythmic alignment.

For gestures rated as partially correct, rhythm also contributed to smoother and more coordinated performance, reaching statistical significance for the pinch gesture ($W = 36$, $p = 0.0070$*). Although the open-hand ($W = 46.5$, $p = 0.0887$*) and fist ($W = 117.5$, $p = 0.945$*) gestures did not show significant differences in this category, their median scores still trended toward improvement under rhythmic conditions.

Finally, the number of incorrect gestures significantly decreased across all gesture types in the rhythm-guided condition: pinch ($W = 28.5$, $p = 0.0073$*), fist ($W = 18$, $p = 0.0018$*), and open-hand ($W = 12$, $p = 0.0063$*). This reduction in errors highlights that rhythmic cues not only enhanced temporal synchronization but also stabilized motor execution, enabling children to perform gestures with greater precision and fewer mistakes.

Taken together, these findings suggest that the integration of rhythm as a temporal scaffold supports the development of coordinated and efficient fine-motor performance. By externalizing timing demands through predictable auditory cues, the rhythmic condition likely reduced cognitive load and facilitated smoother sensorimotor coupling—key mechanisms for effective motor learning and engagement in early childhood.

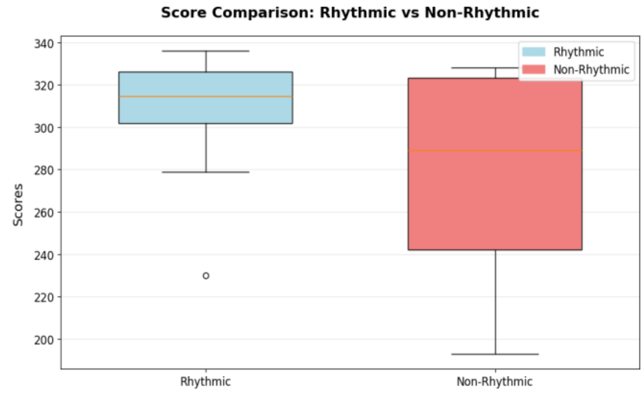

Figure 7. Score comparison between rhythmic and non-rhythmic conditions.

5.2 Perceived experience

The results from the PENS questionnaire revealed significant differences in children's perceived experience between the rhythm-guided and non-rhythmic conditions (See Figure 8). Scores for perceived competence were significantly higher in the rhythm-guided condition ($W = 42$, $p = 0.0073$), indicating that participants felt more capable and successful when their gestures were synchronized with musical cues. Children frequently expressed that the rhythm made the game "easier to follow" and "more fun," describing a growing sense of mastery as they advanced through the session.

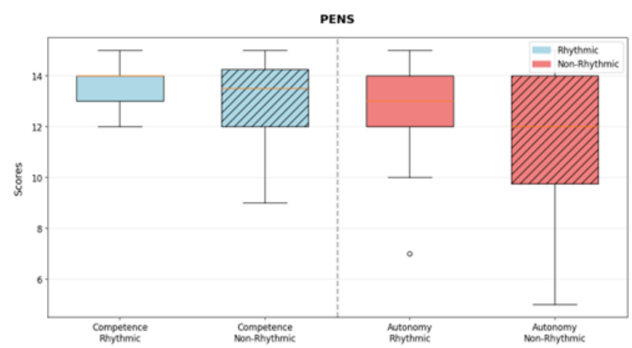

Figure 8. PENS comparison between rhythmic and non-rhythmic conditions.

"Yes, actually... the more burgers I made, the easier it became with practice." [E1]

"With the rhythm, it felt like it helped to do things better." [E2]

Similarly, perceived autonomy scores were also significantly higher under rhythmic conditions ($W = 32$, $p < 0.001$). The addition of auditory cues provided a sense of self-directed flow, allowing children to anticipate each gesture and feel in control of the sequence of movements. Verbal reports reinforced this sense of agency and motivation:

“Music helped me concentrate better.” [E6]

“With the rhythm it was easier... because in the other one I didn't have the rhythm.” [E10]

Finally, the intuitive controls dimension showed a smaller but still significant improvement (W = 49, $p = 0.042$), suggesting that rhythmic structure contributed to smoother interaction and better recall of gesture–action mappings. Children reported that the timing of the cues made it “easy to remember what to do next” reinforcing the connection between auditory feedback and motor intention.

Overall, these findings indicate that rhythmic synchronization not only enhanced motor accuracy (as shown in Section 5.1) but also fostered a stronger perception of competence, autonomy, and intuitive control—key factors for engagement and learning in fine motor training tasks.

6 Discussion and conclusions

This paper presents the design and implementation of *Burger Beat*, an interactive, rhythm-guided game intended to strengthen fine motor coordination in children by synchronizing manual gestures with musical beats. The integration of rhythmic auditory cues within *Burger Beat* appears to produce measurable benefits for fine motor coordination, attentional control, and the subjective experience of movement in children aged 6–7. The observed improvements in gesture accuracy—especially the reduction in incorrect executions across all gesture types and the significant gains in pinch and open-hand gestures—speak to the capacity of rhythm to scaffold precise timing and spatial alignment of movement. Children, in turn, reported that the rhythm “helped me do things better” or made the game “easier to follow,” suggesting that the auditory scaffold functioned as an intuitive guide rather than a distractor.

These results align with broader evidence in motor and cognitive neuroscience about rhythmic entrainment and its role in sensorimotor synchronization. For example, a recent study found that children at risk for developmental coordination disorder (DCD) showed enhanced tapping consistency in the presence of a regular auditory cue compared to no rhythm, pointing to a facilitative effect even in populations with motor timing vulnerabilities [20], supporting the idea that rhythmic structure can compensate for internal timing inconsistencies. Moreover, *auditory rhythmic regularity* has been shown to benefit both perceptual and motor coordination in such at-risk populations [20]. In a related line, a comprehensive review of music-supported therapy highlighted that incorporating rhythmic musical elements can improve upper-limb movement kinematics in neurological populations, often matching the gains from standard rehabilitation protocols [25].

Beyond motor precision, the cognitive dimension of rhythm use in development is compelling. Musical training frequently produces transfer effects into executive control, working memory, and inhibitory control in typically developing children [26]. For instance, children who take music lessons often outperform peers in verbal memory, reading, and attentional tasks, and rhythmic entrainment is posited as a core mechanism driving such cross-domain effects. In the context of *Burger Beat*, then, the advantage of rhythmic guidance may be twofold: it supports immediate motor timing and fosters emergent gains in attentional regulation and temporal anticipation—capacities that are crucial in classroom settings and in the orchestration of complex manual tasks.

Significantly, *Burger Beat* uses low-cost hardware (webcam + laptop) along with gesture-detection and rhythm extraction algorithms, demonstrating that such interventions need not require high-end sensors to be effective. This increases its scalability in schools, clinics, or homes. Still, not all gestures responded equally; the fist gesture lacked a significant difference, possibly because its execution depends more on gross force than fine-tuned timing or because it offers less room for subtle spatial adjustment. This nuance suggests that future design of rhythm-based motor games might need to calibrate the degree of temporal strictness per gesture type.

The limited improvement observed in the closed-fist gesture raises the possibility that rhythmic scaffolding is more effective for movements requiring temporal precision than for those primarily driven by force. This pattern invites future work to examine whether rhythmic cues indeed provide a stronger scaffold for fine-motor coordination, and to explore how this mechanism might deepen our understanding of how rhythm shapes motor learning.

Finally, although the improvements shown in this study are promising, they do not yet guarantee long-term retention or transfer to everyday tasks like handwriting or object manipulation outside the game context. Thus, the present results should be seen as evidence of immediate rhythmic scaffolding benefits, warranting extended follow-up to ensure durability and generalization, as these aspects will be considered in future work to more fully evaluate the persistence and real-world applicability of the observed effects.

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