**Research Article**

# Computer Vision-Augmented Exergaming for Spine Health

**Thandavamurthy Jayasree*, Palchamy Pragathi, Saravanan Premkumar, Senthilkumar Revathi Sree Krishna**

Department of Biomedical Engineering, College of Engineering Guindy, Anna University, Chennai- 600025, India

***Corresponding author:*** Thandavamurthy Jayasree, M.E, PhD, Assistant Professor
Department of Biomedical Engineering, College of Engineering Guindy, Anna University, Chennai – 600025, India
**Email:** jai_t@annauniv.edu

**ORCID ID**:
**Thandavamurthy Jayasree:** 0000-0003-2069-409X
**Palchamy Pragathi:** 0009-0008-9519-6849
**Saravanan Premkumar:** 0009-0005-0558-7837
**Senthilkumar Revathi Sree Krishna**: 0009-0003-7266-2134

**Article info:**
Received: 10 Oct 2025
Accepted: 10 Feb 2026

**Citation:** Jayasree T, Pragathi P, Premkumar S, Krishna SRS. Computer Vision-Augmented Exergaming for Spine Health. Journal of Modern Rehabilitation. 2026;20(2):?-?

**Running title:** Exergaming for Spine Health

***Abstract***
This research introduces a novel, technology-driven approach to back pain rehabilitation by integrating real-time pose detection with interactive Unity-based gaming experiences. Our system delivers personalized exercise regimens targeting flexibility, strength, and posture while providing users with immediate feedback. User friendly gaming platform was developed using the Unity engine that integrates real-time analysis of physical exercises. The system successfully analysed the performance of three major exercises Knee-to-chest stretch (cross crunches), side bend, forward and backward bends and demonstrated a measurable improvement in the user scoring pattern, suggesting enhanced engagement and effective performance analysis. By successfully gamifying these therapeutic exercises, we aim to significantly boost user engagement and adherence to treatment protocols, leading to improved long-term spinal health outcomes. This framework offers a dynamic, adaptable, and highly scalable solution for individuals with varying rehabilitation needs, demonstrating the potential to profoundly impact the quality of life for those affected by back pain. Transforming exercises into a game is key to driving better, sustained outcomes that helps

in achieving superior long-term therapeutic results.

***Keywords:*** Back pain; Pose detection technology; Rehabilitation; Unity; Spinal health; Gaming exercise

## Introduction

Back pain is a prevalent global health issue affecting millions, leading to significant morbidity, reduced quality of life, and substantial healthcare costs. Traditional methods of back pain management often involve physical therapy, medication, and lifestyle adjustments. However, adherence to these treatments can be challenging due often to factors such as monotony, discomfort, and lack of engagement. The need for innovative, engaging, and accessible rehabilitation strategies is therefore critical for improving long-term patient outcomes [1]

The integration of technology in healthcare has opened new avenues for improving the efficacy and accessibility of rehabilitation programs. Specifically, pose detection technology, powered by advanced computer vision algorithms such as OpenCV and MediaPipe, enables real-time analysis of users' movements and postures. By leveraging this technology, clinicians can gain objective insights into patient performance. Moreover, the incorporation of interactive gaming elements into rehabilitation protocols has shown promise in enhancing patient engagement and adherence. Gamification strategies, such as rewards, challenges, and progress tracking, have been effective in motivating individuals to participate consistently in their programs, many recent studies have focused on, especially for at-home recovery using serious games and advanced technologies.

While existing systems have demonstrated the potential of these technologies, there remains a critical gap in the development of integrated, user-centric frameworks that specifically target the form-critical exercises required for back pain rehabilitation and demonstrably link real-time pose analysis to quantifiable improvements in performance and therapeutic scoring. Effective rehabilitation requires precise monitoring of movement patterns to target specific muscle groups and movement impairments, a level of flexibility and engagement often missing in current applications [2]

In direct response to these challenges and the identified gap, this study introduces a pioneering framework that integrates pose detection technology with interactive gaming experiences to enhance back pain rehabilitation. By transforming traditional exercises into interactive and engaging games, this research aims to increase user satisfaction, encourage active participation, and ultimately improve treatment outcomes for individuals with chronic back pain. This work serves as a proof-of-concept for optimizing therapeutic outcomes through real-time feedback and gamified adherence.

Studies indicate that games are an effective tool for back pain rehabilitation, notably by increasing patient motivation and engagement [3], and by providing viable support where traditional in-person care is restricted [4]. Despite this evidence, a key challenge is the current lack of uniform guidelines for the design and development of these rehab games

Devices like Microsoft Kinect and Nintendo Wii are often used to deliver fun and interactive exercises, largely because these commercially available systems are an alternative to specialized clinical equipment. For example, a

Kinect-based system was created for children with cerebral palsy [5], using games to guide and track their arm movements. However, newer, more advanced systems can involve a higher initial investment: another setup combines virtual reality (VR) games with specialized smart gloves and wearable sensors [6] to support intricate hand and finger exercises. This system records movement data and helps doctors track progress using a mobile app, but the cost of such customized hardware introduces a potential barrier to widespread home use.

A review of past studies [7] showed that video games using motion capture can help stroke patients improve balance and walking. Still, more research is needed to figure out the best game type, timing, and amount of use.

Other researchers have created hand-motion-controlled games like the popular game 2048 [8], making rehab more fun and engaging. Hand gestures can also control robotic arms using image processing [9], and new ways of calculating joint angles help in tracking posture more accurately [10-11]. These tools are especially useful for elderly people who need regular movement monitoring.

Artificial intelligence is also being used to track posture and suggest better exercise routines, ensuring people follow safe and effective movements. Systems like HILLES (Home-based Immersive Lower Limb Exergame System) [12] combine VR and motion sensors to help with leg exercises while keeping the experience fun.

Game platforms like UNITY are used to create rehab games for hand injuries. These games track hand movements in 3D and help patients improve without always needing a therapist. Video analysis tools [15] using camera footage can now accurately detect and classify exercises, making therapy monitoring more precise.

Computer vision is widely used to study human motion, especially to estimate joint positions during rehab [16]. Games that provide real-time feedback are also being used to keep patients motivated [17], and many have been found safe and cost-effective [18].

For chronic pain, serious games with full-body tracking and sensors are being used to teach real-world coping and therapy skills [19]. Early studies show that game-based feedback can improve movement and reduce pain in people with long-term back problems [20]. VR games are being tested to safely expose patients to pain-related movements and help them overcome fear [21].

Some VR systems are made especially for older adults with back pain, using simple designs and feedback suitable for their age [22]. Projects like Virtual immersive gaming to optimize recovery (VIGOR) [23] are testing how VR can improve rehab results in people with chronic pain. One study in Nigeria [24] found VR games for back exercises were cheaper and more effective than regular clinic treatments.

Games like “playMancer” help people with chronic pain improve their motor skills and stay engaged in therapy [25]. A Kinect-based rehab system for cerebral palsy showed similar results to traditional physiotherapy [26], proving that such technology can be just as useful. Finally, exercise games using motion tracking have been shown to reduce pain and boost mobility in older adults [27].

Overall, this growing field shows how combining games, computer vision, and AI can create powerful new ways to support physical rehabilitation. New research is also exploring non-contact, real-time pose tracking systems [28], deep learning for recognizing therapy poses [29], and mobile apps that help people continue therapy at home [30]. Camera-based tools for remote tracking [31] and large datasets for posture and movement [32] are helping make these systems more accurate and effective. These studies collectively underline the advancement toward more accessible, efficient, and technology-driven rehabilitation solutions. Although interactive games present a promising, low-cost solution for enhancing back pain recovery and overcoming limitations in in-person care, the field suffers from a lack of standardized design and practical evidence, particularly concerning the use of off-the-shelf development tools. Building upon this recognized gap, this study aims to investigate the practical application and efficacy of interactive games for home-based back pain rehabilitation. Specifically, this research describes the development and implementation of three distinct rehabilitation games for spine health using the Unity engine and assesses their impact on key user outcomes.

## Methodology

This section outlines the systematic approach adopted in the development and implementation of the back pain rehabilitation system which integrates pose detection technology with interactive gaming experiences. This section details the key steps involved in creating a personalized and engaging platform for enhancing flexibility, strength, and posture to alleviate back pain discomfort. Fig. 1. shows the block diagram of the back pain rehabilitation module [14]. The Unity Engine, developed by Unity Technologies, is used on the host computer to create games for rehabilitation training and assessment. These games are specifically designed to assist individuals in their recovery, offering immersive and interactive experiences. By incorporating gamification principles and engaging in gameplay mechanics, therapy sessions become more enjoyable and effective. Moreover, Unity’s flexibility allows developers to customize experiences according to the unique needs and progress of each patient, enhancing the benefits of rehabilitation efforts.

PyCharm is the primary tool for detecting body postures and mapping landmarks via a webcam. The system calculates joint angles on the basis of these landmarks. When a joint angle exceeds a predefined threshold, PyCharm triggers the corresponding arrow key press. These keyboard inputs are then sent to the Unity engine, which responds by executing the associated movement for the in-game elements. This integration between PyCharm and Unity enables real-time interaction between the user’s body movements and the game environment.

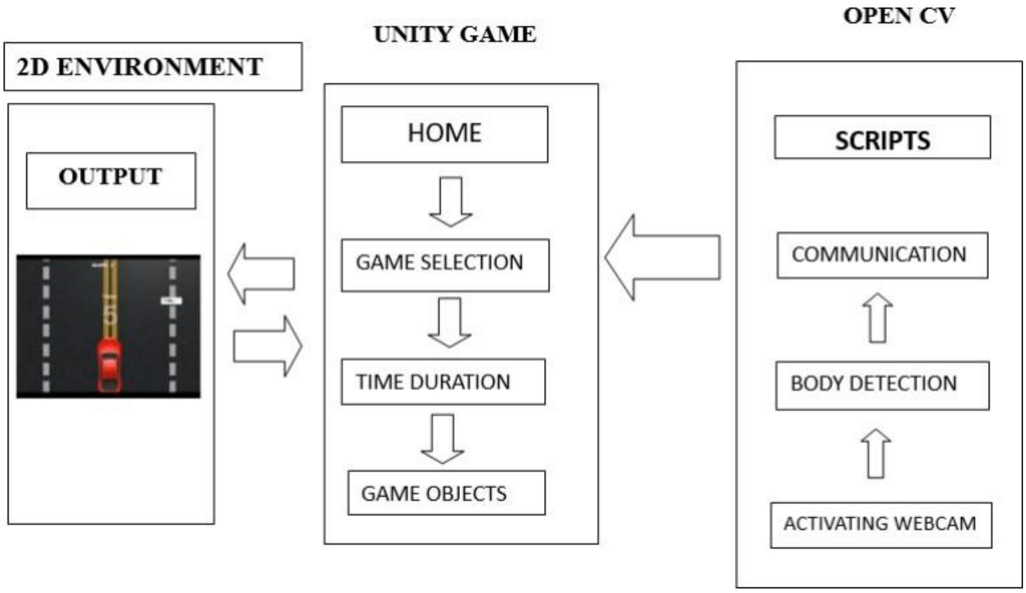



**Fig. 1: Block diagram of the assessment system**

***Game development process***

Bunny Dodge, Road Rush, and Space Run are innovative games developed that combine physical therapy with interactive gaming. These games engage players in exercises targeting core muscles and improving flexibility while offering an enjoyable and immersive experience. By utilizing pose detection technology, they track players' movements in real time, ensuring accurate integration between physical exercises and virtual gameplay. These games provide a fun and motivating way for individuals to engage in rehabilitation while enjoying the excitement of gaming.

As shown in Fig. 2 the rehabilitation gaming system's user interface features three buttons for the games Bunny Dodge, Road Rush, and Space Run. Upon launching the application, users can select their preferred game by clicking the corresponding button, seamlessly transitioning to the game environment.

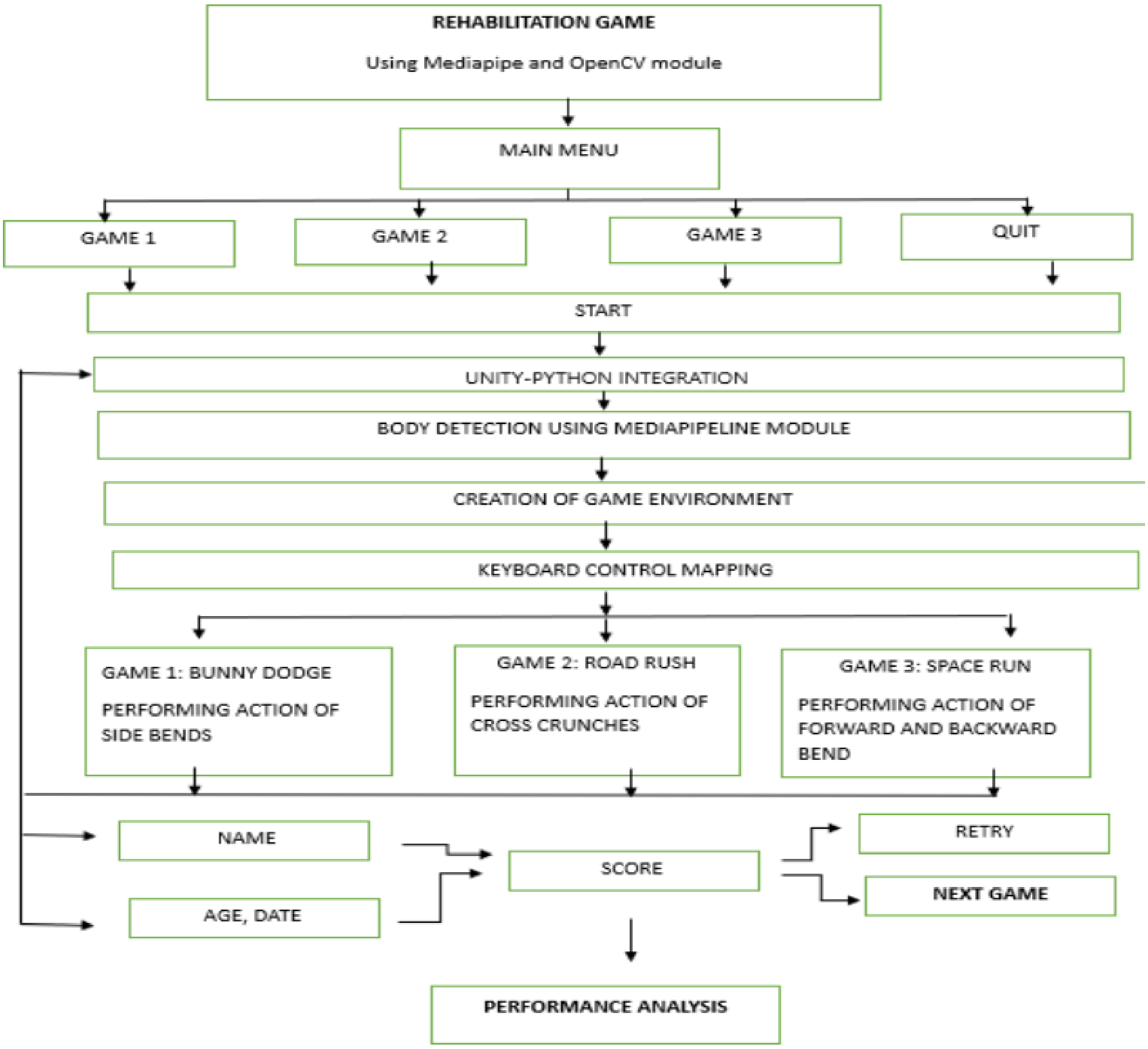



**Fig. 2: Game Menu Screen**

A prominently displayed "Help" button provides essential guidance for interacting with each game. Clicking the "Help" button offers detailed explanations of the required poses and their associated in-game movements, ensuring that users have clear instructions for a smooth and engaging rehabilitationexperience.

Fig. 3 illustrates the detailed architecture of the module which combines three rehabilitation games: Bunny Dodge, Road Rush, and Space Run. The menu offers users a choice among these games, each designed to target specific muscle groups and movements (side bends, cross crunches, and forward/backward bends). The system integrates Unity and Python, utilizing Mediapipe and Open CV for accurate, real-time body movement detection and tracking, allowing seamless interaction between physical exercises and virtual game play. The rehabilitation game features personalized information displays (name, score, age, date), retry options, and performance analysis tools, enhancing motivation and progress tracking. This holistic approach makes rehabilitation enjoyable, engaging and effective.

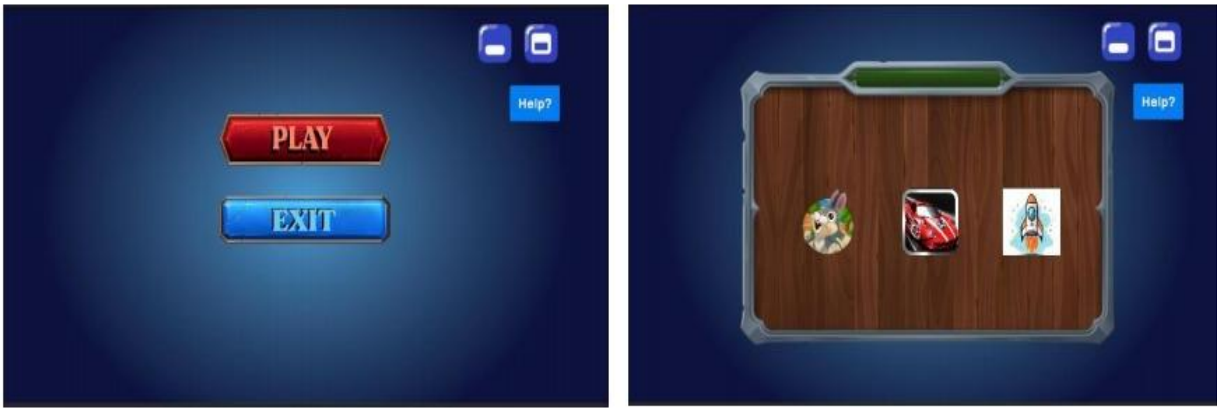



**Fig. 3: Game architecture**

***Pose Detection Algorithm***

Pose detection and classification form the core functionality of the script, enabling it to analyze and interpret human body poses from images or video frames. Using the MediaPipe library, the script employs pretrained machine learning models to accurately detect key landmarks on a person's body, such as joints and body parts. Functions such as detectPose() identify these landmarks, whereas classifyPose() analyzes their spatial relationships and angles to classify specific poses, such as left and right bends (side bends), left knees and right knees up (cross crunches), and forward and backward bends, as shown in Fig. 4. This allows for real-time feedback, facilitating applications such as fitness tracking or motion-controlled gaming [15].

**Fig. 4A Unknown Pose**

**Fig. 4B Right Bend**

**Fig. 4C Left Bend**

**Fig. 4D Right Knee up**

**Fig. 4E Left Knee up**

**Fig. 4F Front Bend**

**Fig. 4G Back Bend**

**Fig. 4: Exercise Pose Detection**

**Video capture via open CV**

The Python script uses Open CV for video capture. It initializes a video capture object to access the default webcam and continuously reads frames in a loop. Each frame is processed for resizing and pose detection/classification. The loop exits when the ’ESC’ key is pressed, releasing resources and closing all the open CV windows. This setup enables real-time video capture and pose detection on each frame, resulting in a graphical interface.

**Body landmark detection**

Body landmark detection is achieved via the MediaPipe library as shown in Fig. 5. The script initializes the MediaPipe pose detection model with mppose._Pose(), configuring it with specific parameters such as static image mode and minimum detection confidence. Within the video processing loop, each frame is passed to the detectPose() function, which detects and returns landmarks representing key body points. Optionally, detected landmarks can be visualized on the frame via open CV drawing functions for debugging or user feedback.

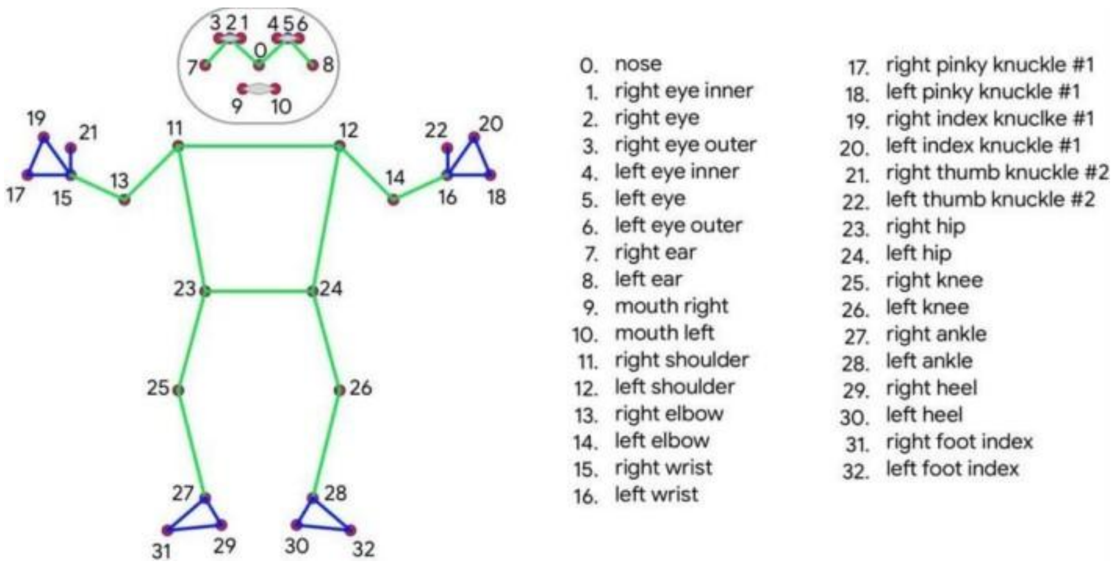



**Fig. 5: Biomarkers - 33 landmarks**

***Joint Angle Calculation***

In the Python script, calculating joint angles is crucial for pose analysis. The ‘calculate angle ()’ function determines the angle formed by three specified landmarks (joints or body parts) via trigonometric principles. It computes the angle between vectors formed by the landmarks on the basis of their x and y coordinates. This angle, expressed in degrees, provides insights into the spatial orientation of the joints, aiding in understanding body posture. After detecting landmarks in each frame, the script uses ‘calculate angle ()’ to compute angles between landmarks representing key joints such as shoulders, elbows, hips, knees, and ankles via (1). By comparing these computed angles against predefined thresholds, the script can classify various body movements. This classification enables the script to provide user feedback or trigger actions such as displaying messages, playing audio cues, or controlling interactive applications.

The formula used to calculate the angle between two vectors AB and BC can be expressed as:

degrees (arctan $2(yc-yb,\ xc-xb)$−arctan $2(ya-yb,\ xa-xb)$) (1)

Where (xa, ya), (xb, yb), and (xc, yc) are the coordinates of the three specified landmarks.

degrees () converts the angle from radians to degrees arctan2() computes the arctangent of the ratio of the differences in the y-coordinates and x-coordinates of the vectors.

***User feedback and data logging***

The rehabilitation script enhances user engagement through audio feedback, data logging, and a game experience questionnaire. With the pygame.mixer module, the script provides immediate auditory cues on the basis of the pose classification results, such as positive sounds for correct poses and warning sounds for incorrect ones, thus offering additional guidance and encouragement. Data logging allows users to input personal information via a Tkinter GUI, capturing details such as name, age, and date as shown in Fig. 6, along with performance metrics. These data are stored in a pandas data frame and saved in an Excel file, enabling personalized fitness tracking and performance analysis. After each game session, users complete a questionnaire, as shown in Fig. 7, with eight questions, rating their experience and the effectiveness of the exercises on a scale from 0 (not at all) to 4 (extremely). This feedback is vital for refining the rehabilitation module to better meet user needs and expectations.

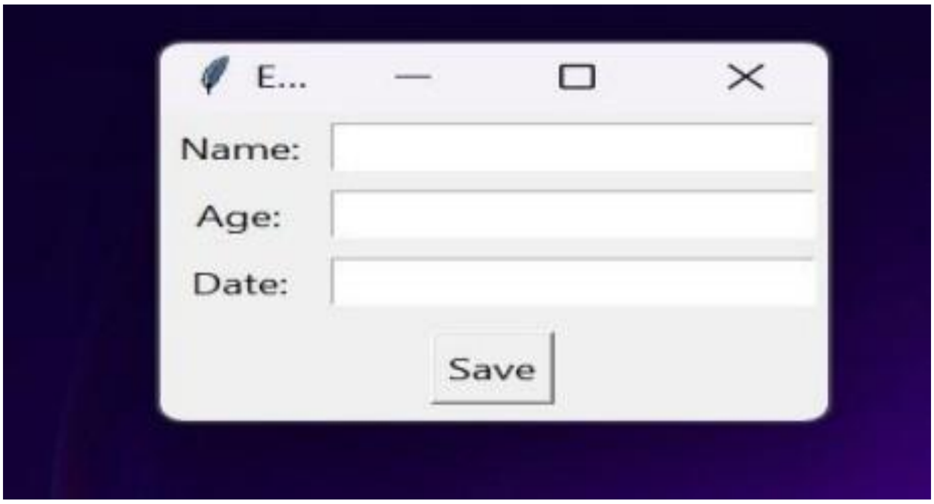
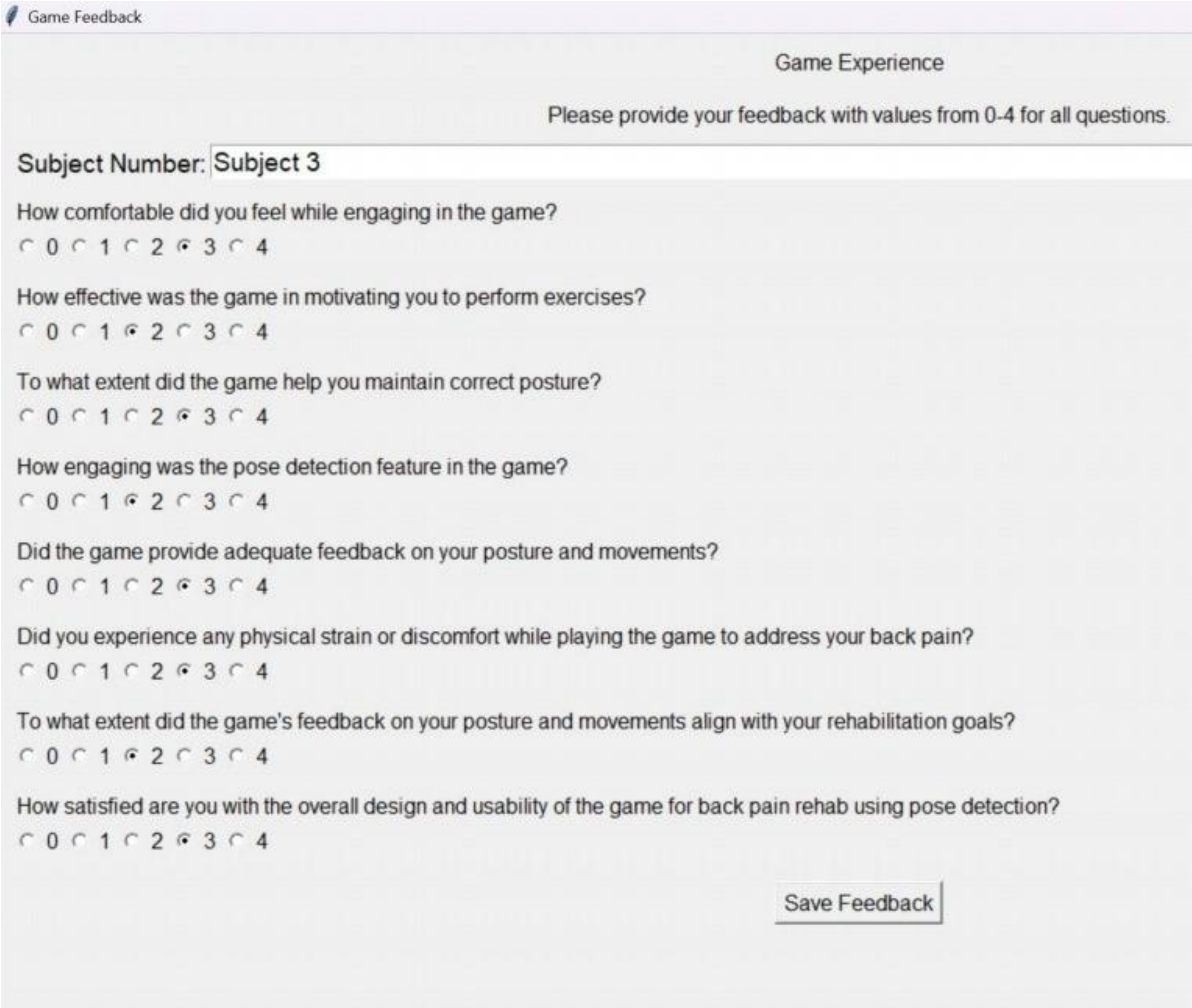



**Fig. 6: Data entry form**



Game Feedback

Game Experience

Please provide your feedback with values from 0-4 for all questions.

Subject Number: Subject 3

How comfortable did you feel while engaging in the game?
0 1 2 3 4

How effective was the game in motivating you to perform exercises?
0 1 2 3 4

To what extent did the game help you maintain correct posture?
0 1 2 3 4

How engaging was the pose detection feature in the game?
0 1 2 3 4

Did the game provide adequate feedback on your posture and movements?
0 1 2 3 4

Did you experience any physical strain or discomfort while playing the game to address your back pain?
0 1 2 3 4

To what extent did the game's feedback on your posture and movements align with your rehabilitation goals?
0 1 2 3 4

How satisfied are you with the overall design and usability of the game for back pain rehab using pose detection?
0 1 2 3 4

Save Feedback

**Fig. 7: Game experience questionnaire**

## Results

The implementation of the back pain rehabilitation module showed promising results, highlighting the benefits of integrating technology and gamification into traditional rehabilitation. Rigorous testing revealed significant improvements in user engagement, exercise adherence, and overall rehabilitation outcomes. Gamification notably boosted user motivation and adherence by transforming exercise into interactive and enjoyable games. This approach increased user satisfaction and encouraged consistent participation, leading to better treatment outcomes.

### *A. Game development*

Bunny Dodge focuses on improving flexibility and coordination by having players control a bunny that dodges obstacles through side bends as shown in Fig. 8. The pose detection algorithm uses a webcam to track movements, translating them into in-game actions: bending right moves the bunny right, and vice versa. A scoring system encourages correct and continuous side bends. A total of 21 subjects (12 males, 9 females) were recruited for this study. The inclusion criteria required participants to be of any age group and present with non-specific chronic low back pain (LBP) lasting more than 3 months. Subjects with specific pain etiologies or recent surgical history were excluded. Within the final cohort, the age range observed was 22 to 45 years. The developed exercise plan was checked and approved by a physical therapist. This was done before any participants started the study to make sure the exercises were safe and medically sound for people with back pain. Significant improvements in flexibility and side bending movements, with high levels of satisfaction and engagement are reported. Road Rush targets overall back flexibility and endurance through cross crunches. In this game, players steer a car left or right by performing cross crunches to avoid obstacles, as shown in Fig. 9. The pose detection system accurately tracks the cross crunches, ensuring that the car's steering responds to the player's movements. Real-time scores and progress trackers provide instant feedback, making the exercise engaging and rewarding. The subjects who were tested on Road Rush showed improvements in core strength and endurance. The Participants appreciated the fun and challenging aspects of the gameplay.

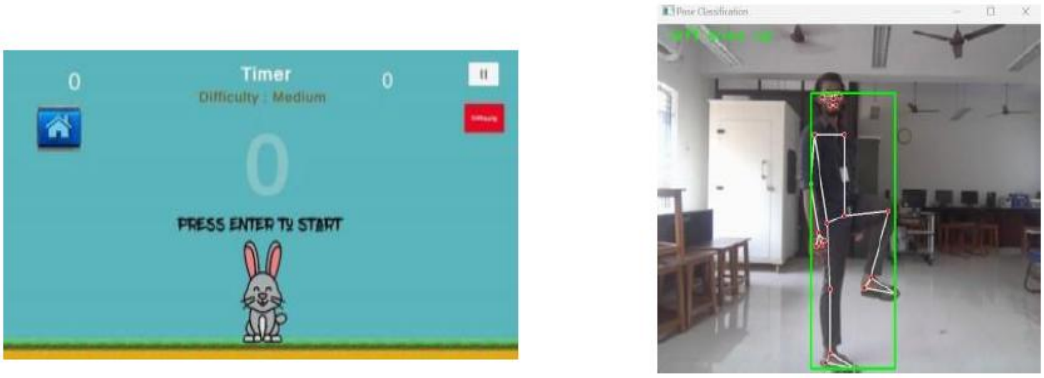



**Fig. 8: User testing of bunny dodge game**

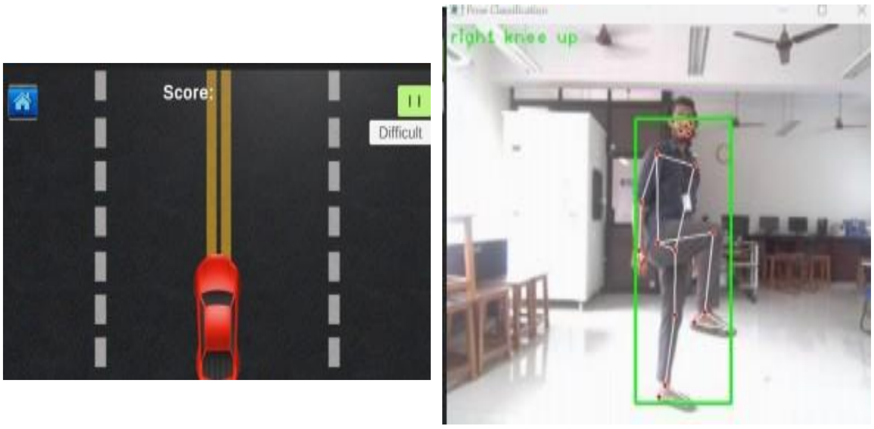



**Fig. 9: User testing of the road rush game**

Space Run enhances the core strength and balance through forward and backward bends. Players navigate a spaceship by performing these bends, as shown in Fig. 10, with the pose detection algorithm tracking their movements. The spaceship’s movement mirrors the player’s bends, supported by visual and auditory feedback for better performance. Testing with subjects revealed significant improvements in the bending range and control. The interactive nature of the game maintained high motivation and adherence to the exercise regimen. Data were successfully collected from all participants experiencing mechanical low back pain (LBP), which was specifically attributed to prolonged activities such as bike riding and car riding. The rehabilitation protocol spanned ten sessions delivered over a period of 25 days. Participants engaged with the developed module. Careful analysis of the results revealed a noticeable improvement in patient performance over the course of the ten sessions, indicating a positive effect of the module.

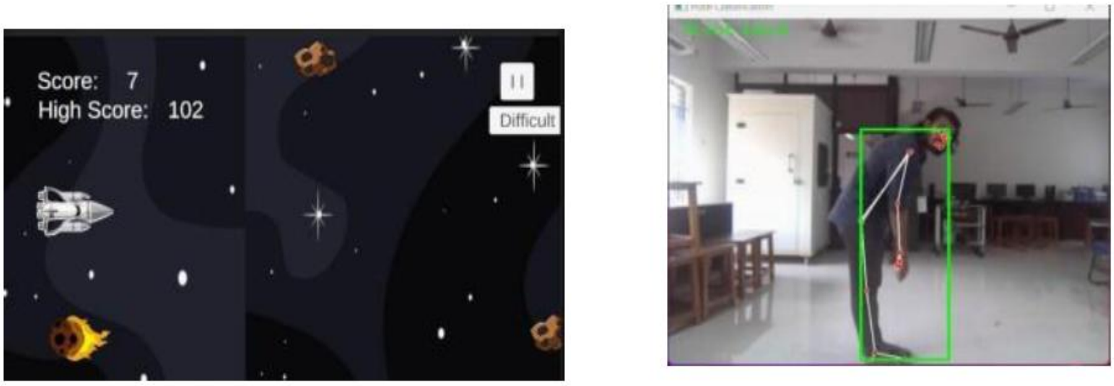
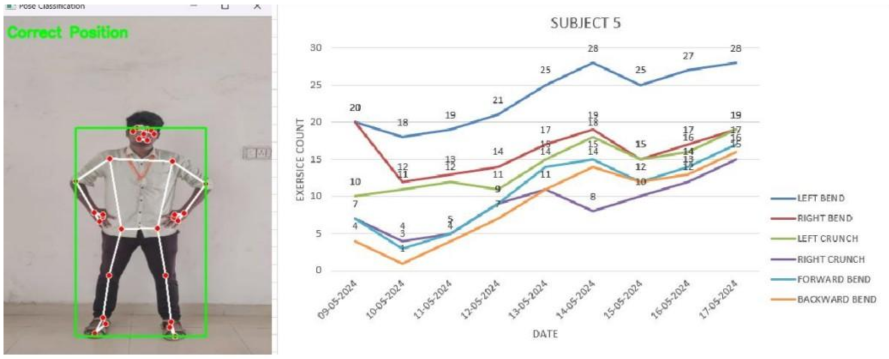



**Fig. 10: User testing of the space run game**

It has been observed consistent improvement in the scores of the physical exercise measurements for most of the subjects. Where the scores obtained in the sequential days are increasing in the exercises.  for example, in subject 1 the “left bend” it increased from 16-29, “right bend” from 12-28, “left crunch” from 10-19, “right crunch” from 9 -22, “forward bend” from 7-23, and “backward bend” from 6 -23 as depicted in. Fig. 11. records “Subject 5’s” physical exercise measurements, showing a general improvement in repetitions over the 10-day period. “Left Bend” increased from 20 to 31 repetitions, with the most significant gain in “Forward Bend,” which rose from 7 to 20. The “These increase in scores indicate enhanced flexibility, core strength, and endurance. The data show steady daily progress, with the highest measurements occurring on the final day, highlighting effective and progressive training.




| date | name | age | Left Bend | Right Bend | Left Crunch | Right Crunch | Forward Bend | Backward Bend |
|---|---|---|---|---|---|---|---|---|
| 09-05-2024 | Subject 5 | 20 | 20 | 20 | 10 | 7 | 7 | 4 |
| 10-05-2024 | Subject 5 | 20 | 18 | 12 | 11 | 4 | 3 | 1 |
| 11-05-2024 | Subject 5 | 20 | 19 | 13 | 12 | 5 | 5 | 4 |
| 12-05-2024 | Subject 5 | 20 | 21 | 14 | 11 | 9 | 9 | 7 |
| 13-05-2024 | Subject 5 | 20 | 25 | 17 | 15 | 11 | 14 | 11 |
| 14-05-2024 | Subject 5 | 20 | 28 | 19 | 18 | 8 | 15 | 14 |
| 15-05-2024 | Subject 5 | 20 | 25 | 15 | 15 | 10 | 12 | 12 |
| 16-05-2024 | Subject 5 | 20 | 27 | 17 | 16 | 12 | 14 | 13 |
| 17-05-2024 | Subject 5 | 20 | 28 | 19 | 19 | 15 | 17 | 16 |
| 18-05-2024 | Subject 5 | 20 | 31 | 21 | 21 | 18 | 20 | 19 |

**Fig. 11: Readings acquired from Subject 5**

To evaluate the progress of each subject in the rehabilitation module, exercise repetition counts were recorded for each day of the 25-day intervention. The total counts for each subject were summed for Days 1 and 10, and the improvement in counts over this period for 10 subjects alone is presented in Fig. 12. Throughout the rehabilitation program, each subject's exercise repetition count was carefully recorded to assess their progress. The results revealed significant improvements in exercise performance from Day 1 to Day 25. For example, Subject 10 increased their exercise count from 55 on Day 1 to 153 on Day 10 and increase to 213 on Day 25, which demonstrates a substantial progress in their rehabilitation journey. This improvement underscores the effectiveness of the rehabilitation module in enhancing exercise engagement and adherence among participants. Overall, the recorded data highlight the positive impact of the program, supporting its potential to contribute to the management and treatment of back pain through personalized exercise regimens. This research introduces a novel approach to back pain rehabilitation by combining pose detection technology with interactive gaming experiences in Unity. Utilizing real-time pose tracking, it provides personalized exercise routines focused on improving flexibility, strength, and posture, ultimately supporting spinal health and relieving back pain. By incorporating gamification into rehabilitation exercises, the framework increases user engagement and adherence to treatment plans, resulting in better long-term outcomes, the module's performance was evaluated using a structured scoring system [13] where subjects rated questions on a scale of 0 (minimum) to 4 (maximum), illustrated in Figure 7. Data collected on the final trial day indicated universal satisfaction, with all volunteers assigning the maximum score of 4 points across the entire questionnaire. The tabulated Day 3 results (Tables 1 and 2) highlight an initial minimum score for Question 6, which pertained to pain during the gaming exercise. Importantly, this feedback improved as the practice continued. These questionnaires are crucial for gathering direct patient feedback on usability, engagement, and efficacy, enabling the refinement of the pose-detection-based rehabilitation game to optimize user experience, comfort, and motivation.

| date | nam | age | Left benc | Right benc | Left crunch | Right crunc | Forward ber | Backward be | total |
|---|---|---|---|---|---|---|---|---|---|
| 2024-05-18 00:00:00 | Subject 1 | 21 | 29 | 28 | 19 | 22 | 23 | 23 | 144 |
| 2024-05-18 00:00:00 | Subject 2 | 20 | 24 | 22 | 19 | 24 | 18 | 17 | 124 |
| 2024-05-18 00:00:00 | Subject 3 | 20 | 30 | 26 | 16 | 16 | 22 | 21 | 131 |
| 2024-05-18 00:00:00 | Subject 4 | 21 | 29 | 29 | 21 | 27 | 28 | 23 | 157 |
| 2024-05-18 00:00:00 | Subject 5 | 20 | 31 | 21 | 21 | 18 | 20 | 19 | 130 |
| 2024-05-18 00:00:00 | Subject 6 | 20 | 31 | 32 | 21 | 21 | 24 | 23 | 152 |
| 2024-05-18 00:00:00 | Subject 7 | 20 | 28 | 29 | 21 | 28 | 26 | 23 | 155 |
| 2024-05-18 00:00:00 | Subject 8 | 21 | 23 | 22 | 23 | 22 | 25 | 17 | 132 |
| 2024-05-18 00:00:00 | Subject 9 | 20 | 29 | 30 | 21 | 19 | 20 | 19 | 138 |
| 2024-05-18 00:00:00 | Subject 10 | 21 | 29 | 28 | 21 | 22 | 27 | 26 | 153 |

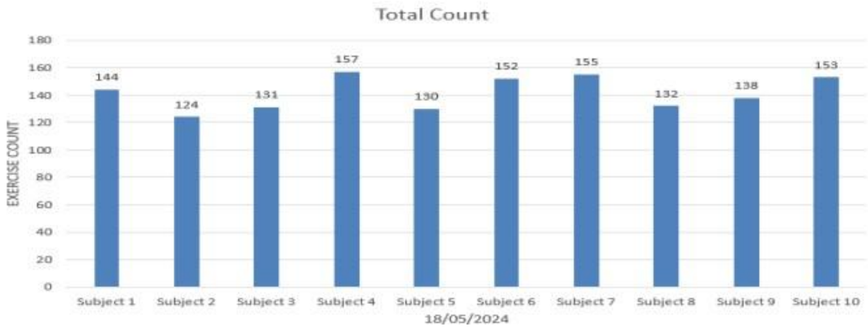



**Fig. 12: Day 10 overall repetitions of 10 subjects**

**Table 1. Questionnaire feedback**

| Questions | Sub 1 | Sub 2 | Sub 3 | Sub 4 | Sub 5 | Sub 6 | Sub 7 | Sub 8 | Sub 9 | Sub 10 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 3 | 3 | 4 | 3 | 4 | 3 | 4 | 4 | 4 | 3 | 3.5 |
| **2** | 3 | 3 | 4 | 4 | 4 | 3 | 3 | 3 | 4 | 3 | 3.4 |
| **3** | 2 | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 2 | 3.5 |
| **4** | 3 | 3 | 3 | 3 | 4 | 4 | 3 | 3 | 3 | 3 | 3.4 |
| **5** | 3 | 4 | 4 | 3 | 3 | 3 | 0 | 3 | 0 | 2 | 3.1 |
| **6** | 2 | 0 | 0 | 0 | 0 | 1 | 3 | 0 | 4 | 2 | 0.5 |
| **7** | 3 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 4 | 3 | 3.6 |
| **8** | 2 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3.8 |

**Table 2. Game Experience Questionnaires (GEQ): Core module component scoring**

| **GEQ Scores: Core Module** | |
|---|---|
| **Component** | **Value** |
| **Competence** | **3.5** |
| **Flow** | **3.25** |
| **Tension/Annoyance** | **0.5** |
| **Challenge** | **3.6** |

| | |
|---|---|
| **Positive Effect** | **3.8** |

**Discussion**

This research introduces a novel approach to back pain rehabilitation by combining pose detection technology with interactive gaming experiences in Unity. Utilizing real-time pose tracking, it provides personalized exercise routines focused on improving flexibility, strength, and posture, ultimately supporting spinal health and relieving back pain. By incorporating gamification into rehabilitation exercises, the framework increases user engagement and adherence to treatment plans, resulting in better long-term outcomes.

The use of pose detection in combination with gaming not only boosts user involvement but also enhances the scalability and accessibility of the system, making it adaptable for individuals with varying levels of mobility and rehabilitation requirements. By encouraging active participation in the recovery process, the framework presents a flexible and dynamic solution to the complex challenges of back pain rehabilitation.

Moreover, the project’s innovative approach holds great potential as a versatile platform for future research and development in this field. With continued refinement and validation, this framework could have a significant positive impact on the lives of those affected by back pain, enhancing their overall well-being and quality of life.

These three Unity-based games utilize common, low-impact back strengthening and flexibility exercises that are widely recommended by physiotherapists. The movements are foundational and can be safely performed by most adult age groups dealing with non-specific back pain, this ensures that the developed system is broadly accessible for home-based rehabilitation. To achieve a deeper understanding and better control of patient movement, the system could be upgraded through the addition of wearable motion sensors. These devices would capture highly precise, three-dimensional kinematic data, enabling more detailed analysis of a user's range of motion, movement quality, and posture. Ultimately, this leads to a more sophisticated and personalized therapeutic feedback loop embedded in the game mechanics. However, the interpretation of the current findings requires careful consideration, as the preliminary nature of the study means the cohort size (N=21) and the focused 25-day intervention period may constrain the generalizability and long-term sustainability of the observed effects. Furthermore, while the pose classification system provides reliable feedback, its reliance on pre-determined, fixed thresholds suggests an opportunity for enhancement, as this approach may not fully accommodate the subtle, personalized movement variability inherent to chronic pain patients. Moving forward, the research focus will shift to a larger, multi-site randomized controlled trial comparing the module against established standard care. Concurrently, an advanced, adaptive tracking system that utilizes user-calibrated thresholds can be developed to tailor rehabilitation feedback precisely to each individual’s unique biomechanics and progression.

**Conclusion**

By gamifying rehabilitation exercises, user engagement and adherence to treatment protocols are enhanced, leading to better long-term outcomes. The proposed framework not only enhances user engagement but also promotes scalability and accessibility, making it suitable for individuals with varying rehabilitation needs. This technology-driven solution offers a dynamic and adaptable approach to address the challenges associated with back pain, with the potential to significantly impact the quality of life of affected individuals.

**Acknowledgments**

We would like to extend our sincere appreciation to Rebalance Physiotherapy and Rehabilitation Centre. During our visit, we had the privilege of engaging with a renowned physiotherapist and her dedicated team of junior practitioners. They took the time to carefully listen to our presentation, which detailed our project's objectives, methodologies, and technical complexities. We are incredibly grateful for their insightful observations and constructive feedback, which played a crucial role in refining and enhancing the effectiveness of our rehabilitation module. Their expertise and recommendations were invaluable in advancing the project's impact.

**Funding:**

Nil

**Authors' contributions:**

1. Dr.T. Jayasree,- Conceptualization (Idea/Design), Original Draft Preparation
2. P.Pragathi,- Designing experiments/protocol, Conducting the study/experiment, Draft Preparation
3. S.Premkumar,- Designing experiments/protocol, Conducting the study/experiment, Draft Preparation
4. S.R. Sree Krishna- Designing experiments/protocol, Conducting the study/experiment, Draft Preparation

**Conflict of interest:**

Nil

**References**

[1] Hayden JA, Ellis J, Ogilvie R, Malmivaara A, van Tulder MW. Exercise therapy for chronic low back pain. Cochrane Database Syst Rev. 2021 28;9(9):CD009790.
doi: 10.1002/14651858.CD009790.pub2. PMID: 34580864; PMCID: PMC8477273.

[2] Cheng, M., Tian, Y., Ye, Q. et al. Evaluating the effectiveness of six exercise interventions for low back pain: a systematic review and meta-analysis. BMC Musculoskelet Disord 2025, 26, 433. https://doi.org/10.1186/s12891-025-08658-0

[3] R. S. Gonçalves, R. A. Prado, G. M. V. Ladeira, and A. L. P. Gasparini, Development of Serious Games for the Rehabilitation of the Human Vertebral Spine for Home Care, Robotics,2023;12:2, 58.

[4] C. Gmez-Portes, C. Lacave, A. I. Molina, and D. Vallejo, Home

Rehabilitation Based on Gamification and Serious Games for Young People: A Systematic Mapping Study, Applied Sciences, 2020;10:24,8849.
[5] M. I. Daoud, A. Alhusseini, M. Z. Ali, and R. Alazrai, A Game-Based Rehabilitation System for Upper-Limb Cerebral Palsy: A Feasibility Study, Sensors,2020;20:8,2416.
[6] R. Alexandre, Octavian Postolache, and Pedro Silva Girao, Physical Rehabilitation based on Smart Wearable and Virtual Reality Serious Game, 2019.
[7] S. Pintado-Izquierdo, R. Cano-de-la-Cuerda, and R. M. Ortiz-Gutiérrez, Video Game-Based Therapy on Balance and Gait of Patients with Stroke: A Systematic Review, Applied Sciences,2020;10:18, p. 6426.
[8] A. Chow, Pang Ying Han, Khoh Wee How, and Ooi Shih Yin, Hand Gesture Controlled Game for Hand Rehabilitation,2022;205–215.
[9] M. Altayeb, Hand Gestures Replicating Robot Arm based on MediaPipe, Indonesian Journal of Electrical Engineering and Informatics (IJEEI), 2023;11:3, pp. 727–737.
[10] J.-W. Kim, J.-Y. Choi, E.-J. Ha, and J. Choi, Human Pose Estimation Using MediaPipe Pose and Optimization Method Based on a Humanoid Model, Applied sciences,2023;13:4, 2700–2700.
[11] . Patil, D. Rao, K. Utturwar, T. Shelke, and E. Sarda, Body Posture Detection and Motion Tracking using AI for Medical Exercises and Recommendation System, ITM Web of Conferences, 2022;44, p.03043.
[12] Y.-Y. Chung, T. M. Annaswamy, and B. Prabhakaran, Performance and User Experience Studies of HILLES: Home-based Immersive Lower Limb Exergame System, 2023.
[13] IJsselsteijn, WA, de Kort, YAW, Poels, K, The Game Experience Questionnaire. Technische Universiteit Eindhoven, Eindhoven, 2013.
[14] J. Jane Elona and T. Jayasree, Smart Gaming System for Hand Rehabilitation, Communications in computer and information science, 2024; p. 35–46.
[15] T. Rangari, S. Kumar, P. P. Roy, D. P. Dogra, and B.-G. Kim, Video based exercise recognition and correct pose detection, Multimedia Tools and Applications, 2022.
[16] B. Debnath, M. O'Brien, M. Yamaguchi, and A. Behera, A review of computer vision-based approaches for physical rehabilitation and assessment, Multimedia Systems,2021;28:1,p. 209–239.
[17] S. Schez-Sobrino, D. Vallejo, D. Monekosso, C. Glez-Morcillo, and Paolo Remagnino, A Distributed Gamified System Based on Automatic Assessment of Physical Exercises to Promote Remote Physical Rehabilitation, IEEE Access, 2020;8, p. 91424–91434.
[18] F. M. Alfieri, C. da Silva Dias, N. C. de Oliveira, and L. R. Battistella, Gamification in Musculoskeletal Rehabilitation," Current Reviews in Musculoskeletal Medicine,2022;15:6, p. 629–636.
[19] C. Schönauer, T. Pintaric, H. Kaufmann, S. M. Kosterink, and M. Marie, Chronic pain rehabilitation with a serious game using multimodal input, International Conference on Virtual Rehabilitation, 2011.

[20] J. Mueller, D. Niederer, S. Tenberg, L. Oberheim, A. Moesner, and S. Mueller, Acute effects of game-based biofeedback training on trunk motion in chronic low back pain: a randomized crossover pilot trial," BMC Sports Science, Medicine and Rehabilitation,2020;14:1.
[21] Z. Trost et al., The promise and challenge of virtual gaming technologies for chronic pain: the case of graded exposure for low back pain, Pain Management,2015;5:3, p. 197–206.
[22] O. Stamm, R. Dahms, and U. Müller-Werdan, Virtual reality in pain therapy: a requirements analysis for older adults with chronic back pain, Journal of NeuroEngineering and Rehabilitation, 2020;17: 1.
[23] C. R. France and J. S. Thomas, Virtual immersive gaming to optimize recovery (VIGOR) in low back pain: A phase II randomized controlled trial," Contemporary Clinical Trials, 2018;69, p. 83–91.
[24] F. Fatoye et al., Cost effectiveness of virtual reality game compared to clinic based McKenzie extension therapy for chronic nonspecific low back pain, British Journal of Pain,2022;16:6, p. 601–609.
[25] S. M. Jansen-Kosterink, R. M. H. A. Huis in 't Veld, C. Schönauer, H. Kaufmann, H. J. Hermens, and M. M. R. Vollenbroek-Hutten, A Serious Exergame for Patients Suffering from Chronic Musculoskeletal Back and Neck Pain: A Pilot Study, Games for Health Journal, 2013;2:5, p. 299–307.
[26] M. I. Daoud, A. Alhusseini, M. Z. Ali, and R. Alazrai, A Game-Based Rehabilitation System for Upper-Limb Cerebral Palsy: A Feasibility Study, Sensors,2020;20:8, p. 2416.
[27] P. Brauner and M. Ziefle, Serious Motion-Based Exercise Games for Older Adults: Evaluation of Usability, Performance, and Pain Mitigation, JMIR Serious Games,2020;8:2, p. e14182.
[28] Kun Zhang , Pengcheng Zhang, Xintao Tu , Danny Crookes , Zhicheng Liu , Peixia Xu, Chenggang Wu, Danny Crookes , Zhicheng Liu , Peixia Xu , , and Liang Hua, SR-POSE: A Novel Non-Contact Real-Time Rehabilitation Evaluation Method Using Lightweight Technology, IEEE transactions on Neural systems and rehabilitation engineering, 2023, 31, p. 4179- 4188.
[29] Dey, Prof. M., Yoga Pose Detection for Human Rehabilitation Using Deep Leaning., International Journal for Research in Applied Science and Engineering Technology, 2023, 11(12), p.231–235.
[30] Pereira, B., Cunha, B., Viana, P., Lopes, M., Melo, A. S. C., & Sousa, A. S. P. A Machine Learning App for Monitoring Physical Therapy at Home, Sensors, 2024, 24(1).
[31] Adolf, J., Dolezal, J., Kutilek, P., Hejda, J., & Lhotska, L., Single Camera-Based Remote Physical Therapy: Verification on a Large Video Dataset, Applied Sciences (Switzerland), 2022, 12(2).
[32] Palermo, M., Lopes, J. M., André, J., Matias, A. C., Cerqueira, J., & Santos, C. P., A multi-camera and multimodal dataset for posture and gait analysis., Scientific Data, 2022, 9(1).