Hand Rehabilitation System Using Gesture Recognition and Game-Based Training

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Write and researched by ZHANG Haoran(张昊冉), modified by ChatGPT, corrected by Zhang haoran

Introduction and Motivation

Hand rehabilitation exercises are crucial for patients recovering from hand injuries or surgeries, yet traditional therapy can be monotonous and difficult to sustain. HandRehab-RPS was conceived to address this challenge by transforming the classic Rock–Paper–Scissors hand gesture game into a structured, engaging rehabilitation exercise. Using a standard webcam, our system recognizes three fundamental gestures—Rock, Paper, and Scissors—along with variants like "hold" (sustained gesture) and "speed-round" rapid gestures. These gestures drive a turn-based game where the patient competes against an opponent (AI or another player), and an analytics module tracks key metrics (e.g. range of motion (ROM), repetition count, reaction time, a proxy for grip strength) in real time for progress monitoring. By introducing an interactive game layer to therapy, we aim to improve patient motivation and adherence while providing clinicians with richer data on patient performance.

Project Motivation: Traditional hand rehab often involves repetitive movements that patients find tedious, leading to low compliance. Moreover, clinicians have limited means to monitor a patient's exercise quality and progress outside of scheduled appointments. We were motivated to create a system that makes rehabilitation fun and game-like, thereby encouraging regular practice. By leveraging inexpensive computer vision technology and game design, our project seeks to turn dull exercises into an immersive experience with instant feedback and clear goals. Ultimately, this system is designed to enhance training accuracy and measurable recovery outcomes by keeping patients engaged and allowing remote tracking of their performance.

Background: Challenges in Traditional Rehabilitation

Hand therapy traditionally requires patients to perform manual exercises (like squeezing stress balls or practicing range-of-motion drills) repeatedly on their own. This process presents several well-known challenges:

- **Patient Engagement**: Exercises are often repetitive and boring, making it hard for patients to stay motivated day after day. Many lose interest or become demoralized when progress is slow or not obvious.
- **Adherence and Consistency**: Because of the monotony and sometimes discomfort, it is difficult for patients to maintain a regular training routine. Skipped sessions or incomplete exercises can delay recovery.
- **Feedback and Correctness:** Patients at home often don't know if they are doing the movements correctly. There is little immediate feedback on form or effort, so exercises may be done improperly or half-heartedly, reducing their effectiveness.
- **Lack of Meaningful Results**: Rehabilitation can feel meaningless when results are unclear. If patients cannot see their improvement or scores, they may become discouraged, unlike in games where scores or levels provide a sense of accomplishment.
- **Equipment and Cost:** Many conventional rehab tools (e.g. specialty devices or therapist-supervised sessions) can require costly equipment or frequent clinic visits. Home alternatives might involve simpler tools but lack interactivity. The high cost of one-on-one therapy sessions means patients get limited guidance time.
- **Clinician Monitoring:** From the clinicians' perspective, once the patient leaves the clinic it's hard to assess their exercise performance.

Therapists rely on patient self-reports or occasional check-ins, and providing feedback or adjusting therapy remotely is time-consuming without a supportive system. There is a clear need for better remote monitoring and data to inform clinicians about a patient's at-home progress.

These pain points guided our project design. By understanding why patients struggle with current rehab methods and what clinicians wish they could track, we focused on solutions that introduce engagement, feedback, and data-driven insights into the rehabilitation process.

User Research Insights

Patient Perspectives

Patients emphasized that monotony was a major barrier. They described home exercises as "repetitive and boring," which led to procrastination or dropout. Many admitted difficulty sticking to the daily regimen without some form of enjoyment or reward. Additionally, patients felt uncertain about their technique — for example, "Am I making a proper fist? Is my motion good enough?" They had no immediate feedback on whether they were performing gestures correctly or improving over time. This lack of feedback made the training feel meaningless, as they couldn't gauge progress in between clinic visits. Some also noted practical issues: certain rehab gadgets or sensor-based systems can be hard to set up or too expensive for home use. These insights underscored the need for a low-cost, easy solution that makes exercise more engaging and provides clear feedback and progress indicators to the patient.

Clinician Perspectives

Clinicians (physical therapists and doctors) highlighted the difficulty of remote monitoring and personalization. Once a patient leaves the clinic, the therapist has little visibility into how well or how often exercises are done. They expressed frustration that they “cannot assess patient performance outside the clinic” and must rely on patient self-reports. Providing feedback is also inefficient — reviewing patient notebooks or asking patients to describe their pain/improvement is subjective and time-consuming. Therapists wanted a way to automatically record exercise data (like movement range or reaction times) and easily review it. Moreover, with objective data, they could adjust therapy more quickly instead of waiting for the next appointment. The clinicians we consulted liked the idea of a game-based tool that would increase patient motivation while simultaneously collecting quantitative metrics for them. They emphasized any system should be easy for patients to use at home and not add burden to the patient or the clinical workflow.

Summary: Both user groups support the idea of a gameful rehabilitation approach. Patients need fun and feedback to stay engaged, and clinicians need data and remote insight. These needs guided us to create a solution that is essentially a game plus a monitoring tool — enjoyable for patients, informative for clinicians.

Game Design and Mechanics

Our rehabilitation system is designed as a gesture-based game with familiar rules to ensure it’s intuitive yet motivating. The core gameplay revolves around Rock–Paper–Scissors (RPS) matches, augmented with scoring and adaptive difficulty to keep users in the optimal zone of challenge. Below we describe the key game mechanics:

Turn-Based Gameplay and Rounds

The rehabilitation game operates in a turn-based match system. Each match consists of multiple quick rounds (on the order of 10–15 seconds per round). At the start of a round, a countdown timer cues the patient to get ready. The patient then performs a hand gesture (Rock, Paper, or Scissors) when time is up, which the system immediately captures via the webcam and classifies. The opponent (either a computer AI or another player) likewise "chooses" a gesture, and the outcome of the round is determined just like classic RPS: Rock beats Scissors, Scissors beats Paper, Paper beats Rock (or a draw if both choose the same). The player receives immediate feedback on the round's result — for example, a win/loss message, updated scores, and possibly an encouraging sound or graphic. Points are gained or lost each round based on the outcome. We set a score threshold (e.g. first to 15 points) to decide the winner of a match. This turn-based structure with rapid cycles ensures the exercise is broken into manageable chunks, keeping the experience lively and avoiding fatigue.

Each round not only yields a win/lose result but also evaluates the quality of the gesture performed. If the patient executed the gesture clearly and with good form (e.g. fully open hand for Paper, or a tight fist for Rock), the system will recognize it correctly and count it. If the gesture was incomplete or ambiguous, the game may register it as a failed attempt or a different gesture (providing feedback so the user knows it wasn't recognized). In this way, the patient is encouraged to perform each movement properly to succeed in the game. Short rounds with instant outcomes create a feedback loop that keeps the player focused and continually informed, which is important for maintaining motivation.

Scoring and Dynamic Difficulty Adjustment

To keep the game balanced and engaging for rehabilitation (rather than frustrating or too easy), we implemented a dynamic difficulty algorithm in place of a standard fixed AI opponent. The computer opponent's behavior adjusts in response to the player's performance, ensuring the patient neither loses every round (which would be discouraging) nor wins too effortlessly (which would reduce the sense of challenge). Specifically, when the player is struggling (e.g. has a low score or consecutive losses), the opponent's moves become more random, increasing the chance that the patient can win a round through luck. Conversely, as the player's score grows and they approach the winning threshold, the system injects a small probability that the opponent will intentionally play the winning move to cause the patient to lose a round. This probability might scale with the player's current score or win streak. For example, each point the player gains could slightly raise the chance of the opponent forcing a loss (one simple model we used was roughly a 5% increased chance per point that the computer will pick the winning counter-gesture against the player). These occasional forced losses prevent the match from ending too quickly in the patient's favor and add tension when victory is near. If a player somehow falls into a negative score (meaning they lost more points than gained), the system does the opposite — it becomes very likely to let them win the next round to get back to zero. This dynamic adjustment keeps the difficulty in a balanced range, maintaining the player's engagement and confidence. In game design terms, it helps induce a state of "flow" — where the challenge matches the player's skill level — avoiding boredom from easy wins and frustration from constant losses.

Importantly, the dynamic difficulty is achieved through simple rule-based tweaks rather than obvious cheating or inscrutable AI. The player still feels the game is fair overall, since they will win roughly as often as they lose when at a middling skill level, and the system's adjustments are subtle. Over time, as the patient's real skill (speed and accuracy of gestures) improves, they will naturally win more even with difficulty adjustments, reflecting progress.

Training Modes (Time-Based vs. Game-Based)

Our system includes two daily training modes, both designed to fulfill a fixed amount of required rehabilitation per day:

In Time-Based Mode, patients must complete a fixed-duration training session. This ensures a stable and predictable training routine, regardless of performance.

In Game-Based Mode, patients must win a certain number of matches to complete the session. In this mode, gesture accuracy is given a higher scoring weight, so patients who perform gestures more accurately can potentially finish the session faster.

Essentially, patients with higher training accuracy can use the game-based mode as a faster way to complete their daily tasks. Meanwhile, those who are less confident in their accuracy can choose the time-based mode as a safer option. Both paths lead to training completion.

To prevent large differences in actual training time, we use dynamic difficulty and algorithmic adjustment. Even patients with high accuracy won't drastically shorten their training time, ensuring they still meet their daily rehabilitation quota.

From an HCI and game psychology perspective, this design introduces a risk-reward mechanism: the game-based mode offers the possibility of finishing faster but comes with the risk of taking longer if performance is poor. It also creates an illusion of skill—patients may believe that better gestures will significantly shorten their session. In reality, due to difficulty balancing, even skilled patients will only shorten their training time slightly, preserving fairness and therapeutic volume.

Multiplayer (PVP) Mode *(Planned)*

In addition to the single-player vs computer mode, we envisioned a Player vs Player (PVP) mode where two patients can play Rock–Paper–Scissors against each other remotely. The idea behind PVP is to introduce a social and competitive element to rehabilitation. Patients could invite a friend or another patient in a similar rehabilitation stage to a match. This not only makes exercises more fun (playing with a real person) but also adds social motivation – each player knows someone else is relying on them to participate, and a bit of friendly competition can push them to try harder. We planned to include a basic matchmaking or invitation system to pair players of comparable skill level or recovery progress, to keep matches fair. For example, a therapist could pair two patients who have similar range of motion capabilities so that one doesn't consistently beat the other easily. While the PVP feature extends beyond the core single-player training, it leverages social presence as a motivational factor in HCI. Competing or even just practicing together can increase engagement and enjoyment, as supported by psychological research on cooperative/competitive play improving adherence.

Due to time constraints in development, the full PVP mode is marked as a future enhancement; however, the architecture was built with networking capabilities in mind (see Technical Implementation). We anticipate that adding multiplayer will further boost user engagement by making rehab feel like a shared game experience rather than a solitary exercise routine.

Motion Quality Scoring and Feedback

One of the key advantages of a software-mediated exercise system is the ability to measure how the movement is performed, not just whether the right gesture was made. Our game incorporates a motion quality scoring system to give patients feedback on the caliber of their hand movements: - For each gesture performed, we estimate the Range of Motion (ROM) achieved — for instance, how fully did the patient extend their fingers for “Paper” or how tightly did they curl the fist for “Rock”. The system can quantify this by analyzing the positions of the 21 hand landmarks (knuckle and joint positions) detected by the computer vision module. - We measure the reaction time, i.e. how quickly the patient reacted to the “Go” signal in each round. Faster reactions indicate improving neuromuscular control and confidence. - We observe the consistency and stability of the gesture. This might include how much the hand trembles or if the gesture is held for the required brief period without switching.

Based on these factors, the system gives a quick qualitative rating each round. We use a simple three-tier feedback: for example, “Good”, “Great”, or “Perfect” (with color-coded indicators) to rate how well the gesture was executed beyond just win/lose. A perfectly formed gesture with full ROM and quick response might get a “Perfect” and maybe extra points, whereas a barely recognized gesture might just be “Good” or even trigger a gentle correction prompt if it was wrong. This concrete feedback on performance serves to reinforce proper motion and builds the patient’s self-efficacy — they can clearly see that they are getting better at doing the movements correctly, not just winning games. Over time, a patient might notice they get more “Great” and “Perfect” ratings, reflecting real improvement in hand function.

To make feedback engaging and clear, we implemented a multimodal feedback system in the UI. When a round ends, the patient sees visual cues (the screen might flash green for a win or show an icon next to the chosen gesture), hears audio cues (a rewarding sound for success, or a gentle “try again” sound for a poor gesture), and reads a brief text encouragement (“Well done!” or “Try to extend your fingers more!” depending on performance). Combining audio, visual, and textual feedback helps ensure the message gets across unambiguously. This redundancy in feedback modalities follows HCI best practices by reducing cognitive load on the user — even if they miss the text, they might notice the sound or color change, etc. It also makes the game more immersive and lively, which keeps users interested. Additionally, at the end of each match or session, the game presents a summary (e.g., “You won 3 out of 5 games. Your average reaction time improved by 0.2s since yesterday. Great job!”). This end-of-session recap gives a sense of accomplishment and progression, which is important for long-term engagement.

Incorporation of HCI and Psychology Principles

In designing HandRehab-RPS, we deliberately applied several Human-Computer Interaction (HCI) and psychology principles to maximize user engagement, motivation, and clarity of feedback. Here are the key principles and how they influenced our design:

- **Flow and Optimal Challenge:** We aimed to keep the difficulty in the patient’s “flow channel.” The dynamic difficulty adjustment ensures the game is neither too easy nor too frustrating, maintaining an optimal challenge level. This prevents boredom and anxiety, aligning with *Flow Theory* in psychology. By scaling the opponent's behavior to the player's performance, we keep the player in a state of engaged focus where they feel challenged just the right amount.

- **Frequent Feedback & Reinforcement:** The game provides immediate, round-by-round feedback on both success (win/lose) and motion quality. These short feedback loops offer frequent, clear reinforcement for the patient, which is known to increase motivation. Instead of waiting weeks to see improvement, the patient gets instant gratification (points, praise, or constructive cues) with each attempt, encouraging continued effort.
- **Autonomy and Choice:** We give users a meaningful choice in how they train (time-based vs goal-based mode). Granting this autonomy supports intrinsic motivation — patients feel in control of their rehabilitation experience, which can lead to better adherence. Even this simple choice can make the user more invested in the process, as self-determination theory suggests.
- **Social Motivation:** By incorporating (or planning) a PVP multiplayer mode, we leverage **social presence** and friendly competition to motivate users. Competing with peers or friends can increase engagement and add accountability. Knowing that another person is involved can push patients to try harder and enjoy the sessions more, addressing the isolation that often comes with home rehab.
- **Self-Efficacy and Mastery:** The system emphasizes progress feedback (like ROM improvements, faster reactions, higher quality ratings) to bolster the patient's belief in their own abilities. Celebrating small wins and showing improvement over time builds self-efficacy — the confidence that "I can do this." Concrete indicators such as achieving a "Perfect" gesture score or seeing a

higher cumulative score provide evidence of mastery, encouraging continued practice.

- **Multi-Modal Clarity (Usability):** Our UI design follows HCI principles of clarity and low cognitive load. By using multi-modal feedback (visual signals, sounds, text prompts), we cater to different user needs and ensure the state of the game is always obvious. For instance, a color-changing gesture icon plus a sound is an intuitive indicator of success/failure even if the patient doesn't read the text. This simplicity and redundancy improves usability and keeps the focus on the exercise itself rather than the software.

All these principles from psychology and HCI were integrated to make the rehabilitation game engaging, motivating, and user-friendly. Our goal was not just to create a fun game, but a therapeutic tool that truly applies the course concepts — from feedback loops and reward systems to autonomy and social factors — to achieve better user outcomes.

Technical Implementation

Behind the scenes, the HandRehab-RPS system consists of several components working in tandem: real-time hand gesture recognition, game logic (rules and scoring), a user interface for interaction and feedback, and data handling for performance tracking. We chose technologies and design approaches that prioritize real-time performance and ease of use, given our target of a smooth, interactive rehab experience.

Figure: System architecture overview. The pipeline begins with capturing the user's hand via webcam, then using MediaPipe for gesture recognition. Recognized gestures feed into the game logic ("Algorithm Combat") which determines round outcomes and scoring. Simultaneously, data (like ROM, reaction time) is recorded for analysis. The front-end (built with Streamlit) displays the game visuals, feedback, and transmits data to a clinician dashboard.

Hand Gesture Recognition

Our system uses a vision-based gesture recognition approach to identify the patient's hand poses in real time. We implemented this using Google's MediaPipe framework, which provides a pretrained hand-tracking solution capable of detecting 21 key landmarks on the hand from a live video feed. These landmarks correspond to knuckles, finger joints, etc., and update continuously as the hand moves. Using the spatial relationships of these landmarks, we defined simple geometric rules to classify the three target gestures: - Rock: All fingers curled (fingertips close to the palm center). - Paper: All fingers extended and spread (distance between fingertips indicates open hand). - Scissors: Two fingers (index and middle) extended, while others curled (distinguishing it from Paper by checking the ring and pinky finger positions).

The MediaPipe solution runs locally through our application (no internet needed), allowing real-time processing (~30 frames per second on a standard laptop). When a frame is captured, we extract the hand landmark coordinates and apply our rule-based classifier to decide if it matches Rock, Paper, Scissors, or no recognized gesture. This approach is explainable and easily tunable — for example, if a user can't fully extend a finger due to injury, the threshold distances can be adjusted by a clinician. We intentionally avoided a complex machine learning model for gesture classification; the rule-based method was sufficient and transparent (no "black box"). As a result, our gesture recognition is fast and requires no training period. A potential limitation is that the user must roughly face the camera and have their hand within the frame, but the system is fairly robust to different backgrounds and lighting conditions thanks to MediaPipe's tracking efficacy. In practice, we found the gesture recognition to be accurate for our needs, after some calibration in early testing.

Game Logic and Scoring System

The game logic module takes the recognized player gesture and, for single-player mode, generates the opponent's gesture and computes the outcome each round. As described earlier, the opponent's behavior is governed by a rule-based algorithm that adjusts difficulty. This was implemented by simple conditional checks on the score: – If the player's score is well below the opponent's (player losing), set the opponent's next gesture completely randomly (33% chance each for R/P/S). This randomness increases the chance the player can win, since a purely random opponent can be beaten by luck or by the player anticipating common patterns. – If the player is nearing the winning score, or has been winning consistently, we trigger a conditional branch where the opponent will sometimes play the exact counter-gesture to what the player showed, causing the player to lose that round. In code, this is a random chance that checks if rand() < someProbability to decide if we "force a loss." We tuned this probability to be low (single-digit percentage) so that it doesn't feel too artificial or discouraging. – Otherwise (scores roughly even or at start), the opponent behaves with moderate randomness or a basic strategy (we kept it simple, not using any predictive AI strategies since the focus is rehabilitation, not competitive gaming).

We maintain a running score tally for both player and opponent. A win might add +1 (or more if we weight for a perfect gesture), a loss subtracts a point, and a draw could be 0 (or small +/– to encourage not settling for draws). These specifics were adjusted during development to ensure the scoring felt fair and motivating. A match ends when either side reaches the predefined score threshold (e.g. +15 points). At match end, the game announces the winner (in single-player, essentially whether the patient “won” against the computer), and then either resets for another match or ends the session, depending on the mode.

Front-End User Interface (Streamlit App)

For the user interface, we chose to build the application with Streamlit, a Python framework for creating web apps with minimal boilerplate. Streamlit allowed us to rapidly develop a clean, browser-based UI for the game without dealing with low-level GUI code. The interface is accessible — the patient can simply click a link or run a script to launch the app and see the game window, which includes: – A live video feed window showing their hand (so they can align themselves and also have a visual cue that the system sees their gesture). – The scoreboard and progress indicators (e.g. a progress bar toward the win threshold, or a timer counting down in time mode). – Mode selection buttons or dropdown (to choose Time vs Game mode at start). – Feedback areas: text messages (like “Great job!” or “You won this round”), color highlights around the gesture area, and possibly simple graphics that appear for wins/losses. – End-of-session summary pop-ups or sections that show stats from the session (total wins, average reaction time, etc.).

The Streamlit app structure defines different “views” or sections of the interface, and we used the session state to preserve game variables across reruns. For example, when the user presses “Start Game,” we initialize the scores and timer in state. Each round triggers an update to these states, and Streamlit updates the components (like the live camera frame and scores).

One advantage of Streamlit is that it easily supports web deployment, which means a patient or therapist could run the interface from anywhere (assuming camera access and internet, if hosted). For our development, we ran it locally. We found Streamlit sufficient for our needs, although being designed for data apps, it required some creativity to manage real-time interactions.

Data Logging and Visualization

A key feature of HandRehab-RPS is that it doesn't just provide real-time feedback; it also logs the data from each session for later review by the patient or clinician. During gameplay, we record events and metrics such as: - Timestamp of each round and the gesture performed. - Outcome of the round (win/lose/draw) and points gained/lost. - Measured reaction time for the round. - Estimated ROM or gesture quality score for that attempt. - Any self-reported pain or effort level (if we include a prompt for the patient to rate discomfort, etc. — this was considered as an extra input).

These data are stored either in a local CSV file or a SQLite database on the device. We implemented simple CSV logging first for ease of access. After a session, the user or clinician can open these logs to see quantifiable progress. To make this data meaningful at a glance, our application includes a "Summary Dashboard" view. In Streamlit, after the game ends, we generate charts like a line graph of ROM over time (or across sessions), a bar chart of reaction times for each round, and cumulative stats (e.g. best reaction time achieved today, average ROM compared to last session, etc.). Historical data visualization helps in identifying trends — for instance, a patient may see that their average finger bending angle (ROM) is improving each week, which can be very encouraging. Clinicians can also spot if a patient is plateauing or if their reaction times are getting slower (perhaps indicating fatigue or an issue).

We also added an export option for reports. At the end of a session, the system can compile a brief PDF report that includes the summary stats and graphs. This can be sent to a clinician or kept by the patient. The doctor's view (in future iterations) could aggregate these session reports for each patient, making it easy for a therapist to review progress before each appointment. In our current implementation, the groundwork for data capture is in place, and basic visual feedback is shown to the user, but a fully featured clinician dashboard is earmarked as future work. Still, even the existing data logs provide more insight than traditional home exercise, and this data-centric approach is one of the strengths of the system.

Networking for Remote Play (Optional Feature)

We built the core system to support single-player training by default. However, anticipating the PVP feature, we structured the code to allow a network connection module. The idea was to use a simple server or peer-to-peer connection to exchange gestures between two players in real time. Due to course timelines, we only prototyped this feature: essentially, when in PVP mode, the app would send the local player's recognized gesture to the server and receive the opponent's gesture in return, then determine the outcome.

Challenges and Limitations

While developing HandRehab-RPS, we encountered several challenges and also recognized limitations that remain to be addressed:

- **Gesture Recognition Limitations:** Ensuring accurate hand gesture detection for all users was a challenge. Different hand sizes, skin tones, and backgrounds can affect MediaPipe performance. We noticed that in poor lighting or if the camera angle isn't ideal, the recognition may fail or be erratic. Also, the system currently expects one hand in view; if the user's other hand or another person appears, it might confuse the detection. We mitigated some issues by instructing users on camera placement and using a plain background. Meanwhile, for patients who wearing therapeutic braces or having hand deformity could be hard to recognize now. We expect to receive data from clinical applications and medical sources in the future to improve detection accuracy and user-friendliness, with a particular focus on accommodating hand disabilities or deformities.

- **Technical Constraints of Streamlit:** Using Streamlit for a real-time interactive game was non-traditional and introduced performance constraints. Streamlit's framework isn't optimized for continuous video processing and quick state updates (it's more for static or periodic updates). We had to hack around this, and as a result the frame rate of the game can drop on slower machines, and there might be a slight delay in feedback compared to a native application. This isn't ideal for fast reflex training — a few testers noticed a small lag between doing the gesture and seeing the response. Additionally, deploying the game on the web could be limited by Streamlit's server load and the need for camera access permissions. While it worked, a more optimized or custom front-end (perhaps using OpenCV or a game engine) could provide a smoother experience.
  Streamlit is used for build a PoC temporarily, and we are expecting to build a native application in future for better effect.
- **Limited Rehabilitation Scope:** Our game focuses only on a few hand gestures (R, P, S and variants). This covers basic flexion/extension of fingers and some speed/coordination aspects, but it is not a comprehensive hand therapy program. Real hand therapy might involve multiple exercises for different joints (wrist rotations, individual finger movements, etc.), so our system addresses only a subset of

needs. Clinicians might view it as a supplementary tool rather than a replacement for all exercises. We also assume the patient can perform these three gestures; patients with more severe impairments might not be able to form a "Scissors" at all, for example. In such cases, the game would need adapting (or those gestures skipped), which currently isn't accommodated.

- **Lack of Formal Validation:** Because of the project timeframe, we have not conducted formal user studies with actual patients, nor have we clinically validated the measurements (e.g., is the ROM we calculate accurate compared to a goniometer reading by a therapist?). Without validation, we cannot be certain that the system's feedback correlates with real therapeutic progress. There is a risk of false feedback — for instance, the system might say "Great job" based on relative improvement, but maybe the patient's form was still not therapeutically sufficient. This could potentially reinforce suboptimal movements. It's a limitation that can only be addressed by involving medical experts and iterating on the system's accuracy and messaging.

Despite these challenges, we were able to deliver a functional prototype that demonstrates the core concept. Many limitations (like expanding exercise variety, improving recognition, etc.) were known from the start; we had to scope the project to fit course timelines. We consider these not failures, but opportunities to improve in future iterations.

Future Improvements

There are several avenues to enhance HandRehab-RPS beyond its current state, both to make it a more effective rehab tool and a more polished application:

- **Expanded Gesture Library:** To cover a broader range of hand rehabilitation needs, we plan to include more gestures or exercises. For example, incorporating pinching motions (thumb to index finger), wrist rotations, or other hand signs could exercise different muscle groups. The game could then have multiple mini-games or levels focusing on different movements (e.g., a "thumb war" game for pinch strength). We would need to extend the gesture recognition logic or perhaps use a machine learning model for more complex motions.
- **Personalized Difficulty and Progression:** Currently, difficulty adjustment is rule-based and general. In the future, the system could learn from the patient's performance data to personalize the experience. For instance, if a patient is consistently winning easily, the game might increase the speed requirement or add more rounds to challenge them. If a patient struggles, the system might drop the required win threshold or give more reaction time. We could implement a simple adaptive algorithm or integrate reinforcement learning to tailor the game's responses to each user's ability, ensuring a continually optimal challenge.
- **Improved User Interface and Graphics:** While Streamlit served well for a prototype, a future version could be redeveloped with a game engine (like Unity or Unreal) or a more interactive web framework. This would allow richer graphics, animations, and possibly AR/VR integration. For example, an Augmented Reality version could show a virtual hand or objects the patient is interacting with, increasing immersion. Better graphics and smoother animations would make the game more fun (e.g., showing an animated hand character for the AI opponent, or celebratory effects when the user wins).
- **Enhanced Clinician Dashboard:** We plan to build out the clinician side of the platform. This means a secure login for therapists where they

can select a patient and view their history of sessions, charts of progress, and perhaps configure the game parameters (e.g., set a target ROM to achieve, or restrict certain gestures if not advised medically). A clinician could remotely monitor if the patient did their "homework" and how well, and adjust the rehab program accordingly. This dashboard could also allow exporting data to electronic health records. Implementing this would involve more robust back-end development, possibly a cloud database to store multiple patients' data.

- **User Accounts and Data Sync:** Related to the above, adding a user account system would let patients log in from different devices and have their data synced. It would also enable the multiplayer matchmaking beyond just exchanging gestures (we'd need accounts or codes to invite friends, etc.). Security and privacy of medical data would be a consideration here, so we'd plan to encrypt and protect any stored information.
- **Formal Testing and Iteration:** Future work would involve conducting user studies with actual patients and therapists. Their feedback would be invaluable to refine the game mechanics (maybe some rules need tweaking), the UI (is everything clear for elderly users?), and the motivational aspects (what really keeps them coming back daily?). We would also validate the system's effectiveness by measuring outcomes: compare a group doing HandRehab-RPS with a control group doing standard exercises to see differences in adherence and recovery metrics. Based on results, we might iterate on the design — perhaps adding more narrative or rewards if motivation still wanes after a while, or adjusting difficulty curves if we find drop-off points.
- **Multiplayer and Social Features:** Once the basic PVP is in place, we can expand social features. For example, leaderboards or group

challenges for rehab (patients could see how they stack up in terms of points or improvements, in a friendly competitive spirit), or the ability to cooperate in a game against an AI boss (two patients team up to “defeat” a challenge by both doing their exercises). We could also add chat or communication features so patients feel part of a community, which psychological research shows can improve adherence.

- **Polish and Deployment:** Finally, we’d work on packaging the system for easy deployment. That includes a proper installation or a hosted web service, thorough documentation for users, and tutorials. We’d also address any remaining bugs or stability issues. Our goal would be to move from a prototype to a pilot program in a clinic, and eventually, if proven effective, make it available as a product that clinics or patients can use on their own.

In conclusion, HandRehab-RPS demonstrates how combining gesture recognition technology with game design and HCI principles can create an innovative rehabilitation experience. Our final prototype successfully turns a simple hand exercise into an interactive game that is engaging and informative. There is ample room to grow this project, but we believe it lays a strong foundation for future development. With further improvements, this approach could help make rehabilitation more enjoyable for patients and more trackable for clinicians — ultimately contributing to better health outcomes through the power of play.

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Haoran Zhang

Muzhou Yang

Qianbing Dong

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Reference

Vieira, C., Ferreira da Silva Pais-Vieira, C., Novais, J., Perrotta, A. (2021). Serious game design and clinical improvement in physical rehabilitation: Systematic review. JMIR Serious Games, 9(3), e20066. https://doi.org/10.2196/20066

McLaughlin, M. T., Moura, S. P., Edalatpour, A., Seitz, A. J., & Michelotti, B. F. (2024). Insurance status predicts hand therapy adherence following flexor tendon repair: A retrospective cohort study. Plastic and Reconstructive Surgery, 153(5), 942e—951e. https://doi.org/10.1097/PRS.0000000000010702

Toci, G. R., Green, A., Mubin, N., Imbergamo, C., Sirch, F., Varghese, B., Aita, D., Fletcher, D., & Katt, B. M. (2023). Patient adherence with at-home hand and wrist exercises: A randomized controlled trial of video versus handout format. Hand, 18(4), 680—685. https://doi.org/10.1177/15589447211052750

Deshaies, L. D. (2012). The evidence on ways to improve patient's adherence in hand therapy. et.al.