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Article

eJamar and Exergames for Hand Rehabilitation: Four Case Studies

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Abstract

Hand and wrist rehabilitation is essential for restoring motor function in patients with neurological, traumatic, or degenerative conditions. Conventional therapy can be repetitive and time-consuming, motivating the use of digital tools such as exergames to enhance engagement and outcomes. This study explored the feasibility and potential benefits of integrating the eJamar game controller with exergames as a complement to conventional hand rehabilitation. A case series of four female patients with hand and wrist impairments due to arthritis, arthrosis, or fractures was conducted. Each participant completed a three-week intervention comprising fifteen 1-hour sessions that combined traditional therapy with three exergames: Peter Jumper, Andromeda, and KARS. Functional outcomes were assessed before and after the intervention using range of motion (ROM), hand-grip strength, the Visual Analog Scale for pain, the Medical Research Council scale, a modified Nine-Hole Peg Test, and the Duruöz Hand Index. The intervention was feasible and well tolerated, and all participants demonstrated functional improvement, with the largest gains observed in grip strength and ROM, particularly in pronation, supination, and wrist deviation. These exploratory findings suggest that combining conventional therapy with the eJamar controller and exergames may support hand-function recovery. However, due to the small and heterogeneous sample, the findings should be interpreted as exploratory.

1. Introduction

1.1 Background

The hand is the principal effector organ of the human body, essential for grasping and exploring the environment through fine and gross motor functions [1]. Its key movements include pronation, supination, flexion, extension, radial and ulnar deviation, and hand-grip strength (HGS) [2]. When hand function is compromised, these movements become restricted and grip strength often decreases [1]. Rehabilitation therapy for the hand therefore focuses on restoring range of motion (ROM) and strength through targeted exercises [2], which may include massage therapy, magnetotherapy, infrared light application, ultrasound, or medicated paraffin immersion [3].

Upper-limb physical rehabilitation plays a crucial role in improving the quality of life of individuals with neurological disorders such as stroke [4] or Parkinson's disease [5], traumatic injuries like fractures or surgeries [6], and degenerative conditions such as arthritis or osteoarthritis, where recovery is often uncertain [7]. These pathologies severely affect the ability to perform daily activities such as zipping a jacket, holding a book, or carrying a bag. The Duruöz Hand Index (DHI) is commonly used to evaluate these functional limitations in various diseases [8]. According to the World Health Organization [9], structured rehabilitation programs can substantially improve quality of life, provided that patients adhere consistently to therapy. Such programs usually require repetitive motor patterns to promote effective recovery [10]; even in degenerative conditions, therapy helps maintain strength and mobility that would otherwise decline [7].

In recent years, exergames have been introduced into rehabilitation as a means to increase motivation and adherence. Unlike conventional therapies, often monotonous and passive, exergames encourage active participation and enjoyment during therapy [11]. They also provide digital records of movement [12], strength, and mobility, enabling clinicians to track progress objectively. Prior research has explored both commercial gaming platforms, like Xbox, PlayStation, Oculus, HTC Vive, and specialized rehabilitation systems such as Neuroball or Bright Brainer, which employ controllers designed to measure hand and wrist movement and grip strength [13].

1.2 Knowledge Gap

Many studies have demonstrated the benefits of exergames as complements to conventional rehabilitation. For instance, Borges et al. [14] reported sensory and functional improvements in two patients with ulnar-nerve injuries after 16 weeks of serious-game training using electromyography and dynamometers. Bressi et al. [15] combined ten sessions of conventional rehabilitation with the Gloreha Sinfonia robotic glove in a 10-year-old girl with hemiparesis, achieving sensorimotor improvements and greater motivation for both patient and family. Similarly, Hashim et al. [16] implemented a 10-session program using four exergames with amputee and non-amputee participants, observing gains in strength, coordination, and motivation.

Despite these advances, many exergame systems do not include electromechanical devices capable of actively engaging hand movement or developing grip strength [13]. Most rely on camera-based tracking to capture limb motion, limiting direct interaction with a tangible controller. Conversely, specialized devices for hand and wrist rehabilitation remain underrepresented in research, and published evidence about their clinical application is scarce [13].

1.3 Objective of the study

Similar to prior works, such as Kosar et al. [17], who tested the RehabHand system in a pilot case, and Burdea et al [18], who evaluated two case studies using a robotic rehabilitation table, controllers, and exergames, this research examines the feasibility of combining conventional rehabilitation with game-based therapy. Specifically, this study reports the outcomes of integrating the eJamar game controller (eJGC), a Bluetooth-enabled device that measures hand motion and grip strength, with three exergames.[19] Peter Jumper (PJE) was developed to promote grip strength, Andromeda (AE) to improve pronation, supination and wrist deviation, and KARS (KE) to sustain grip force. The combined protocol was applied to four patients referred by a traumatologist over three weeks (15 sessions) to explore its feasibility and potential benefits for hand and wrist rehabilitation.

2. Methods and Material

The rehabilitation system based on exergames consists of three main components: the player, the eJamar controller, and the video games, as illustrated in the system architecture in Figure 1. The games transmit configuration parameters to the controller through wireless communication.

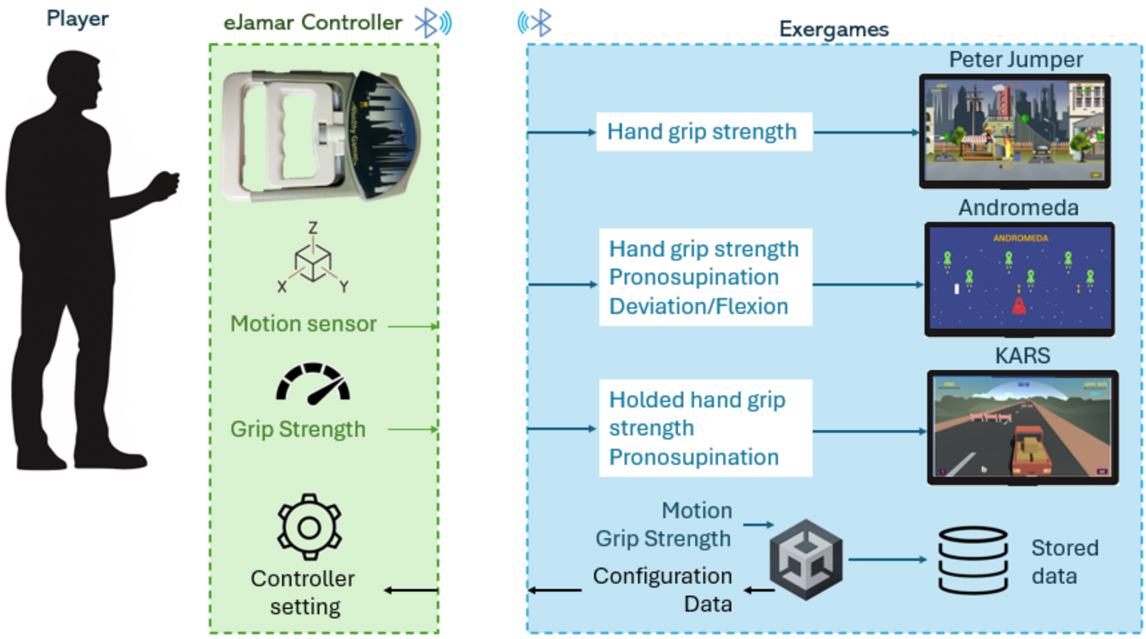

Figure 1. Architecture of the exergame - based rehabilitation system.

Once configured, the eJamar sends the required motion and force data back to the games. Additionally, each game stores this data for further analysis.

2.1 Game framework

Each game was designed to promote specific movement patterns aimed at exercising grip strength and enhancing mobility across the full ROM. While the exergames were developed to allow independent use by patients, in this study every session was conducted under the supervision of a rehabilitation specialist. The exergames and their main features are described as follows.

2.1.1 Peter Jumper exergame

PJE was developed to train patients' grip strength through repetitive grasping movements. In this game, the main character, Peter, must jump over obstacles that appear in front of him to avoid collisions and lose a life. To make Peter jump, the player must press the eJamar controller. When the applied pressure exceeds a predefined threshold, the jump is triggered. During the initial configuration stage, the system calibrates the force according to the patient's maximum grip strength, ensuring that all level thresholds are adjusted accordingly. PJE features three levels, each increasing in difficulty by raising the jump threshold. Figure 2A shows a scene of PJE, level 2.

Beyond entertainment, this exergame specifically targets improvements in hand-grip force, endurance, and reaction speed. The eJamar continuously records the force applied (in kgf) and the timing of each grasp to quantify both maximum and sustained grip effort. The system provides visual and auditory feedback after each jump, reinforcing successful performance and promoting motor learning through repetition. Game parameters, including duration (1–3 min per level), speed, and threshold percentages relative to the individual's maximum voluntary contraction, can be customized by the therapist. Data (player settings, force, time) from each session are stored automatically in a CSV log for later clinical review.

2.1.2 Andromeda exergame

AE was designed to enhance HGS and encourage wrist and ROM exercises, incorporating pronation, supination, flexion, extension, radial deviation, and ulnar deviation movements. In this game, enemy ships appear randomly and must be destroyed. The patient fires by pressing the eJamar controller. Each destroyed enemy ship earns points, as do collected coins and hearts. Every five coins or one heart grants an extra life. AE includes different game modes, allowing users to engage in all hand and wrist movements. Each level lasts between 1 and 3 minutes, depending on the initial configuration settings. Figure 2B shows a scene of AE in deviation mode.

The game uses the IMU data from the eJamar to detect angular motion across three axes, translating real wrist rotation and deviation into spaceship navigation. Difficulty is automatically scaled by modifying the angular thresholds required for target alignment. This design stimulates smooth and controlled movements through the entire range of motion, supporting both mobility and proprioceptive retraining. AE has been especially useful for patients with limited pronation–supination control or post-fracture stiffness. All movement and scoring data are logged, enabling therapists to track progression in angular amplitude and coordination accuracy.

2.1.3 KARS exergame

KE was developed to improve grip strength and pronation–supination movements. KE consists of a vehicle moving along a highway, where the patient must rotate their wrist in pronation and supination to steer the car left or right, avoiding obstacles. In level 1, shown in Figure 2C, the speed of the vehicle is constant, and the player just has to control the car doing pronation–supination movements. In Level 2 the player controls the speed of the car by pressing the eJamar and the rotation by doing pronation–supination movements. Finally, Level 3 consists of a race between two vehicles on an obstacle-free road. To maintain the speed of their vehicle, the player must sustain a constant grip force on the eJamar. The opponent's speed is based on the player's own performance in Levels 2 and 3, meaning the player is essentially competing against themselves.

This exergame focuses on motor control, grip endurance, and sustained muscle activation, requiring the player to maintain steady pressure and precise wrist rotation simultaneously. The eJamar collects continuous grip-force and angular-motion data, allowing the therapist to analyze fluctuations in sustained effort and coordination. By adjusting the sensitivity of steering and the required grip thresholds, KE can be adapted to each patient's functional capacity. The combination of dynamic (rotation) and isometric (sustained grip) tasks provides a balanced training stimulus for muscle strengthening, fine motor control, and fatigue resistance.

2.1.4 System connectivity and configuration

The eJamar game controller transmits data to the computer via Bluetooth wireless communication. Therefore, the computer running the games must support Bluetooth connectivity. Within the system's Bluetooth settings, the device labeled AC_BTX must be selected, which corresponds to eJGC. The controller must be powered beforehand to enable pairing. Once connected, the games can be launched. The controller vibrates twice when turned on and three times upon successfully connecting to a game and receiving its initial configuration, which sets the game in default mode.

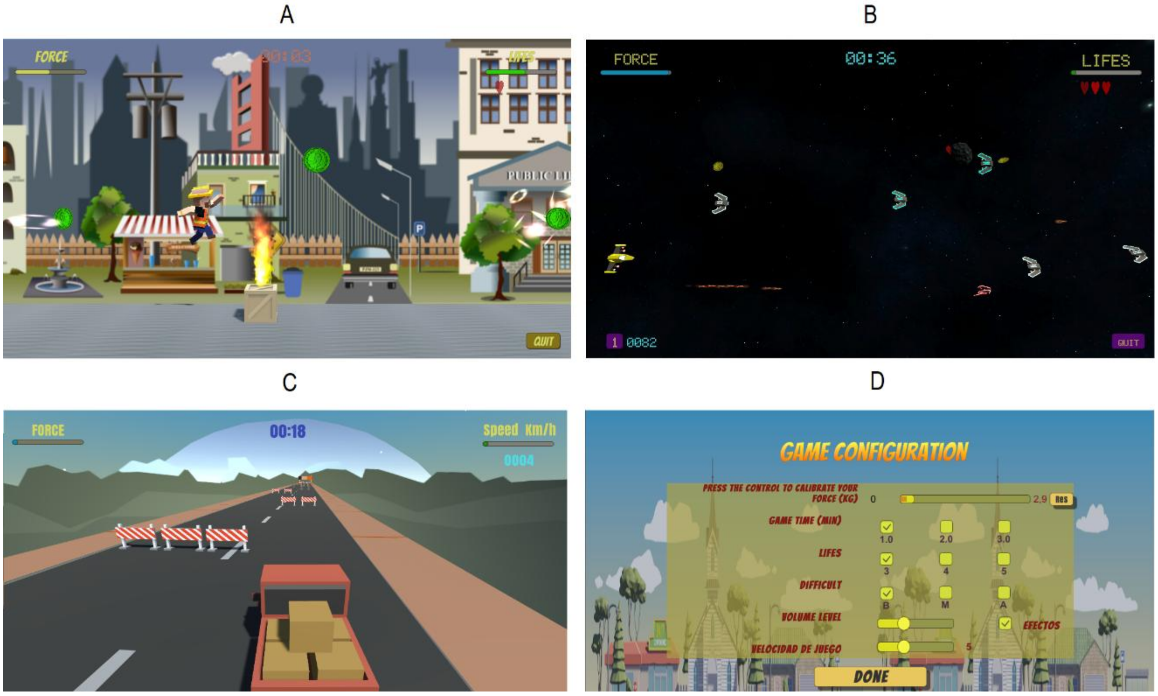

Figure 2. A) Peter Jumper Exergame – Level 2. B) Andromeda Exergame, deviation mode – Level 1. C) KARS exergame – Level 1. D) PJE Configuration Screen.

PJE allows both game and controller configurations. Within the game, users can set the initial number of lives, the difficulty level, obstacle appearance speed, character running speed, volume level, and sound effects, as shown in Figure 2.D. The game also requires an initial grip strength calibration for each hand, in which the player's maximum grip force is measured to define the jump thresholds across all levels.

At the controller level, it is possible to configure the jump mode (grip strength or motion acceleration), the orientation (vertical or horizontal), haptic feedback on collision, and overall sensitivity. For this study, due to the nature of the intervention, the controller was used exclusively in vertical mode, and character jumps were triggered by grip strength measurement.

AE also offers game and controller configuration options. AE supports both vertical and horizontal controller orientations. In vertical mode, pronation-supination movements control the spaceship from left to right, while radial and ulnar deviation move the spaceship up and down. In horizontal mode, flexion and extension movements control vertical displacement. In all cases, projectiles are fired by squeezing the controller, as previously described.

KE only requires initial grip strength calibration, which defines the threshold needed to accelerate the vehicle during Levels 2 and 3.

2.1.5 Stored Data

Each video game stores key mobility and grip strength data in CSV files. Additionally, player performance is recorded in a separate file. For example, in PJE, two files are generated per session. The first file logs the player's HGS along with timestamps and the moments when obstacles appear. The second file records the score obtained by collecting coins and the number of collisions per level. The other two exergames operate similarly, storing data related to movement parameters, applied force, and gameplay scores. These datasets enable tracking of the patient's progress across different rehabilitation sessions.

Figure 3 shows an example of HGS data recorded from a player during a session in Level 1 of PJE. The blue line represents the grip force applied throughout the game, while red asterisks indicate the moments when an obstacle appears in the scene. The player applies force shortly, resulting in peak force values occurring a few seconds ahead of the obstacle's appearance, as shown in Figure 3.

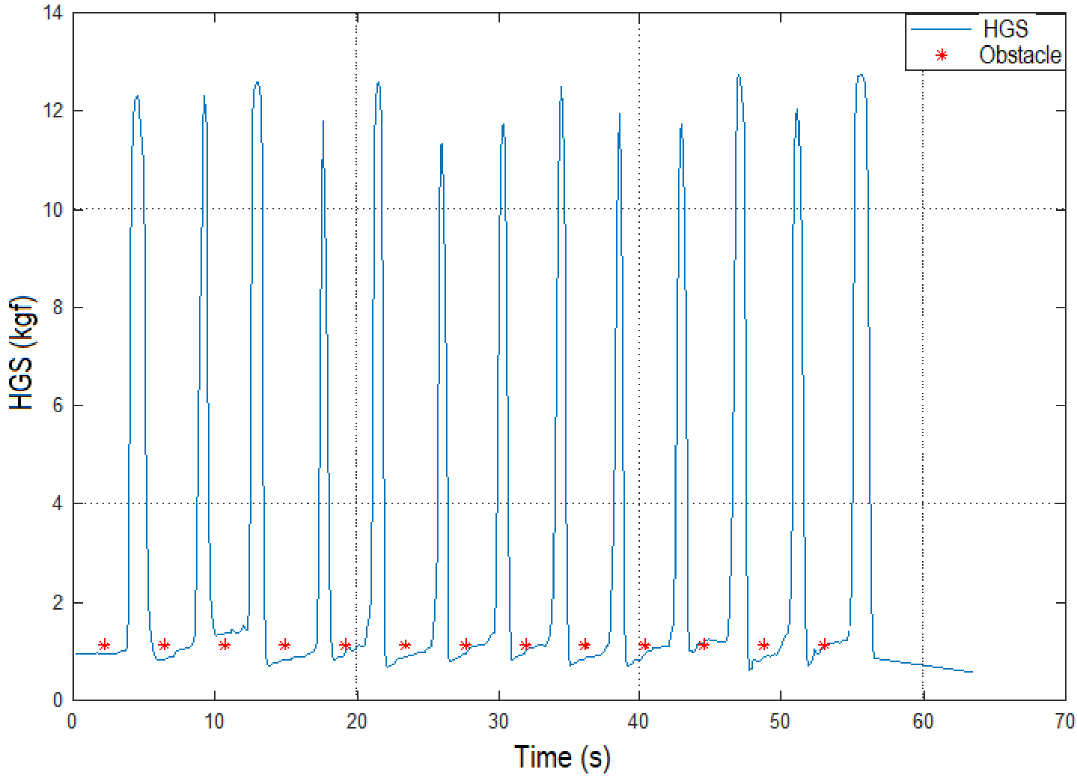

Figure 3. Plot of Hand Grip Strength and Obstacles vs time stamp.

2.2 eJamar game controller

The eJGC is an electronic device equipped with integrated force and motion sensors, wireless Bluetooth communication, control buttons, indicator lights, and other embedded electronic components. The HGS is measured through a strain gauge load cell, with force values expressed in kilogram-force (kgf) and a maximum error of ±2% of full scale. To capture wrist and hand movements across the full range of motion, including pronation, supination, flexion, extension, and radial–ulnar deviation, the eJGC incorporates a six-degrees-of-freedom Inertial Measurement Unit (IMU). This IMU records linear acceleration and angular orientation along the three spatial axes. The acquired data are digitally filtered to minimize noise and then transmitted in real time via Bluetooth for further processing and analysis. Figure 4 shows the patterns of movements of the eJGC.

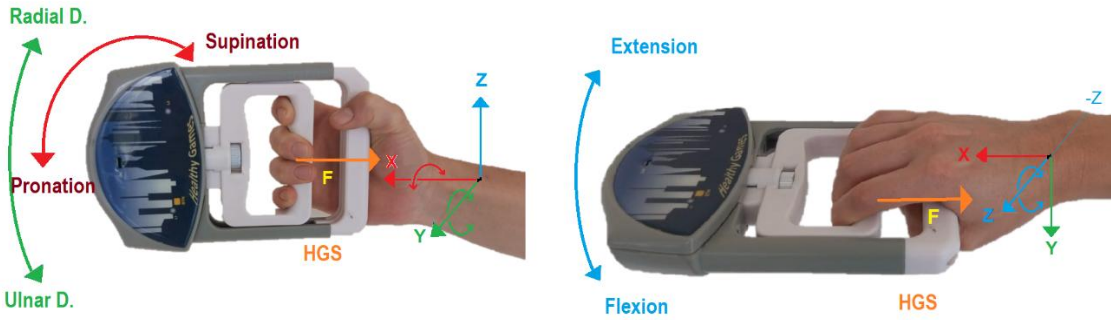

Figure 4. Patterns of movements of the eJGC.

In this way, the eJGC functions as an input device that enables the user to control the characters within the exergames. Players interact with the games by moving or pressing the controller, allowing therapeutic activities to be gamified and engaging. Sensor data is transmitted wirelessly to a computer via Bluetooth and is automatically stored in structured files. Upon completion of each session, rehabilitation specialists can review the recorded data to monitor the patient's performance and progress over time.

Further technical details about the eJGC device and the exergames can be found in a previous publication [19].

An explanation of the full system functionality could be seen on *https://www.youtube.com/watch?v=XTqtEGaFCvw*

2.3 Protocol

The protocol consisted of two parts. The first one is focused on the upper limb motor function assessment which is evaluated at the beginning (initial assessment t0) and at the end (final assessment t1) of the rehabilitation treatment. The second part is focused on the therapy performance, where the patient receives conventional rehabilitation therapy combined with the exergames-based treatment. The rehabilitation protocol was performed for 3 weeks, 5 sessions per week. Due to any limitations in the medical center like, workspace, equipment and available time of spaces, the initial and final sessions were also the first and the final days of the 15 sessions treatment.

The protocol was conducted by two rehabilitation specialists and one technical assistant. Specialist 1 (S1) was responsible for general supervision and conventional rehabilitation treatment. Specialist 2 (S2) did the initial and final assessments, and guided participants to complete the exergame-based therapy. The technical assistant (TA) participated only in the initial and final sessions to record assessment data.

The rehabilitation protocol was implemented at the Ambulatory Surgical Clinical Center El Batan, located in Quito, Ecuador, during June of 2025. It was approved by the Ethics Committee of the Central University of Ecuador, under registration 003-EXT-2025.

2.3.1 Inclusion and Exclusion criteria

Inclusion criteria: Participants were adult patients (aged 18 years or older) referred by a specialist physician to the hand and wrist rehabilitation unit. Additional inclusion criteria included the ability to understand and follow basic instructions necessary to operate the exergames on a computer, a muscle strength score greater than grade 2 on the Medical Research Council scale (MRC), and the provision of written informed consent prior to participation.

Exclusion criteria: Patients were excluded if they presented severe cognitive impairment that could interfere with task comprehension or performance (e.g., clinically diagnosed dementia or significant cognitive deficit observed by the clinician), debilitating acute pain, recent fractures without bone consolidation, or recent surgical procedures that contraindicated active upper-limb movement during therapy.

2.3.2 Participants

The study included four female patients who were directly referred by their treating traumatologist to participate in a three-week hand and wrist rehabilitation program. In this medical center, patients commonly present with conditions such as fractures, osteoarthritis, or post-surgical cases (e.g., trigger finger release or other upper-limb interventions). Accordingly, the selected participants reflected examples of cases typically managed in this setting, while still representing individual clinical variability in diagnosis and rehabilitation needs. All participants met the predefined inclusion criteria, and no eligible patients were excluded. Each participant received a detailed explanation of the study protocol and provided written informed consent prior to participation.

Participant 1 (P1) was a 53-year-old woman diagnosed with bilateral osteoarthritis. Participant 2 (P2), aged 67 years, had a history of ischemic stroke approximately five years earlier, resulting in left-arm paresis, and also sustained a left wrist fracture eight months before the study. Participant 3 (P3) was a 71-year-old woman who had suffered a left wrist fracture five months prior to enrollment. Participant 4 (P4), aged 64 years, was diagnosed with bilateral osteoarthritis affecting both hands. The demographic and clinical characteristics of the participants are summarized in Table 1.

To avoid compromising the results, the four patients who participated in this therapy did not take part in any other rehabilitation protocol or additional therapy during the study period.

Table 1. Demographic information of the participants.

Case	Sex	Age	Diagnosis	Affected hand	Severity (MRC/5)*	Duration of condition
P1	F	53	Osteoarthritis	Both	3.7	1 Year
P2	F	67	Stroke / Fracture	Left	2.7	5 Years / 8 Months
P3	F	71	Fracture	Left	2.2	5 Months
P4	F	64	Osteoarthritis	Both	4.8	4 Year

* Baseline Severity was assessed according to the initial Medical Research Council (MRC) scale score.

2.3.3 Outcomes measures

Once the four participants were recruited, the baseline assessment (t_0) was conducted on the first day of the intervention for all cases. Given the heterogeneity of their underlying conditions, outcome measures were selected based on their broad applicability across diverse hand and wrist pathologies. The chosen assessments focused on evaluating functional recovery through objective measures of ROM, muscle and grip strength, and patient-reported outcomes related to pain and daily-hand functionality.

S2 started the ROM assessment for the hand and wrist through the goniometer standard which is capable of measuring angles from 0 to 90 degrees [1]. S1 assessed the angles of pronation and supination of wrist, flexion, extension, radial and ulnar deviation for each hand. The ROM measurements outlined by the National Library of Medicine [20].

After that, S2 applied the MRC scale for muscle for each hand. This method involves testing key muscles from upper or lower limbs against the specialist's resistance [21]. The MRC scale ranges from 0 to 5. A score of 0 indicates a total absence of muscle strength, with no visible or palpable contraction. A score of 1 signifies the presence of muscle contraction without any joint movement. A score of 2 indicates that joint movement is present but only when gravity is eliminated, such as when the hand is supported on a table. A score of 3 represents full movement against gravity but without any external resistance. A score of 4 denotes full movement within the joint's range with moderate resistance applied. Finally, a score of 5 signifies full movement through the complete ROM with maximum resistance applied [21].

S2 administered the Visual Analog Scale (VAS) to the participants. The VAS pain scale, ranging from 0 to 10, provides a quantifiable measure of the pain perceived by the individual[22]. In this scale, a score between 0 and 1 indicates no pain, 2 to 3 represents mild pain, 4 to 6 corresponds to moderate pain, 7 to 8 indicates severe pain, and 9 to 10 reflects extreme pain [22].

S2 measured the HGS using a digital dynamometer capable to measure to 100 Kgf of hand grip with 0.1kg of resolution. The measures were done 3 times in each hand. Although all values were recorded, just the maximum value was considered for analysis.

A modified version of the 9-Hole Peg Test (9HPT) was used to assess gross motor dexterity and hand functionality in patients. In this variation, nine large pegs were used, each approximately 7 cm in height with a diameter of 15 mm, allowing for the evaluation of gross motor skills instead of fine motor dexterity. The time taken by each patient to place and remove the pegs one by one from the holes was recorded. The completion times for each hand were documented. These pegs were used because they were routinely employed in this medical center as part of the rehabilitation instruments. Although the results obtained with this modified version of the 9HPT are not directly comparable to those from studies using the standard version, this adaptation allowed us to monitor the patients' functional progress throughout the treatment.

Next, the DHI survey was applied to assess patients' perception of their manual functionality [8]. This questionnaire consists of 18 questions, where patients report their ability to perform various daily tasks. The responses are rated on a 0 to 4 scale, where 0 indicates no difficulty in performing the task, while 4 represents complete inability to perform it. While S2 administered the assessment, TA registered all measured values in a computer.

Finaly, in this session, participants were introduced to the exergames and trained on using the eJamar controller by approximately 15 minutes where they play the exergames controlled by the eJGC.

At the end of treatment, in an additional session, all initial assessments were repeated to evaluate rehabilitation progress. The selected outcomes included both objective device-based metrics (ROM, HGS) and functional or patient-reported measures (MRC, VAS, DHI, and 9HPT), providing a comprehensive evaluation of motor recovery and perceived functionality.

2.3.4 Rehabilitation Sessions

The rehabilitation treatment lasted one hour per session, five days a week for three weeks (a total of 15 sessions, including the initial assessment). Each session included 35 minutes of conventional rehabilitation, consisting of 10-minute medical paraffin hand immersion, 10-minute hand stretching exercises and massage and 15-minute magnetotherapy treatment. Afterward, 25 minutes of exergame-based therapy were performed, alternating between PJE, AE, and KE using the eJGC. Since all three exergames aim to enhance HGS and ROM, the supervising specialist selected two exergames for each session according to the patient's therapeutic needs and progression. At the beginning of each session, HGS was measured and recorded for both hands.

2.4 Data Analysis

The data collected from the eJamar system and the clinical assessments were analyzed using descriptive statistics. For each outcome measure, pre- and post-intervention values (t_0 and t_1) were compared within each participant to quantify individual progress. Changes over time were expressed both as differences ($\Delta = t_1 - t_0$) and as percentage change relative to the baseline value. The analysis focused on individual case trends rather than inferential comparisons, given the small sample size (n = 4). Quantitative data (ROM, HGS, VAS, 9HPT, DHI) were summarized in tables, while qualitative observations from the therapist were used to complement interpretation of functional improvement.

Data from the eJamar device and exergames were exported as CSV files, processed in Microsoft Excel and visually inspected using tables and plots to identify improvement trends.

Table 2 summarizes the outcome measures used in this study, including both objective device-based metrics and functional or patient-reported assessments. Each participant was evaluated at baseline (t_0) and after completing the three-week intervention (t_1). The combination of quantitative data and patient-reported measures provided a comprehensive view of functional recovery.

Table 2. Outcome measures and corresponding instruments used for descriptive analysis in the study.

Outcome	Instrument	Unit of Measurement	Time Points*	Purpose	Type**
Range of Motion (ROM)	Goniometer	Degrees (°)	t_0, t_1	Evaluates wrist mobility (flexion, extension, pronation, supination, radial and ulnar deviation).	Motor
Hand Grip Strength (HGS)	Digital dynamometer	Kilogram-force (kgf)	t_0, t_1, each session	Measures maximum voluntary contraction and strength recovery.	Motor
Muscle Strength	Medical Research Council (MRC) Scale	0–5 scale	t_0, t_1	Assesses overall muscle strength of the affected hand.	Functional
Pain Intensity	Visual Analog Scale (VAS)	0–10 scale	t_0, t_1	Rates the patient's perceived pain level.	Functional / Self-reported
Gross Motor Dexterity	Modified Nine-Hole Peg Test (9HPT)	Time (s)	t_0, t_1	Evaluates coordination and gross motor control.	Functional
Hand Function in Daily Activities	Duruöz Hand Index (DHI)	0–90 points	t_0, t_1	Measures perceived difficulty in performing daily tasks.	Functional / Self-reported

* t_0 (baseline), t_1 (post-intervention), ** Outcome type based on the International Classification of Functioning [23].

3. Results

Upon completing the 15 rehabilitation sessions, S2 re-evaluated the patients' parameters. The results are presented as follows.

3.1 Range of Motion

Tables 3 and 4 summarize the ROM outcomes for the right and left hands, respectively. Overall, three out of four participants demonstrated improvements across most wrist movements, particularly in flexion and deviation.

P1 exhibited the most notable improvement in right-hand flexion (+40°), reaching approximately 100% of the normal range of motion. A slight decrease was observed in ulnar deviation (–8°). The left hand also showed substantial gains in flexion (+28°), nearly achieving full range of motion.

P2 demonstrated consistent progress in right-hand ulnar and radial deviation (+21° and +12°, respectively), with minor reductions in pronation (–6°) and supination (–1°). In the left hand, all parameters improved except for a minimal decline in ulnar deviation (–1°).

Table 3. Comparison of ROM between initial and final assessments for the right hand.

Measurements*	P1			P2			P3			P4		
	t_0	t_1	ΔRH	t_0	t_1	ΔRH	t_0	t_1	ΔRH	t_0	t_1	ΔRH
Radial dev.	20	40	+20	30	42	+12	25	27	+2	20	32	+12
Ulnar dev.	50	42	-8	29	50	+21	43	38	-5	45	31	-14
Flexion	50	90	+40	82	90	+8	90	90	0	90	80	-10
Extension	49	50	+1	50	51	+1	49	58	+9	55	60	+5
Pronation	90	90	0	89	83	-6	89	90	+1	90	90	0
Supination	89	86	-3	90	89	-1	90	90	0	90	90	0

* All measurements are in degrees (°). t0 is the initial assessment. t1 is the final assessment. ΔRH is the difference between both measures of the right hand.

P3 displayed moderate improvement in right-hand extension (+9°) and more pronounced gains in the left hand, where flexion, extension, and ulnar deviation increased by up to +39°, representing approximately 70% recovery relative to baseline.

P4 showed the lowest overall gains, with a reduction of about 30% in ulnar deviation (–14°), but a positive change in radial deviation (+12°). In contrast, left-hand pronation improved by approximately +10°.

Interestingly, pronation and supination movements across all participants nearly reached 90°, corresponding to full functional range, as shown in Tables 3 and 4. These movements appeared to be the least affected compared with other motion directions.

Overall, flexion and deviation movements showed the greatest gains across participants, while minor declines were mainly associated with pronation or ulnar deviation, reflecting individual variability in recovery.

Table 4. Comparison of ROM between initial and final assessments for the left hand.

Measurements*	P1			P2			P3			P4		
	t_0	t_1	ΔLH	t_0	t_1	ΔLH	t_0	t_1	ΔLH	t_0	t_1	ΔLH
Radial dev.	50	47	-3	30	40	+10	30	28	-2	39	40	+1
Ulnar dev.	20	40	+20	20	19	-1	11	40	+29	30	37	+7
Flexion	61	89	+28	70	90	+20	60	90	+30	80	80	0
Extension	40	58	+18	25	39	+14	21	60	+39	59	59	0
Pronation	90	89	-1	78	90	+12	89	90	+1	80	90	+10
Supination	90	90	0	78	90	+12	90	90	0	90	90	0

* All measurements are in degrees (°). t0 is the initial assessment. t1 is the final assessment. ΔLH is the difference between both measures of the left hand.

3.2 Medical Research Counsil Scale for Muscle

Tables 5 and 6 summarize the muscle strength results according to the Medical Research Council (MRC) scale for the right and left hands, respectively. Overall, three out of four participants showed strength gains in several wrist movements, with the most notable improvements observed in flexion, extension, and pronation.

P1 exhibited a +1 increase across all right-hand movements except pronation, which remained stable at grade 4. In the left hand, greater progress was noted, with +2 improvements in ulnar deviation, extension, and pronation, indicating enhanced muscle activation and control.

P2 maintained maximum strength (grade 5) in all right-hand movements, while the left hand showed moderate gains of +1 in ulnar deviation, pronation, and supination, with a slight decline (–1) in extension.

Table 5. Comparison of MRC between initial and final assessments on the right hand.

Measurements*	P1			P2			P3			P4		
	t_0	t_1	ΔRH	t_0	t_1	ΔRH	t_0	t_1	ΔRH	t_0	t_1	ΔRH
Radial dev.	4	5	+1	5	5	0	4	4	0	5	4	-1
Ulnar dev.	4	5	+1	5	5	0	3	4	+1	5	4	-1
Flexion	4	5	+1	5	5	0	4	4	0	5	5	0
Extension	4	5	+1	5	5	0	3	4	+1	5	5	0
Pronation	4	4	0	5	5	0	3	4	+1	5	5	0
Supination	3	4	+1	5	5	0	3	4	+1	5	5	0

* t0 is the initial assessment. t1 is the final assessment. ΔRH is the difference between both measures of the right hand.

Table 6. Comparison of MRC between initial and final assessments on the left hand.

Measurements*	P1			P2			P3			P4		
	t_0	t_1	ΔLH	t_0	t_1	ΔLH	t_0	t_1	ΔLH	t_0	t_1	ΔLH
Radial dev.	4	5	+1	3	3	0	2	4	+2	4	5	+1
Ulnar dev.	3	5	+2	2	3	+1	3	4	+1	5	5	0
Flexion	4	5	+1	3	3	0	2	4	+2	5	5	0
Extension	3	5	+2	3	2	-1	2	3	+1	5	5	0
Pronation	3	5	+2	4	5	+1	2	4	+2	5	4	-1
Supination	4	4	0	1	2	+1	2	3	+1	4	4	0

*t0 is the initial assessment. t1 is the final assessment. ΔRH is the difference between both measures of the left hand.

P3 demonstrated consistent +1 increases in ulnar deviation, extension, pronation, and supination on the right side. In the left hand, strength improved across all movements, with the largest gains (+2) in radial deviation, flexion, and pronation, reflecting a generalized strengthening trend.

P4 presented minor reductions (–1) in right-hand radial and ulnar deviation, whereas the left hand showed a small increase (+1) in radial deviation but a decrease (–1) in pronation strength.

Overall, most participants displayed measurable gains in muscle strength, particularly in flexion and pronation, though slight reductions in isolated movements reflected individual variability in recovery.

3.3 VAS Pain Scale

The VAS pain scale ranges from 0 (no pain) to 10 (maximum pain). Negative differences between the baseline (t_0) and post-treatment (t_1) values indicate pain reduction.

As shown in Table 7, P1 reported no changes in pain levels in either hand. P2 experienced a decrease of –2 points in the left hand only, while P3 showed a –1 point reduction in the same hand. P4 reported a –3 point decrease in right-hand pain but a +1 increase in the left hand. Overall, most participants demonstrated mild to moderate pain reduction following the intervention.

3.4 9-Hole Peg Test-Based Evaluation

Table 7 presents the results of the modified 9HPT, which assessed changes in gross-motor performance before and after rehabilitation. Overall, participants showed heterogeneous outcomes.

P1 demonstrated improved dexterity, reducing right-hand completion time by 4.7 s, while the left hand remained stable at approximately 23 s. P2 exhibited slower performance in both hands, with an increase of about 4 s in the right and 12 s in the left hand, the latter affected by hemiparesis and a previous fracture. P3 achieved faster completion times, decreasing by 2.0 s (right) and 3.7 s (left), whereas P4 showed minimal increases of +0.36 s and +2.2 s, respectively. Overall, these findings indicate variable gross-motor outcomes among participants, reflecting differences in baseline condition and motor control recovery.

3.5 Duruöz Hand Index

The DHI assesses patients' perceived difficulty in daily hand activities, where 0 means no difficulty and 4 means unable to perform. As shown in Table 7, all participants reported reduced difficulty in performing daily tasks, reflected by lower DHI scores at post-intervention (t_1). These findings indicate a general improvement in self-perceived hand function following the rehabilitation program. P2 exhibited the largest reduction (–1.5), suggesting a marked improvement in functional ability, while P1 reported the lowest post-treatment difficulty (0.28), reflecting minimal residual limitation in daily activities. Overall, these results highlight a consistent trend toward better perceived functional performance across all participants.

Table 7. VAS, 9HPT and HFI measurements.

Measurements	P1			P2			P3			P4		
	t_0	t_1	Δ	t_0	t_1	Δ	t_0	t_1	Δ	t_0	t_1	Δ
VAS_RH*	4	4	0	0	0	0	0	0	0	5	2	-3
VAS_LH	4	4	0	8	6	-2	7	6	-1	2	3	+1
9HPT_RH**	23.17	18.44	-4.73	17.68	21.63	3.95	28.82	26.8	-2.02	22.4	22.76	0.36
9HPT_LH	22.98	22.84	-0.14	2:35	2:47	12	35.61	31.93	-3.68	22.36	24.56	2.2
DHI_mean***	1.44	0.28	-1.16	2.22	0.72	-1.5	1.11	0.5	-0.61	0.83	0.44	-0.4
DHI_SD	0.92	0.46	-0.46	0.43	1.18	0.75	1.13	0.62	-0.51	1.04	0.51	-0.5

* VAS scale 0 means no pain and 10 means extreme pain. ** The 9 Hole Peg Test Based evaluation is measured in seconds [s]. *** For DHI scale 0 means no difficulty to do the tasks, while 4 means patient is not able to do the tasks.

3.6 Hand Grip Strength

HGS for right and left hands were measured in each session, tracking the evolution of both hands of each patient. The results are shown in Figure 5.

The progression of P1 HGS is shown in Figure 5A where both the right-HGS (blue line) and left-HGS (orange line) increased, starting at approximately 24 kgf and reaching 30 kgf, with the right hand displaying greater strength. Since both hands were affected in P1, their force values remained relatively close. Figure 5B illustrates the strength progression in P2. The right-HGS (blue line) increased from 21 kgf to approximately 26 kgf, while the left-HGS (orange line) improved from 9 kgf to about 17 kgf. This difference is due to left-hand impairment, but a considerable improvement was observed. Figure 5C shows that right-hand strength increased from 20 kgf to approximately 25 kgf.

Since P3's left hand was impaired, its initial strength was significantly lower, increasing from 9 kgf to around 20 kgf. This represents the greatest improvement observed, with an approximate increase of 10 kgf. Figure 5D illustrates HGS changes in P4, who had both hands affected. The strength values for both hands remained within the same range, increasing from 15 kgf to about 23 kgf.

Patients P1 and P4 had both hands affected, while patients P2 and P3 had the left hand affected. It is shown in Figure 5, where the HGS of patients P1 and P4 for both hands started in near values, while HGS of left hand (orange line) of patients P2 and P4 started in the lowest values, around 9kgf, which is lower than right HGS values (blue values). Across all cases, an increase in HGS for both hands was observed.

4. Discussion

The findings of this case series indicate potential benefits from integrating the eJamar device and exergames into standard hand rehabilitation protocols. Improvements were observed in ROM, HGS, pain perception, and perceived functional performance in daily tasks. These outcomes suggest that the combined use of eJamar and exergames can effectively complement conventional rehabilitation by promoting active participation and sustained motivation among patients.

Commercial gaming controllers such as the Wii Remote or Kinect have been explored in rehabilitation contexts; however, these systems are not certified as medical devices under the European Medical Device Regulation (MDR 2017/745)[24]. As a result, their use in clinical settings is limited to exploratory or research contexts, as they do not meet the regulatory requirements related to safety, hygiene, and clinical validation required for routine therapeutic application. This regulatory limitation reinforces the importance of developing purpose-built, medical-grade tools, such as eJamar, which are specifically designed to comply with MDR requirements and to be safely integrated into clinical and rehabilitation environments [19].

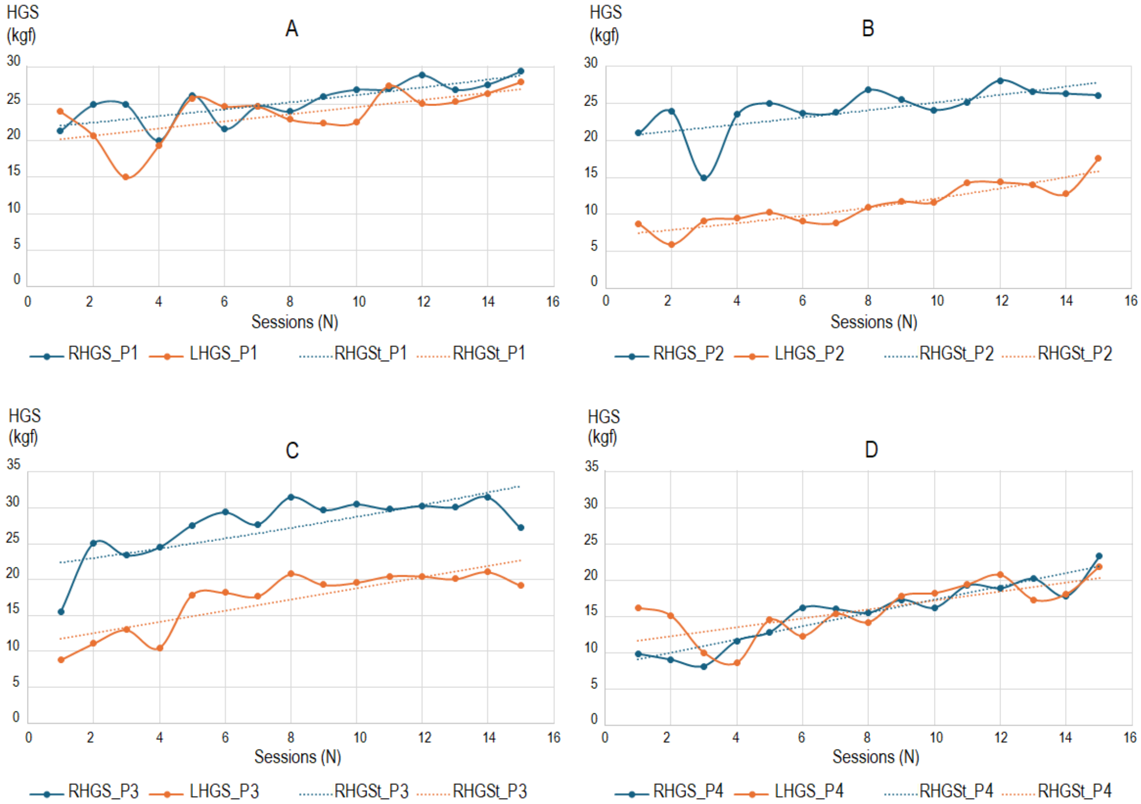

Figure 5. Progression of HGS from session 1 to session 15. The blue line represents the right HGS, and the red line represents the left HGS. Dotted lines indicate the functional trend for each case. A) Patient 1. B) Patient 2. C) Patient 3. D) Patient 4.

Given the exploratory nature of this case series and the small sample size, the analysis was limited to descriptive trends that illustrate individual recovery rather than group-based inferences. Participants P2 and P3 demonstrated notable improvements in flexion, extension, and deviation, particularly in the left hand, supporting previous findings that engaging and repetitive tasks can enhance neuroplasticity and joint mobility through active involvement [18].

Marked individual differences were observed. P1 achieved a 40° increase in right-hand flexion and a 28° improvement in the left hand, while P2 gained 21° in right-hand ulnar deviation and 20° in left-hand flexion. P3 exhibited the most pronounced gains, with a 39° increase in left-hand extension, whereas P4 showed the least improvement, including a 14°

decrease in right-hand ulnar deviation but a 12° gain in radial deviation. The variability among cases likely reflects differences in baseline impairment, pathological type, and disease chronicity. For instance, P4's osteoarthritis could explain limited progress and suggests that personalized treatment plans emphasizing pain management and mobility preservation may be more appropriate for such patients [7].

Muscle strength improvements were evident in three of the four patients, mainly in flexion and radial deviation, which aligns with reports that gamified rehabilitation promotes voluntary and repetitive muscle activation essential for strength recovery [14]. Minor reductions in isolated cases (e.g., P4) may reflect transient fatigue or discomfort, emphasizing the need for continuous monitoring of exertion levels.

Pain levels decreased or remained stable in most cases. P4 showed the greatest reduction (–3 points) in the right hand, consistent with prior research demonstrating that interactive or virtual-reality-based rehabilitation can reduce pain perception [25], [26]. Limited or inconsistent pain reduction in some participants may relate to session timing, as eJGC activities followed manual therapies (e.g., massage), which could transiently affect pain perception. The mild pain increases in P4's left hand suggests that excessive load or device positioning should be further examined.

Gross-motor improvements were modest but evident in P1 and P3, who reduced completion times in the modified 9HPT. These findings are consistent with prior work indicating that interactive, task-based training enhances motor coordination and precision [27]. Conversely, the performance decline in P2, who presented hemiparesis following stroke, highlights the limited efficacy of exergames in severe neurological cases [28].

All patients showed reduced DHI scores, reflecting improved ability to perform daily tasks. These outcomes are aligned with existing studies demonstrating that technology-assisted rehabilitation can enhance perceived functional independence [29]. The concurrent improvements in DHI and VAS scores indicate that motor recovery was accompanied by increased comfort and reduced effort in daily activities, reinforcing the clinical relevance of this intervention.

The HGS increased across all participants, with P3 exhibiting the largest gain (+10 kgf) in the affected hand. This finding supports previous evidence that repetitive, interactive exercises foster grip recovery even in chronic cases [30]. Bilateral engagement, despite unilateral impairment in some cases, may also have contributed to symmetrical coordination and overall functional improvement [31].

Although patient satisfaction was not formally evaluated, participants informally reported enjoyment, motivation, and willingness to continue training. This positive engagement reflects the potential of exergames to increase adherence to therapy. Overall, the results suggest that combining conventional therapy with exergame-based rehabilitation can lead to meaningful functional benefits. Nevertheless, larger controlled studies are required to confirm these preliminary findings and to establish the clinical effectiveness of the eJamar system in broader rehabilitation contexts.

4.1 Limitations

Despite the promising results, this study has several limitations. The small and heterogeneous sample limits generalization of the findings, and the absence of a control group prevents direct comparison with conventional treatment outcomes. The short intervention period and lack of long-term follow-up further restrict conclusions about sustained benefits. Moreover, the modified version of the 9HPT reduces comparability with other studies employing the standard version. Future research should address these issues through larger, controlled trials and standardized assessment protocols.

4.2 Future research

Future work will expand this study to include at least 40 patients divided into experimental and control groups. This will enable a more robust statistical analysis and evaluation of the specific effects of eJamar-assisted therapy. Additional variables such as user satisfaction, motivation, and long-term retention of motor gains will also be incorporated to provide a more comprehensive understanding of the system's therapeutic value.

5. Conclusions

This exploratory case series provides preliminary evidence supporting the feasibility of integrating the eJamar device and exergames into conventional hand rehabilitation. Across participants, improvements were observed in ROM, HGS, and functional performance, suggesting that this combined approach may enhance motor recovery through engaging, task-oriented, and repetitive movements. The eJamar device appears to contribute to grip-strength enhancement, while the exergames promote active wrist and finger mobility, potentially improving adherence and motivation during therapy.

Clinically, these findings highlight the potential value of incorporating medically designed digital tools to complement standard therapeutic exercises. However, given the small and heterogeneous sample and the absence of a control group, the results should be interpreted with caution.

Future research will involve a larger, more homogeneous cohort and a control group to verify the observed effects. Additional studies will also evaluate long-term outcomes, user satisfaction, and functional independence to confirm the therapeutic impact of eJamar-assisted rehabilitation.

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Conflicts of interest

We, the authors, declare that we have no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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