Development of rehabilitation exercise program using AI-based motion analysis system

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Abstract

Development of rehabilitation exercise program using an AI-based motion analysis system

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The aim of this study was to develop a personalised rehabilitation exercise programme using an AI-based motion analysis system to increase interest and motivation during rehabilitation exercises for people with disabilities. A motion analysis system was developed using the Mediapipe algorithm. The first programme focused on upper limb exercises, specifically developing a system to count repetitions for three movements (chest press, shoulder press, arm curl). The second programme, based on CrossFit exercises, was designed to program five basic movements (squat, arm curl, chest press, lateral raise, dip) for rehabilitation exercises. In the second programme, a system was created to assess the individual's range of motion prior to training, allowing for individualised rehabilitation exercises. The measured range of motion was used to count the repetitions of each movement. To increase interest in the exercise, participants could see their own movements projected onto the screen, and the system tracked and calculated calories based on the number of repetitions of each movement.

For the clinical trials, the first upper limb training system was tested on nine people with spinal cord injuries who completed three one-hour sessions per week for eight weeks. The second CrossFit exercise programme was tested on 20 stroke survivors who completed two one-hour sessions per week for twelve weeks. Both trials were conducted as randomised controlled trials (RCTs), with participants divided into experimental and control groups. Physical assessments were made before and after training. The experimental group used the developed programme during exercise, while the control group exercised without the programme.

The results of the upper limb exercise programme showed improvement in all assessments for the experimental group, while the control group either maintained or showed decreased results, although no significant differences were observed between the two groups. In the CrossFit exercise programme, the experimental group showed improvement in all assessments, with significant differences in some assessments. Conversely, the control group showed improvement only in the assessment of the affected side, with maintenance or decline observed on the unaffected side. No significant differences were observed in any of the assessments.

The AI-based motion analysis system developed in this study is considered effective for rehabilitation exercises. It is anticipated that the results of this research will serve as valuable baseline data for the future development of AI-based rehabilitation exercise systems.

Key Words : Rehabilitation exercises, Artificial Intelligence, Motion analysis, Spinal Cord Injury, Stroke

Chapter1 Introduction

1.1 Research background

According to the 2020 Disability Status Survey announced by the Ministry of Health and Welfare, the registered disabled population in South Korea, as of May 2020, was 2,623,201 individuals. This accounts for approximately 5% of the total population, and notably, nearly half (49.9%) of the disabled population is aged 65 or older. The data indicates a gradual increase in the elderly disabled population, driven by the overall aging of the population.[1].

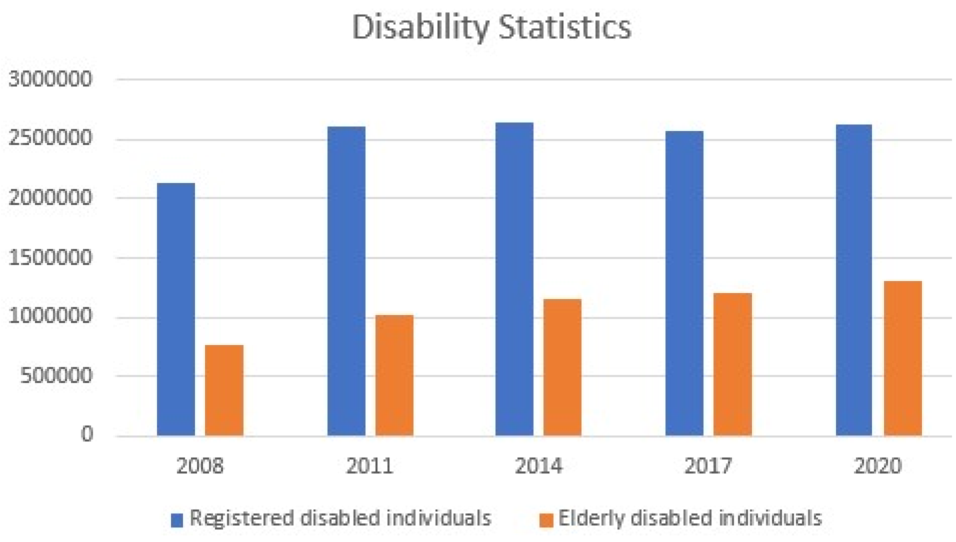


Figure 1 Statistics for registered persons with disabilities

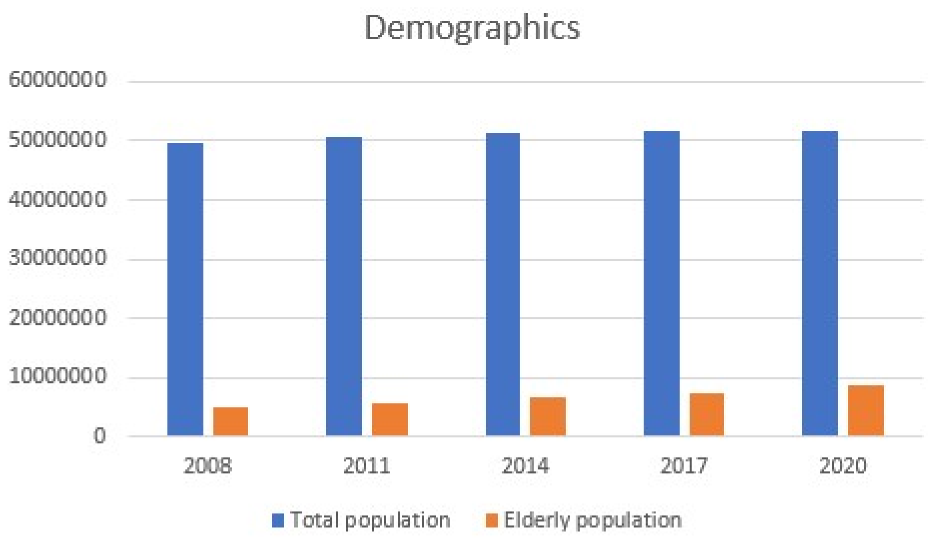


Figure 2 population statistics

As society transitions into an aging population, many individuals prioritize their health and engage in exercise for overall well-being. While there is a growing number of people with disabilities participating in recreational sports, a significant portion still faces barriers to such participation[2].

For individuals with disabilities, exercise is a crucial factor directly impacting their health. Numerous previous studies have shown that exercise for people with disabilities has positive effects across various aspects of life, including quality of life[3].

In 2015, South Korea established legal provisions for rehabilitation exercises and sports for people with disabilities through Article 15 of the Disability Rights Act. However, the current reality is that there is still a lack of detailed infrastructure for exercise. People with disabilities often face challenges in venturing outside for exercise due to physical or psychological limitations, highlighting the need for user-centric rehabilitation training systems and initiatives that encourage voluntary participation from diverse individuals[4-6].

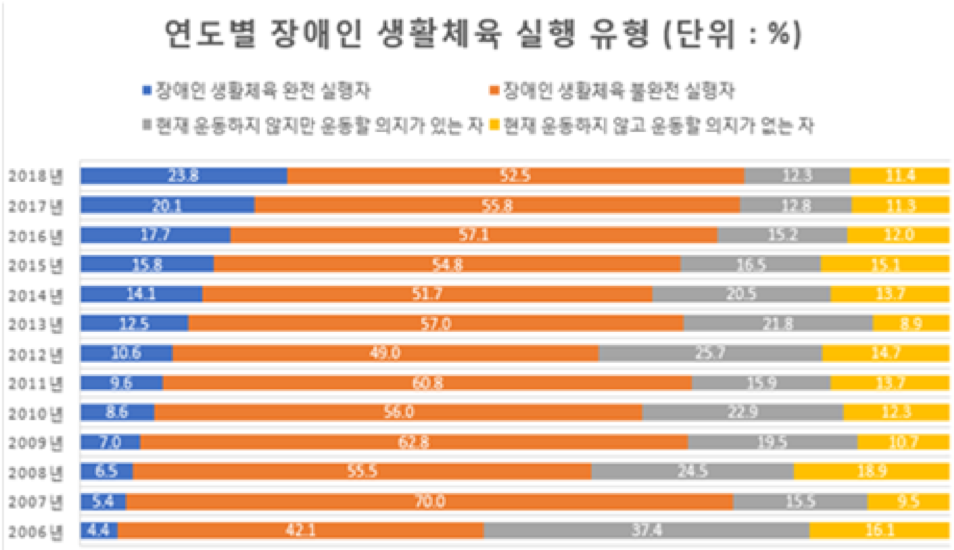


Figure 3 Types of sports for the disabled by year (Development of smart exercise treatment devices and pre-opportunity research report on the establishment of convergence services to promote the health of the elderly with disabilities in the community, 2019.8)

Individuals with spinal cord injuries experience various impairments in sensory, motor, and autonomic functions due to damage to the central nervous system. On the other hand, stroke survivors face impairments in cognitive abilities, motor skills, perception, and language due to causes such as blockages or ruptures in brain blood vessels. Given the significant constraints experienced in daily life by individuals with spinal cord injuries and stroke, diverse rehabilitation treatments are essential for achieving independent daily living and improving their quality of life[7-13].

Rehabilitation exercises primarily focus on functional recovery or improvement in areas such as movement, sensation, and cognition. Exercise plays a crucial role in enhancing physical function, strengthening muscles, and providing various positive effects, including stress reduction[13].

For individuals with neurological pain, such as those with spinal cord injuries or stroke, cardiovascular endurance and muscle exercises are particularly important. Cardiovascular endurance helps enhance heart and lung function and improves blood circulation, leading to increased supply of oxygen and nutrients, elevating basal metabolic rate, and increasing energy expenditure. Muscle exercises contribute to improving walking or posture maintenance, enhancing stamina and strength, facilitating activities of daily living[7-13].

To engage in both cardiovascular endurance and muscle exercises simultaneously, circuit training is often adopted. Circuit training involves performing multiple exercises in rotation rather than focusing on a single exercise at a time. CrossFit training has gained popularity as a form of circuit training among both disabled and non-disabled individuals[14].

CrossFit, a term derived from "Crossover" and "Fitness," originated in California in 1996 under the guidance of weightlifting coach Greg Glassman. In 2001, it officially established its website. The primary goal of CrossFit is to pursue overall health, emphasizing functionality and achieving an exceptional level of physical fitness in all aspects. It is characterized by functional movements, high-intensity, and constant variation, based on scientific evidence[15-16].

The concept of CrossFit involves pursuing overall body movement rather than focusing on specific body parts. It is an intentional and high-intensity training lasting within 20-30 minutes, aiming to maximize various physical abilities such as power, speed, stamina, cardiovascular endurance, flexibility, balance, accuracy, coordination, strength, and agility, by expending a significant amount of energy[17-18].

CrossFit aims to acquire all the necessary elements of fitness in one go, leading to shortened exercise durations compared to traditional fitness routines, with amplified effectiveness and the opportunity to experience diverse programs to overcome monotony. CrossFit can help achieve various goals, including fat loss and muscle strengthening. Participants engage in daily Workout of the Day (WOD) programs, aiming to complete them as quickly as possible, accumulating more exercise volume for a healthier body and mind. Greg Glassman, the founder of CrossFit, has outlined simple and clear rules for the practice[16-17].

Characterized by randomized workouts that vary every month, sometimes even over a period of two years, CrossFit starts with nine fundamental movements such as shoulder press, push press, push jerk, deadlift, sumo deadlift high pull, medicine ball clean, squat, front squat, and overhead squat. These exercises progress from easy to challenging, simple to complex, providing incremental challenges in movement[19].

However, it's important to note that while CrossFit has proven beneficial for overall health, it involves high-intensity exercises, and the competitive nature of the practice may lead individuals to overexert themselves, resulting in improper form and, consequently, injuries[20-21].

To address this issue, one-on-one coaching tailored to each individual is ideal, but this is often impractical. Many people rely on visual feedback, such as mirrors, to self-monitor their movements and ensure correct form during exercise[22-25].

Recent research has explored the use of real-time motion analysis systems to provide immediate feedback on users' movements. Traditional motion analysis often involved attaching markers or IMU sensors to the body and wirelessly or wiredly collecting data for analysis. However, this approach can be inconvenient for users and poses challenges in equipment setup[29]. Instead, markerless motion analysis systems using devices like Kinect cameras have emerged, and with the advancement of artificial intelligence technology, real-time motion analysis can now be achieved using only a smartphone camera or webcam[30-33].

Despite these technological advancements, there is still a lack of research utilizing artificial intelligence technology for rehabilitation exercises, especially for individuals with spinal cord injuries or stroke.

1.2 Research objectives

In this study, an exercise program for the rehabilitation of individuals with disabilities was developed using an artificial intelligence-based real-time motion analysis system. The aim is to assess the effectiveness of the developed program.

1.3 Research limitations

In conducting this study, there were the following limitations

1. The recruitment of participants for the clinical trial was significantly hindered by the COVID-19 pandemic.
2. All participants had chronic disabilities, making it challenging to regulate activities outside the experiment
3. The study was conducted with a small number of individuals with disabilities, limiting generalizability

Chapter2 Background

2.1 Spinal Cord Injury

2.1.1 Definition and Causes of Spinal Cord Injury

Individuals with spinal cord injuries experience a loss of neurological function due to various accidents, injuries, or illnesses. Spinal cord injury can occur directly by physical impact, such as in traffic accidents, falls, sports-related incidents, or indirectly due to diseases affecting the spinal cord, leading to a loss of function[7-9].

2.1.2 Characteristics of Spinal Cord Injury

Individuals with spinal cord injuries vary based on the location and severity of the injury. The spinal cord, a component of our central nervous system, plays a crucial role in transmitting commands from the brain to the entire body and relaying sensory information from various body parts back to the brain. When the spinal cord is damaged, the neurological functions below the affected area may be lost or impaired[10].

Common characteristics include a decline in motor and sensory functions, making walking difficult or completely impossible. Additionally, individuals may experience an inability to perceive sensations such as pain, temperature, and pressure. In severe cases, problems may extend to the autonomic nervous system and respiratory functions.

2.1.3 Classification of Spinal Cord Injury

Individuals with spinal cord injuries exhibit different characteristics depending on the location of the injury, primarily categorized into three regions: cervical (neck), thoracic (chest), and lumbar (lower back).

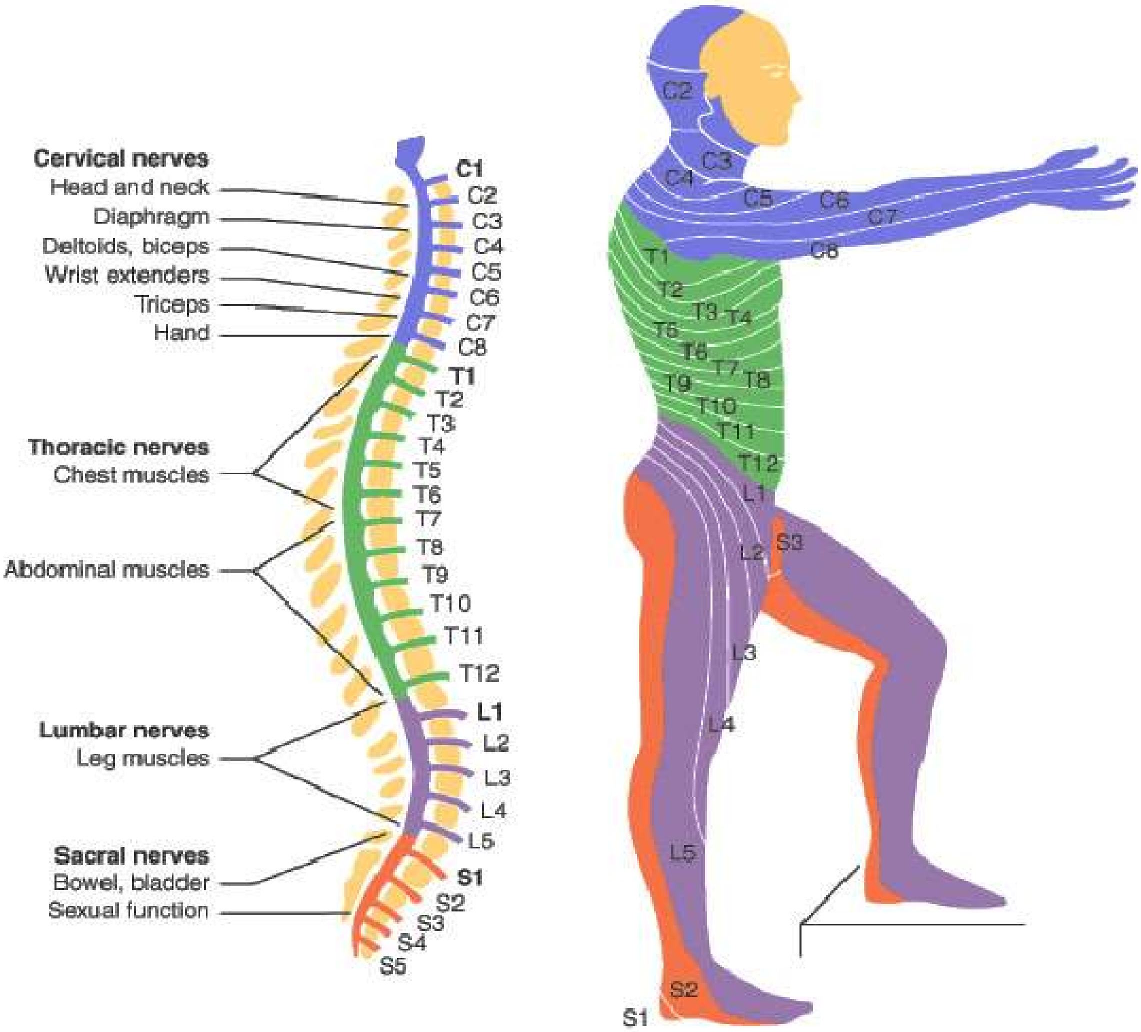


Figure 4 Classification of Spinal Cord Injury
(https://forum.facmedicine.com/threads/types-of-spinal-cord-injuries.30050/)

In cases of cervical spine injury, where the nerves in the neck region are affected, problems arise in both the upper and lower extremities, impacting motor function, respiration, and sensation.

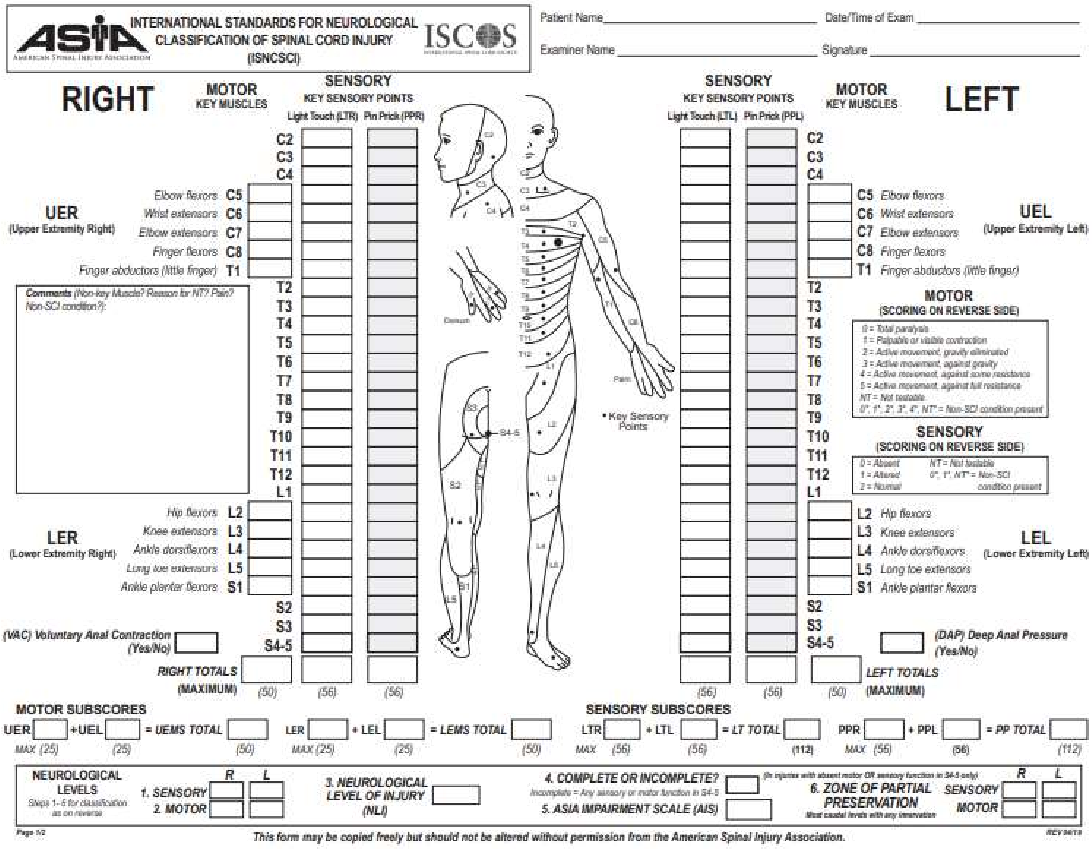
Thoracic spine injuries generally maintain upper body motor function while potentially affecting the motor function and sensation of the lower extremities.

Lumbar spine injuries may result in lower limb paralysis and sensory loss.

The severity of spinal cord injuries can be classified into complete and incomplete injuries. According to the classification by the American Spinal Injury Association (ASIA), the degree of impairment is further divided into five stages, as shown in the table. The ASIA assessment includes a sensory component, scored on a 3-point scale (0 = Absent, 1 = Altered, either decreased or impaired sensation or hypersensitivity, 2 = Normal), with a total score of 224 points for both sides. The motor examination component is scored on a 6-point scale (0 = total paralysis, 1 = palpable or visible contraction, 2 = active movement, full ROM with gravity eliminated, 3 = active movement, full ROM against gravity, 4 = active movement, full ROM against gravity and moderate resistance in a muscle-specific position, 5 = (normal) active movement, full ROM against gravity and full resistance in a functional muscle position expected from an otherwise unimpaired person), with a total score of 100 points for both sides[34-35].

Table 1 ASIA Impairment Scale for classifying spinal cord injury

Grade	name	Description
A	Complete	No motor or sensory function is preserved in the sacral segments S4 - S5.
B	Sensory Incomplete	Sensory function preserved but not motor function is preserved below the neurological level and includes the sacral segments S4 - S5
C	Motor Incomplete	Motor function is preserved below the neurological level, and more than half of key muscles below the neurological level have a muscle grade less than 3.
D	Motor Incomplete	Motor function is preserved below the neurological level, and at least half of key muscles below the neurological level have a muscle grade of 3 or more.
E	Normal	Motor and sensory function are normal.



ASIA — AMERICAN SPINAL INJURY ASSOCIATION
INTERNATIONAL STANDARDS FOR NEUROLOGICAL CLASSIFICATION OF SPINAL CORD INJURY (ISNCSCI)
ISCOS

Patient Name ____ Date/Time of Exam ____
Examiner Name ____ Signature ____

RIGHT — MOTOR KEY MUSCLES — SENSORY KEY SENSORY POINTS: Light Touch (LTR), Pin Prick (PPR)

LEFT — SENSORY KEY SENSORY POINTS: Light Touch (LTL), Pin Prick (PPL) — MOTOR KEY MUSCLES

C2, C3, C4

UER (Upper Extremity Right) / UEL (Upper Extremity Left):
- C5 Elbow flexors
- C6 Wrist extensors
- C7 Elbow extensors
- C8 Finger flexors
- T1 Finger abductors (little finger)

Comments (Non-key Muscle? Reason for NT? Pain? Non-SCI condition?):

T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, L1

MOTOR (SCORING ON REVERSE SIDE)
0 = Total paralysis
1 = Palpable or visible contraction
2 = Active movement, gravity eliminated
3 = Active movement, against gravity
4 = Active movement, against some resistance
5 = Active movement, against full resistance
NT = Not testable
0*, 1*, 2*, 3*, 4*, NT* = Non-SCI condition present

SENSORY (SCORING ON REVERSE SIDE)
0 = Absent, 1 = Altered, 2 = Normal, NT = Not testable, 0*, 1*, NT* = Non-SCI condition present

LER (Lower Extremity Right) / LEL (Lower Extremity Left):
- L2 Hip flexors
- L3 Knee extensors
- L4 Ankle dorsiflexors
- L5 Long toe extensors
- S1 Ankle plantar flexors

S2, S3, S4-5

(VAC) Voluntary Anal Contraction (Yes/No)
(DAP) Deep Anal Pressure (Yes/No)

RIGHT TOTALS (MAXIMUM) (50) (56) (56)
LEFT TOTALS (MAXIMUM) (56) (56) (50)

• Key Sensory Points

MOTOR SUBSCORES
UER + UEL = UEMS TOTAL — MAX (25) (25) (50)
LER + LEL = LEMS TOTAL — MAX (25) (25) (50)

SENSORY SUBSCORES
LTR + LTL = LT TOTAL — MAX (56) (56) (112)
PPR + PPL = PP TOTAL — MAX (56) (56) (112)

NEUROLOGICAL LEVELS (Steps 1-5 for classification as on reverse): R L — 1. SENSORY, 2. MOTOR
3. NEUROLOGICAL LEVEL OF INJURY (NLI)
4. COMPLETE OR INCOMPLETE? Incomplete = Any sensory or motor function in S4-5
5. ASIA IMPAIRMENT SCALE (AIS)
6. ZONE OF PARTIAL PRESERVATION (In injuries with absent motor OR sensory function in S4-5 only) — Most caudal levels with any innervation — SENSORY, MOTOR (R, L)

Page 1/2
This form may be copied freely but should not be altered without permission from the American Spinal Injury Association.
REV 04/15

Figure 5 ASIA Evaluation Table (American Spinal Injury Association. International Standards for Neurological Classification of Spinal Cord Injury. Atlanta, GA, Revised 2011, Updated 2015. Published with permission of the American Spinal Injury Association, Richmond, VA, USA)

2.2 Stroke

2.2.1 Definition and causes of stroke

A stroke, known as a cerebrovascular accident (CVA), refers to neurological symptoms caused by damage to the brain, which can occur due to either a blockage in the brain's blood vessels (ischemic stroke) or the rupture of a blood vessel in the brain (hemorrhagic stroke). In South Korea, ischemic strokes are widely reported as a common cause of strokes[12-13].

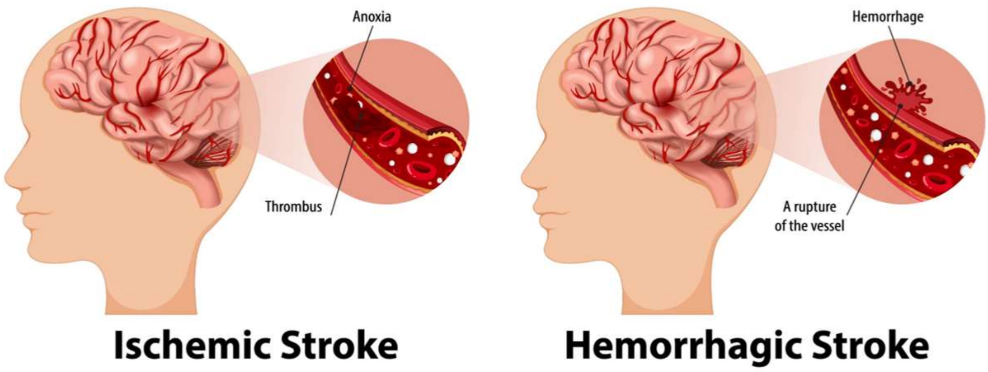


Figure 6 Types of Stroke (Created by brgfx - Freepik.com)

2.2.2 Characteristics of Stroke

The primary characteristics of individuals with stroke-related disabilities include physical symptoms, cognitive and communication impairments, sensory deficits, and emotional and affective changes. Following a stroke, paralysis symptoms may occur on the right or left side, affecting muscles in the arms, legs, face, etc. Additionally, abilities such as language, memory, and attention are impacted, and sensory disturbances like pain and temperature sensitivity may arise. These issues often lead to emotional challenges such as depression and anxiety.

The brain, as illustrated in Figure 7, governs a variety of functions based on its location, so disability symptoms and characteristics vary depending on the affected area[36-37].

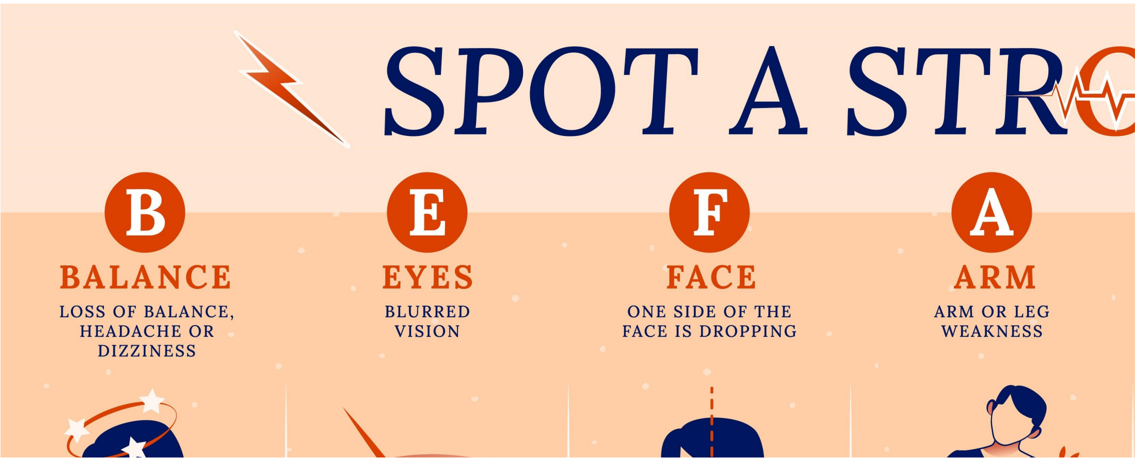


Figure 7 Characteristics of stroke(Created by freepik-Freepik.com)

2.2.3 Functional evaluation tool for stroke

There are various assessment tools for evaluating the functions of individuals with stroke-related disabilities. The Modified Ashworth Scale (MAS) is one such tool used to measure muscle spasticity and assess the degree of paralysis. The MAS is structured on a scale from 0 to 4 points, as shown in Table 2[38].

The evaluation method for MAS, illustrated in Figure 8, involves therapists moving the patient's range of motion to assess muscle spasticity[38].

Table 2 MAS grade attributes

Grade	Descriptions
0	No increse in muscle tone
1	Slight increase in muscle tone Minimal resistance at end of ROM
1+	Slight increase in muscle tone Minmal resisttance through less than half of ROM
2	More marked Increase in muscle tone through mast of ROM Affected part easily moved
3	Considerable increase in muscle tone Passive movement difficult
4	Affected part rigid in flexion or extension

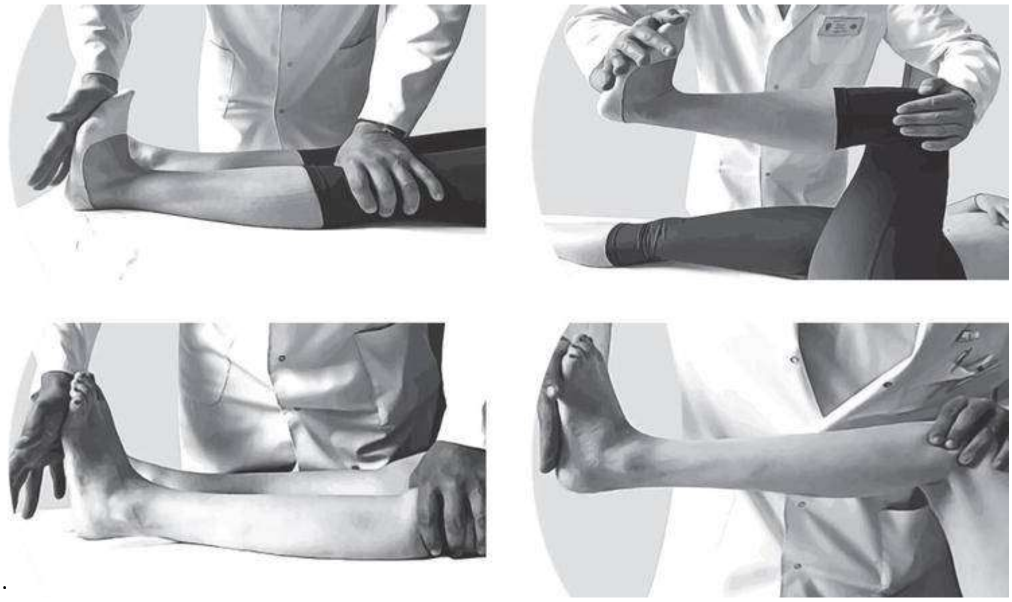


Figure 8 MAS measurement examples
(https://mantracare.org/physiotherapy/scale/modified-ashworth-scale/)

2.3 Motion Analysis System

Motion analysis systems are technologies used to analyze the movements of people or objects, and they find applications in various fields such as security, sports science, healthcare, and research. Generally, there are two types of motion analysis systems: camera-based systems that track the movements of reflective markers using cameras, and wireless motion analysis systems that utilize sensors like Inertial Measurement Units (IMUs) attached to the body. In recent years, advancements in artificial intelligence have led to the development of technologies that enable motion analysis without the need for markers or sensors, based on camera systems[39-40].

2.3.1 Marker-Based Motion Analysis System

The marker-based motion analysis system, as illustrated in Figure 9, involves the use of Vicon equipment. This system analyzes movements by attaching reflective markers to the human body and capturing them with cameras. It is currently considered one of the most accurate measurement devices as it utilizes multiple cameras simultaneously for recording. However, it has drawbacks, such as being restricted to the location where the cameras are installed, a lengthy setup time, and the high cost of the equipment[39].

Figure 9 Marker-Based Motion Analysis System (visolmocap.com)

2.3.2 Wireless Motion Analysis System

The wireless motion analysis system, as depicted in Figure 10, involves attaching sensors such as IMUs to the human body and wirelessly receiving data for motion analysis. Being a sensor-based wireless system, it offers the advantage of portability, allowing usage anywhere without the need for a fixed setup. Additionally, it provides real-time feedback. However, it has drawbacks, including data loss issues associated with wireless devices and limitations on prolonged measurements due to device battery life[40].

Figure 10 Wireless Motion Analysis System (noraxon.com)

2.3.3 Camera-based Motion Analysis System

For camera-based motion analysis, devices such as Microsoft's Kinect are available. Kinect utilizes RGB, depth, and infrared cameras for motion analysis. Kinect has the advantage of analyzing motion without the need for sensor attachments on the user's body and is more cost-effective compared to other motion analysis systems. However, it has limitations in terms of accuracy and spatial constraints[31-32].

Recently, due to advancements in artificial intelligence technology, it has become possible to perform motion analysis using a regular camera without the need for special equipment. Camera-based pose estimation has two main methods Top-down and Bottom-up. In the Top-down approach, the system first detects the person in the image, marks key points, and then analyzes the person's motion. On the other hand, the Bottom-up approach identifies a person's keypoints first and then recognizes the person and analyzes their motion, as illustrated in Figure 11.

For the Top-down approach, a prominent algorithm is Mediapipe, developed by Google. Mediapipe employs the Blaze Pose algorithm, an artificial intelligence model, for motion analysis. Blaze Pose utilizes 33 keypoints for modeling, as shown in the illustration. Unlike the bottom-up approach of OpenPose, Blaze Pose estimates only the minimum keypoints for each body part, making it slightly less accurate but lightweight in terms of model complexity. This design allows for real-time analysis using only a CPU, making it suitable for applications requiring quick, on-the-fly analysis[33].

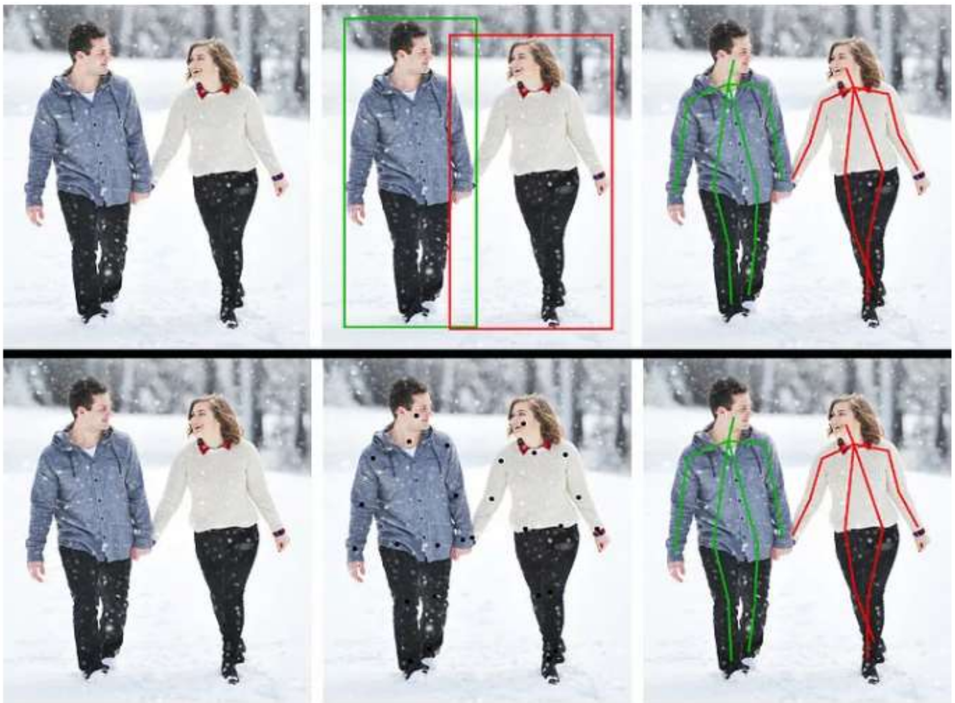


Figure 11 AI motion analysis method 'Top down' above and 'Bottom up' below
(https://www.kdnuggets.com/2019/06/human-pose-estimation-deep-learning.html)

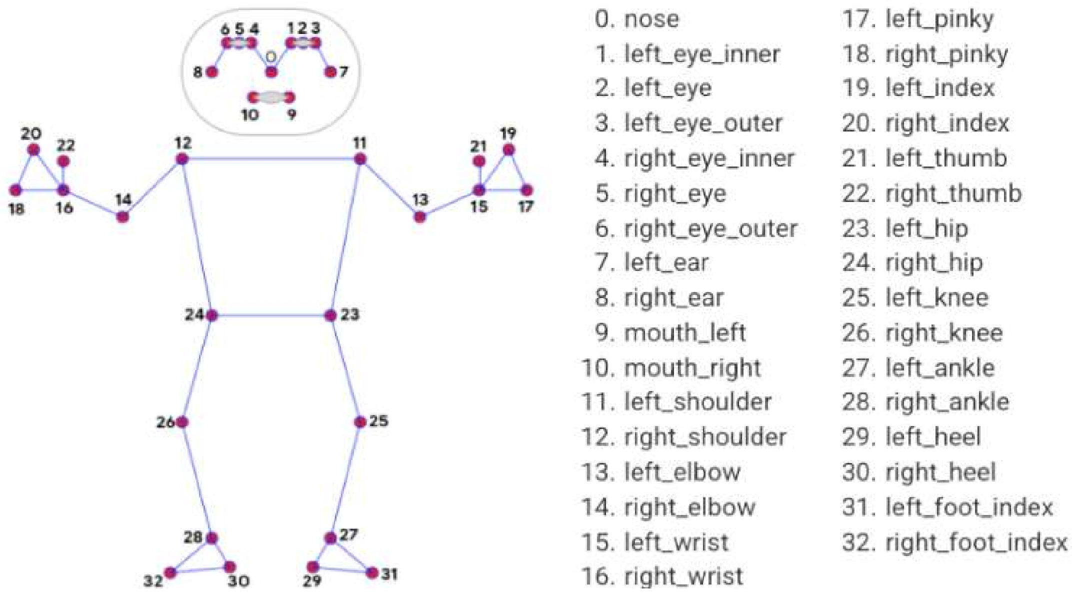


Figure 12 Mediapipe modeling examples
(https://developers.google.com/mediapipe/solutions/vision/pose_landmarker/)

2.4 CrossFit

CrossFit is a form of high-intensity interval training characterized by short periods of intense exercise providing various benefits such as weight loss, reduced body fat, muscle development, and improved cardiovascular fitness[13-15]. This exercise primarily involves bodyweight movements without the need for specialized equipment. It operates on a daily basis with constantly varied workout goals known as WOD (Workout Of the Day), shared on the official CrossFit website. Participants compete by adapting these WOD to their individual fitness levels, engaging in a collective effort to complete as many rounds as possible within a set time frame[16].

CrossFit exercises primarily utilize two formats. The first is AMRAP (As Many Rounds As Possible), where participants aim to complete as many rounds of exercises as possible within a given time. As illustrated in Figure 13, individuals perform burpees and snatches for a specified number of repetitions, striving to accomplish as many rounds as they can in the given 17 minutes.

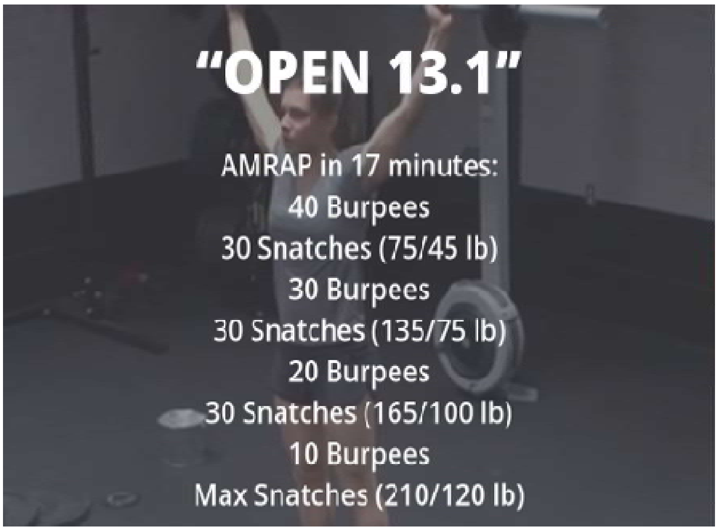


Figure 13 Example of AMRAP

The second format is "For Time" (FT), where the goal is to complete a given set of exercises as quickly as possible. For example, as shown in Figure 14, participants aim to perform squats, pull-ups, and shoulder-to-overhead as rapidly as possible, completing the specified number of repetitions for each exercise.

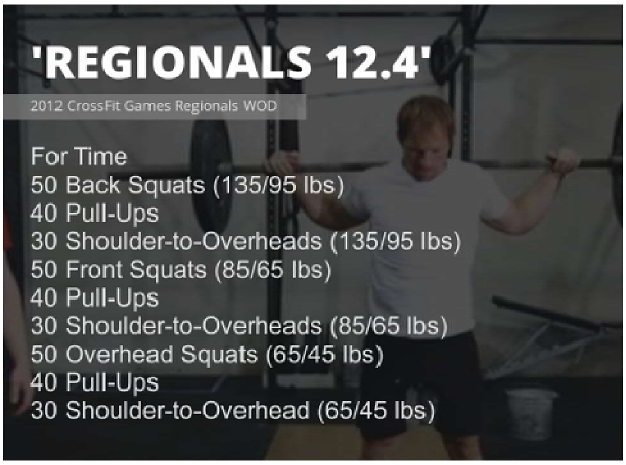


Figure 14 Example of For Time

In addition, there are more specific formats such as Fifty Fifty For Time, where participants repeat each designated exercise 50 times, and Ladder, where the repetition count increases by 1 for each round until reaching an all-out effort.

Figure 15 Example of Crossfit exercise

2.5 Exercise Intensity Classification

Exercise intensity refers to the level of difficulty individuals perceive during physical activity, often categorized into three levels: Low Intensity, Moderate Intensity, and High Intensity. When classifying exercise intensity, heart rate is commonly used as a criterion, as depicted in Figure 16. Low intensity is represented by 50-60% of the maximum heart rate, moderate intensity by 60-70%, and high intensity by 70-85%.

Figure 16 Exercise Intensity Classification
(https://www.parkfitnz.com/hiit)

To measure heart rate, equipment such as Polar devices or smartwatches needs to be worn, but these devices can sometimes be uncomfortable during exercise. To address this, a simple method for assessing exercise intensity is to periodically ask the user for a numerical rating of perceived exertion (RPE). The Rating of Perceived Exertion (RPE) model, shown in Figure 17, ranges from 6 to 20, dividing the scale between "No exertion" and "Maximal exertion"[41-42].

Rating	Perceived Exertion
6	No exertion
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

Figure 17 Rating of Perceived Exertion

2.6 Physical Fitness Assessment

Typically, both individuals with and without disabilities assess their fitness or body condition through tools like InBody or fitness evaluations before engaging in tailored exercises. For individuals with disabilities, personalized rehabilitation exercises are particularly important, making the evaluation of their physical condition essential before starting any exercise.

Conducting a physical fitness assessment allows individuals to understand their body's current state, providing insights into the type and intensity of exercises suitable for them[43-44].

Physical fitness assessments for individuals with disabilities are broadly categorized into health fitness assessments and exercise fitness assessments, as outlined in Table 3. Additionally, these assessments differentiate between groups that can perform walking exercises and those that cannot.

The method of physical fitness assessment is conducted as shown in Figure 18. A physical education instructor is assigned to each participant to ensure safe and injury-free measurements during the assessment process.

Table 3 Physical Fitness Assessment

Health fitness assessments
Cardiovascular Endurance - 6-Minute Walk Test Smart Neck Muscular Strength (Grip Strength, Chest Press, Leg Extension, Leg Flexion) Muscular Endurance (Arm Curl for 60 seconds, 1RM for 60%, Sit-Up) Flexibility (Seated Forward Bend)
Exercise fitness assessments
Agility - Visual Reaction T-Wall Balance - Time Up and Go
For the group able to walk
Cardiovascular Endurance (6-Minute Walk Test) Smart Neck (Demonstration, flexibility, and strength of the neck) Muscular Strength (Grip Strength, Chest Press, Leg Extension, Leg Flexion, Arm Curl) Muscular Endurance (Sit-Up) Flexibility (Seated Forward Bend) Agility (Visual Reaction) Balance
For the group unable to walk (Wheelchair)
Cardiovascular Endurance (6-Minute Walk Test) Muscular Strength (Grip Strength, Chest Press, Shoulder Press, Lat Pull) Muscular Endurance (Arm Curl) Flexibility (Reach behind the back) Agility (Visual Reaction)

(a)

Cardiovascular Endruance	
6-Minute Walk Test	6-Minute Wheelchair Test
	
The person waits at the starting line. Following the inspector's starting signal, they move around the track for 6 minutes.	

(b)

<table>
<tr><th colspan="2">Muscular Strength</th></tr>
<tr><th>Grip Strength</th><th>Chest Press</th></tr>
<tr><td></td><td></td></tr>
<tr><td>In a standing position, the person extends their arms about 15 degrees, then straightens and grips the dynamometer in their hand. According to the inspector's signal, they grip the dynamometer firmly and pull to measure maximum grip strength.</td><td>In a seated position, the person places their hands on the handle. Following the inspector's signal, they push forward with maximum force.</td></tr>
</table>

(c)

Muscular Strength	
Shoulder Press / Lat Pull	Leg Extension / Leg Flexion
	
In a seated position, the person places their hands on the handle. Following the inspector's signal, they exert maximum force while pushing and pulling the handle up and down.	In a seated position, the person wears a belt on their thigh. Following the inspector's signal, they push the leg forward or pull it backward.

(d)

<table>
<tr><th colspan="2">Muscular Endurance</th></tr>
<tr><th>Arm Curl</th><th>Sit-Up</th></tr>
<tr><td></td><td></td></tr>
<tr><td>In a seated position, the person supports their upper body close to a support and places their elbows on the support, preparing for measurement. Following the inspector's signal, they repeat bending and straightening their arms for 1 minute to measure arm flexion and extension.</td><td>In a lying position, with both legs fixed and hands gathered in front of the chest, the person prepares. Following the inspector's signal, they repeat lifting and lowering the upper body for 1 minute to measure the motion.</td></tr>
</table>

(e)

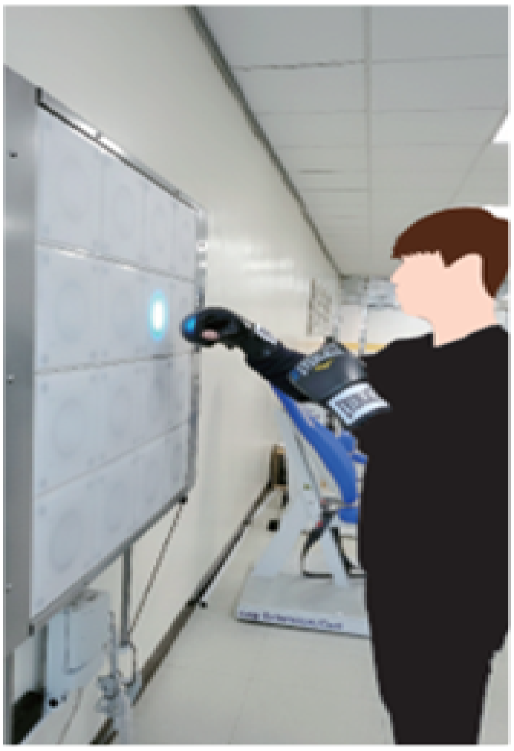
Coordination	
T-wall	Timed Up and Go
	
Wearing gloves, the person sits or stands in front of the measuring device. For 1 minute, they quickly and accurately press the panel in response to randomly appearing lights.	In a seated position, the person prepares while wearing gloves. With the inspector's starting signal, they return to the target and sit back down.

Figure 18 Introduction to Physical Fitness Assessment Types and Measurement Methods (Department of Rehabilitation Exercise, National Rehabilitation Center Disability Fitness Certification Center Leaflet) a: Cardiovascular Endurance, b, c: Muscular Strength, d: Muscular Endurance, e: Coordination

Chapter3 Method

3.1 Experimental Design

This study is divided into two phases: the first phase involves an Artificial Intelligence (AI)-based upper limb exercise system, and the second phase involves an AI-based CrossFit exercise system. The upper limb exercise system conducted a clinical trial with groups using and not using the system, targeting individuals with spinal cord injuries. The CrossFit exercise system conducted a clinical trial with groups using the system and engaging in general fitness training, targeting stroke patients.

Both clinical trials followed a randomized controlled trial (RCT) design and were conducted as single-blinded studies. All participants were assigned to groups through a random draw, unaware of their group assignment. The experimental group utilized the developed program, while the control group engaged in general exercise without using the developed program. The experimental design is illustrated in Figure 19.

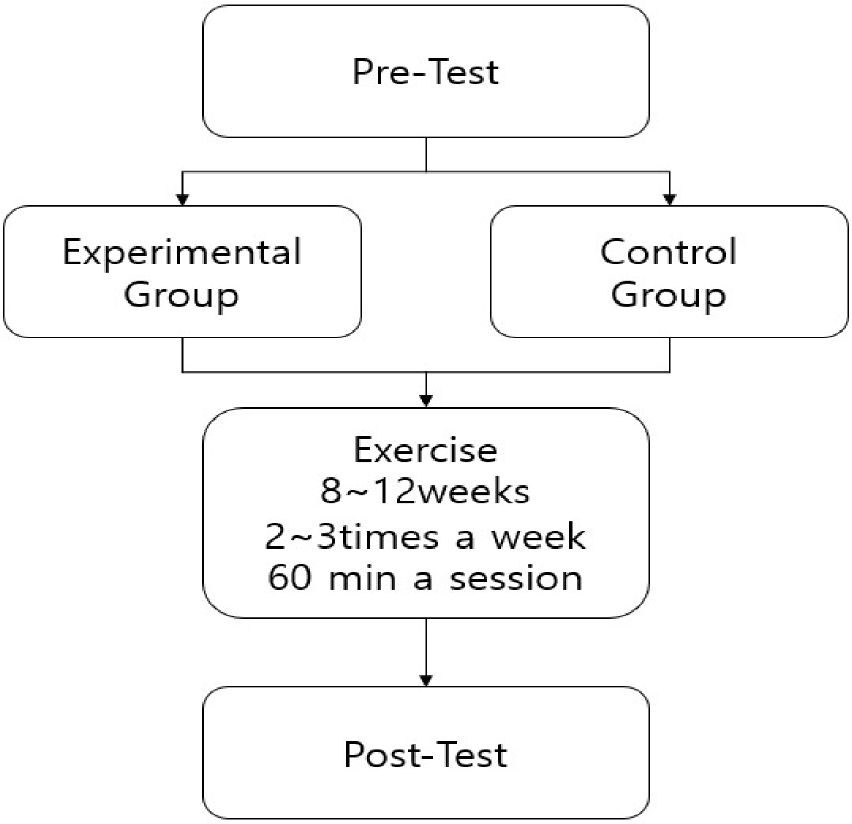


Figure 19 Experimental Design

3.2 Subjects

The study targeted individuals aged 19 or older with chronic spinal cord injuries and stroke disabilities. For spinal cord injuries, participants capable of self-performance with AISA Impairment Scale A to D were recruited. Stroke patients with MAS scores of 2 or less were recruited.

Participants in both groups were excluded if they did not understand the researcher's instructions, were incapable of voluntary upper extremity exercise, or had cardiovascular and musculoskeletal disorders that could impact physical activity.

In the case of spinal cord injury patients, a total of 9 individuals were recruited, with 4 in the experimental group and 5 in the control group. Participant information is presented in Table 4.

Table 4 Subjects of Spinal cord injury

Code	Age	Sex	Weight (Kg)	Height (cm)	Neurologic level of Injury	Types of spinal cord injuries
E1	66	F	70.1	145.1	Lumbar	x
E2	80	M	65.3	157.7	Cervical	x
E3	56	M	72.7	165.6	Cervical	x
E4	70	M	102.4	181.4	Thoracic	x
C1	64	M	70.8	170	Thoracic	x
C2	49	F	75.2	162	Thoracic	o
C3	59	F	43.3	153	Cervical	x
C4	57	F	58.4	159.6	Lumbar	x
C5	68	M	84.6	170	Thoracic	x

E: experimental group, C: control group, M: male, F: female

For stroke-disabled individuals, a total of 20 participants were recruited, with 10 in the experimental group and 10 in the control group. Participant information is provided in Table 5. Among stroke-disabled individuals, the exercise was conducted with 5 participants in Groups A and B.

In the experimental group, the average age was 53.7±17 years, with a height of 161.73±7.32cm and a weight of 61.36±7.80kg. In the control group, the average age was 60.4±8.89 years, with a height of 169.15±8.31cm and a weight of 71.57±12.90kg.

Table 5 Subjects of Stroke

Code	Group	Age	Sex	Weight (Kg)	Height (cm)	Affected side
E1	A	73	F	155	54.1	Q
E2	A	51	M	15736	71.1	Q
E3	A	58	F	151.5	49.3	L
E4	A	69	M	166.8	72.6	L
E5	A	22	M	171.3	60.3	R
E6	B	55	M	167.7	56.6	Q
E7	B	66	M	165.7	73.2	R
E8	B	58	F	159.7	60.7	Q
E9	B	22	M	170.9	58.4	R
E10	B	63	F	151.1	57.3	L
C1	A	79	M	179.7	77	Q
C2	A	61	F	163	57.7	R
C3	A	55	M	171	62	R
C4	A	72	M	175.3	78	R
C5	A	61	F	156.8	59.2	L
C6	B	56	M	172	82	R
C7	B	45	M	177.8	97.2	R
C8	B	57	F	156.2	62.4	R
C9	B	57	F	162.9	57.8	Q
C10	B	61	M	176.8	82.4	L

E: experimental group, C: control group, M: male, F: female, R: right hemiplegia, L: left hemiplegia, Q: Quadriplegia

3.3 Physical Fitness Evaluation

The physical fitness evaluation, as shown in Figure 20, utilized the Chest Press and Shoulder Press equipment manufactured by Hur, along with the force measurement device PR1 (HUR Limited, Kokkola, Finland). The PR1 device, which measures force isometrically using tension-compression load cells, was attached to the evaluation equipment. The force was measured for 5 seconds. The data were recorded in kilograms and can be converted to Newton meters [45].

For individuals with spinal cord injuries, four fitness evaluations—Shoulder Press, Lat Pull Down, Chest Press, and Arm Curl—were performed. For stroke-disabled individuals, six evaluations—Chest Press, Lat Pull Down, Arm Curl, Leg Extension, Leg Flexion, and a 6-minute walking test—were conducted. Equipment-based evaluations were performed twice, and the best result was utilized. For Arm Curl, the number of repetitions with a set weight within one minute was counted, and the score was calculated by multiplying the weight by the number of repetitions. The 6-minute walking test involved calculating the distance covered during a 6-minute walk in the gym.

Shoulder Press Lat Pull Down | Chest press | Arm Curl | Leg Extension Leg Flexion | 6 Minutes of Movement

Figure 20 Physical Fitness Evaluation

3.4 Development of an AI-Based Upper Limb Exercise System for Spinal Cord Injury Patients

For the AI-based motion analysis program designed for upper limb exercises, we utilized MediaPipe, developed by Google. MediaPipe automatically recognizes 33 key points in the human body and is lightweight, making it suitable for running on CPUs without the need for a GPU. Moreover, previous research by Ameur L. involved the validation of reliability and validity using goniometers and MediaPipe in collaboration with physical therapists, resulting in a 95% agreement. This validation made us confident in choosing MediaPipe for our program [20].

The developed program consists of a 20-inch monitor, a mini-PC (AMD Ryzen 5 5600G with Radeon Graphics 3.90GHz), and a webcam. The front-facing webcam captures individuals performing exercises, allowing real-time motion analysis. The monitor is divided into two sections, as shown in Figure 21 one side displays the ideal exercise posture, while the other side projects the user's own movements.

The program provides real-time visual feedback on movements, aiming to motivate users. Additionally, it includes features to count the number of exercise repetitions and calculate calories based on the repetition count to enhance users' motivation for exercise.

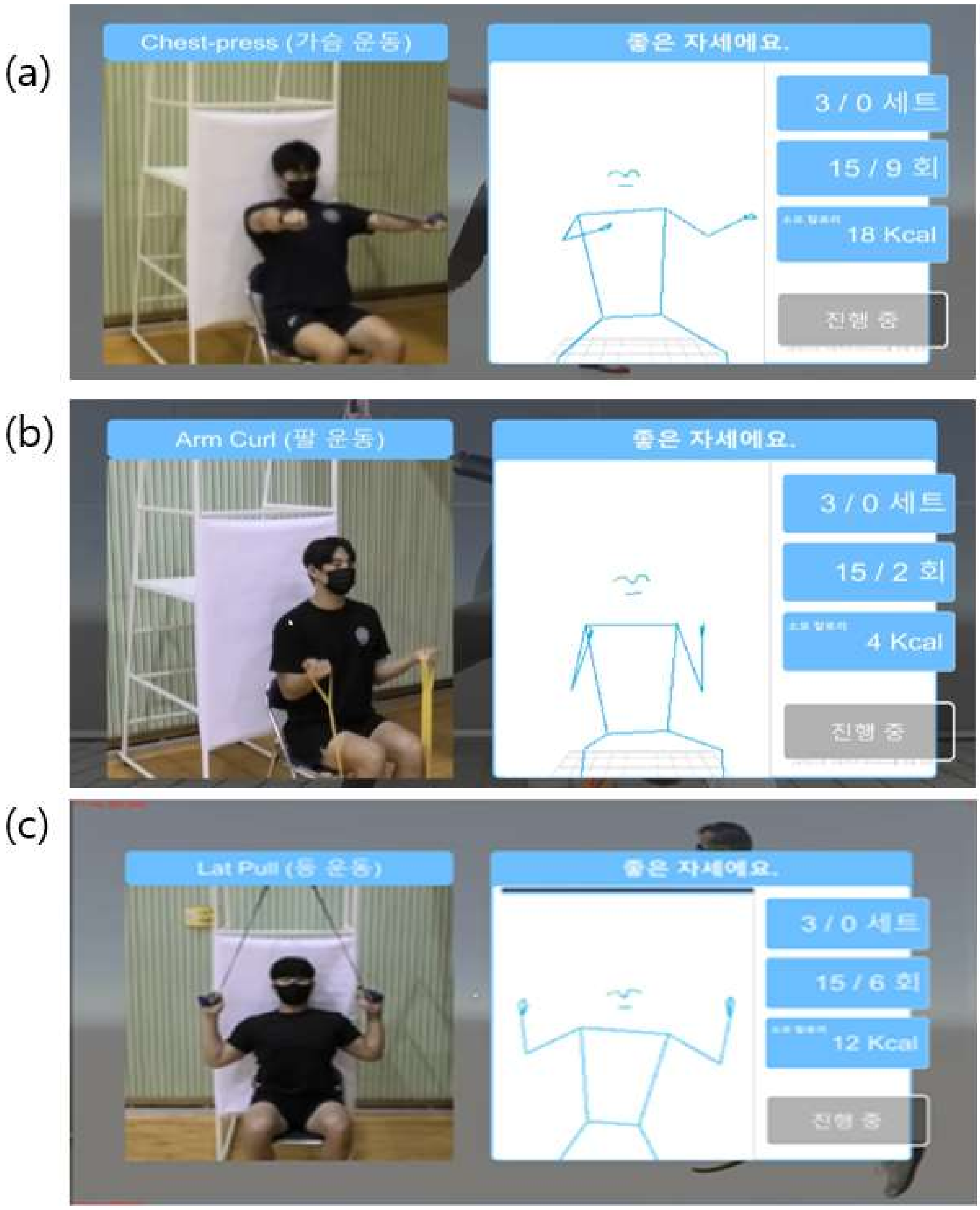


Figure 21 Developed program appearance (a) Chest press, (b) Arm curl, (c) LetPull
*Korean to English translation of the right column: From the top; 좋은 자세예요 (Good Posture!), 세트 (Set), 회 (Times), 소모 칼로리 12 Kcal (Calories consumed: 12 kcal), and 진행 중 (In progress).

3.4.1 Movement Repetition Counter

In reference to previous studies [46 - 48], where upper extremity exercises using a Thera-band were used on people with SCI, the exercise protocol to activate the crucial upper extremity muscles, from the shoulder depressors to shoulder extensors, shoulder external rotators, scapular retractors, and triceps muscles, was revised every 1 or 2 weeks and was accommodated as required to individually suit the fitness purpose of this study. Furthermore, it allowed the motion analysis system to count the repetitions of the three motions: chest press, shoulder press, and arm curl.

All images were created using Unity. A single count with four values (x, y, z, and w) was recorded on the user's motion outside the set boundary, as shown in Table 6, after which the counter was reset. In Unity, the values x, y, z, and w represent orientation and rotation with quaternion values. Here, x, y, and z denote vector values, representing each axis, while w is a scalar value indicating the magnitude of the rotation. These quaternion values were employed to achieve smooth 3D motion

Table 6 Counting and reset criteria for each motion

	Chest Press	Arm curl	Lat pull down
Count	x, z and w of Left_elbow: $x<0$, $z>0$, $w>0.5$	y of Left_wrist > y of Left_elbow	y and w of Left_elbow: $y>0$, $w<0$
Reset	x, z and w of Left_elbow: $x>0.5$, $z<0.5$, $w<0$	y of Left_wrist < y of Left_elbow	y and w of Left_elbow $y<0$, $w>0$

3.4.2 intervention

The upper limb exercise system was implemented in both the experimental and control groups for 8 weeks, with three sessions per week, each lasting for an hour. The exercise routine included a 10-minute warm-up, 40 minutes of the main exercise, and a 10-minute cool-down. During the 40-minute main exercise, upper limb exercises using bands and dumbbells were conducted under the guidance of an instructor. Throughout the 60-minute exercise, the instructor ensured that the same upper limb exercises were performed by both the experimental and control groups.

The exercise routine comprised movements that could be performed using bands, targeting a range of muscles from larger ones like those in the shoulders, back, and chest to relatively smaller ones like the biceps and triceps. To avoid adaptation to the exercises, the intensity was progressively increased every 1-2 weeks. Changes in band color and the addition of dumbbells were used to vary the exercise intensity gradually.

The basic exercise used a green band from TheraBand, with the band color changing (yellow to black) based on the user's exercise ability. Both the experimental and control groups followed the instructions of the same instructor. The experimental group had the advantage of watching their own movements on the developed program in addition to following the instructor's guidance. In contrast, the control group only followed the instructor without visualizing their own movements (Figure 22). Real-time counting of exercise repetitions was possible for chest press, shoulder press, and bicep curl in the experimental group's program, while for other exercises, the count was not displayed on the monitor. After completing the 8-week exercise program, a usability evaluation was conducted, gathering feedback on the program's usage experience, advantages, disadvantages, suggestions for improvement, and opinions. The usability evaluation employed a 5-point scale questionnaire with ten structured questions, including five semi-structured questions, and also allowed for free-form verbal comments.

(a)
(b)

Figure 22 (a) Experimental group, (b) control group

3.5 AI-Based CrossFit Exercise System for Stroke

The CrossFit exercise system designed for stroke survivors incorporates both upper and lower limb exercises, utilizing a circuit-style format to facilitate high-intensity workouts. Inspired by the popularity of CrossFit among able-bodied individuals, the system was developed to include five different movements, performed sequentially with short rest intervals.

To create a circuit-style rehabilitation exercise system using motion analysis, we purchased and installed exercise boxes commonly used in CrossFit workouts. Exercise zones were designated based on the position of the boxes, and camera and monitor placements for facial recognition and motion analysis were determined (Figure 23). Additionally, a monitor for the instructor was installed at the top of the box to enable simultaneous monitoring and management of users by instructors (Figure 24). To prevent collisions with equipment during exercise, visible lines and columns were excluded from the floor, considering both individuals with disabilities and able-bodied users.

For the user's monitor, a 20-inch monitor was used to ensure users could clearly see their own movements. The monitor arm was welded to the box stand, allowing for height adjustments. The computer was attached behind the monitor using a rack. The camera setup included a facial recognition camera placed on top of the monitor, and a motion analysis camera positioned at a 30 to 45-degree angle from the user for diagonal capture. Ultimately, a circuit-style rehabilitation exercise system was developed, featuring five areas: 1. Leg exercise (squat), 2. Arm exercise (arm curl), 3. Chest exercise (chest press), 4. Shoulder exercise (lateral raise), and 5. Back exercise (dips).

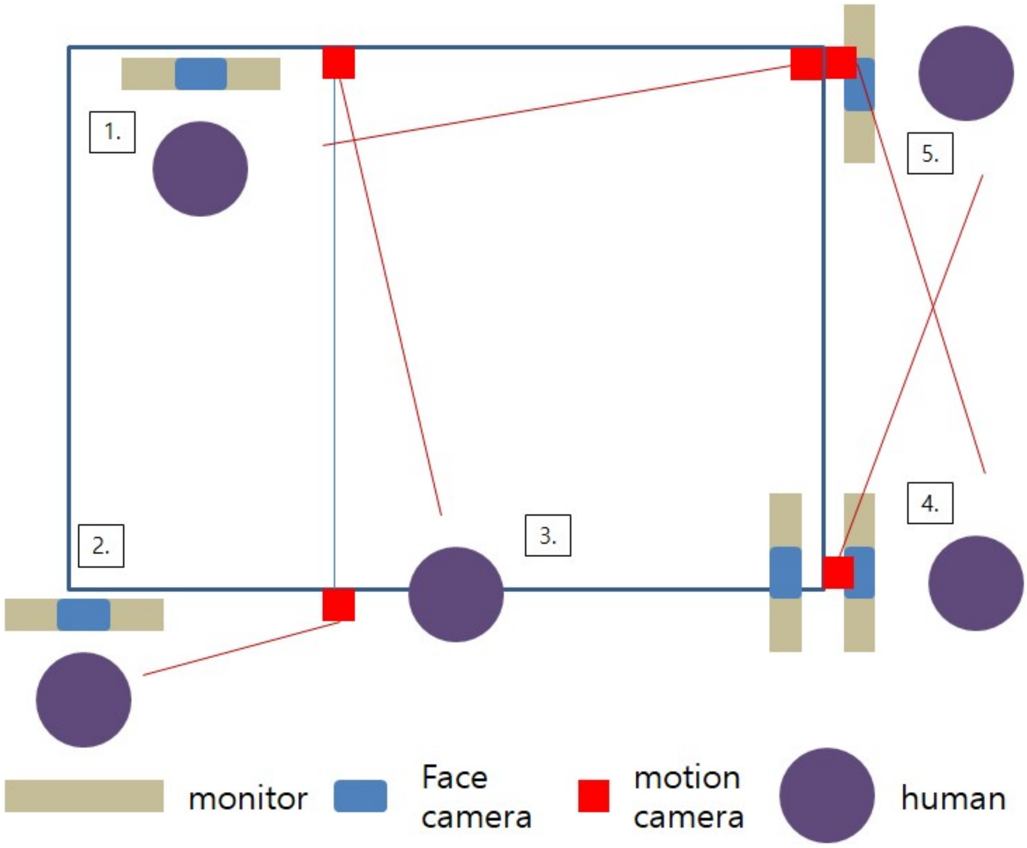


Figure 23 System Installation Configuration

Figure 24 Developed System View

The system is designed to facilitate circuit training, allowing up to 5 users to engage in consecutive exercises. Given the high-intensity nature of the workouts, minimal rest time is incorporated between exercises, enabling users to seamlessly transition from one activity to the next.

For real-time motion analysis, the developed product utilizes Google's lightweight AI model, Mediapipe, same to the upper limb exercise system. The circuit training program follows the sequence depicted in Figure 25, incorporating three main technologies: facial recognition for user identification, range of motion measurement for personalized exercise difficulty, and motion counting for real-time tracking of exercise repetitions.

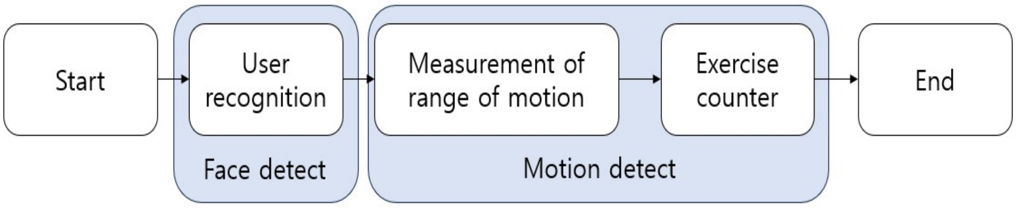


Figure 25 Program flow chart

3.5.1 Face Recognition Feature

The face recognition process, as illustrated in Figure 26, involves positioning the nose within the circular target inside the square box displayed on the screen. This step is implemented to verify the user just before starting the exercise. Before commencing the workout, users undergo registration, during which they input their information and register facial data. This allows for the automatic recording of relevant exercise information for the day through face recognition performed at the start of each exercise session.

Figure 26 Face Recognition Feature

3.5.2 Exercise Range Measurement and Counting Technology

Understanding one's exercise capabilities is crucial, especially for individuals with disabilities whose abilities may vary. The exercise range measurement technology assesses the user's maximum range of motion, enabling them to determine the safe and effective limits for each exercise. The technology measures the user's self-movability within the maximum and minimum ranges for each specific exercise. Within the measured range, exercise zones are designated in three levels: green (50%), yellow (30%), and red (20%), providing users with visual guidance during exercise, as illustrated.

The settings for exercise zones for each specific exercise are designed as outlined in Table 11. The key points for preparation and completion movements for each exercise were determined in collaboration with the exercise instructor. Taking into account the camera's installation position, the key points were set based on specific coordinates. For example, in the case of lag, the y-value of the right hip was used as a reference. For bicep curls, the y-value of the right wrist was considered, for chest press, the x-value of the left wrist, for shoulder exercises, the y-value of the left wrist, and for back exercises, the y-value of the left shoulder.

Regarding exercise counting, as outlined in Table 7, when the angle of each key point for a specific exercise falls within the designated exercise zone (green zone), it is counted as one repetition.

Table 7 Setting motion range and count

	Squat
Range of motion	Maximum and minimum y-values for the right hip.
Ready	Angle of the right hip < 15.
Count	Angle of the right hip > 80 + right hip y < Green Zone.
	Arm curl
Range of motion	Maximum and minimum y-values for the right wrist.
Ready	Elbow angle of the right arm < 30.
Count	Elbow angle of the right arm > 100 + right wrist y < Green Zone.
	Chest Press
Range of motion	Maximum and minimum x-values for the left wrist.
Ready	Elbow angle of the left arm > 100.
Count	Elbow angle of the left arm < 30 + left wrist x > Green Zone.
	Shoulder Exercise
Range of motion	Maximum and minimum y-values for the left wrist.
Ready	Angle of the left shoulder > 160
Count	Angle of the left shoulder < 100 + left wrist y > Green Zone.
	Dips
Range of motion	Maximum and minimum y-values for the left shoulder.
Ready	Elbow angle of the left arm > 45.
Count	Elbow angle of the left arm < 30 + left shoulder y > Green Zone.

Squat	
Ready	End
	
Range of motion	
	

<table>
<tr><td colspan="2">Chest Press</td></tr>
<tr><td>Ready</td><td>End</td></tr>
<tr><td>
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<tr><td colspan="2">Range of motion</td></tr>
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<table>
<tr><td colspan="2">Shoulder Exercise</td></tr>
<tr><td>Ready</td><td>End</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Range of motion</td></tr>
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<table>
<tr><td colspan="2">Arm curl</td></tr>
<tr><td>Ready</td><td>End</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Range of motion</td></tr>
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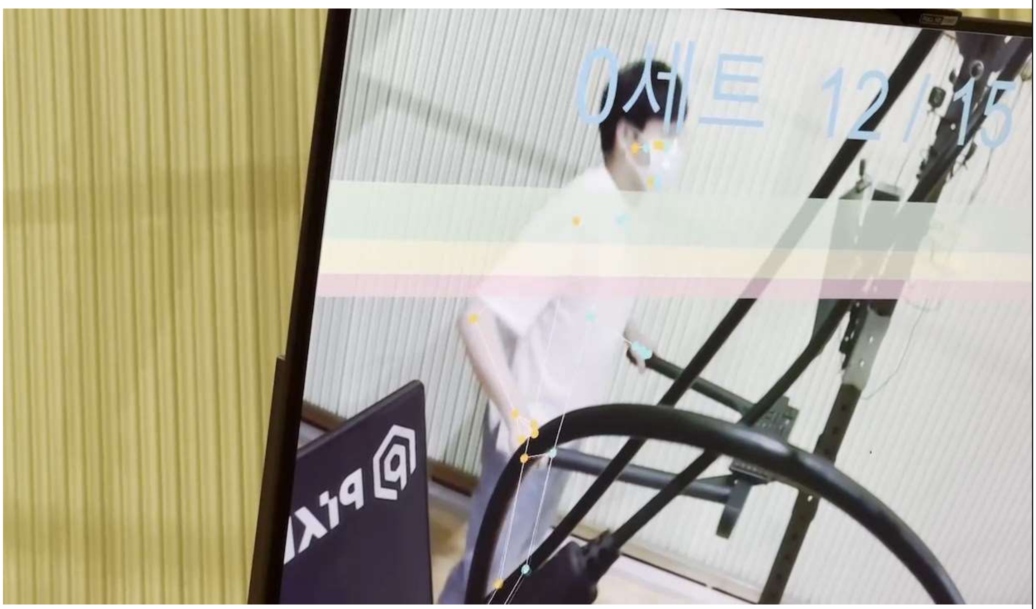
<table>
<tr><td colspan="2">Dips</td></tr>
<tr><td>Ready</td><td>End</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Range of motion</td></tr>
<tr><td colspan="2">
</td></tr>
</table>

Figure 27 Range of motion and count

3.5.3 intervention

In the context of the CrossFit exercise system, both the experimental and control groups were divided into A and B groups, each consisting of 5 participants. The intervention spanned 12 weeks, with sessions held twice a week, each lasting one hour. In the experimental group, there were 2 instructors and 5 users. The newly developed AI-based CrossFit exercise system was employed, encompassing 10 minutes of warm-up, 40 minutes of the main exercise, and a concluding 10-minute cool-down.

The control group, on the other hand, engaged in free-form exercises at a gym for one hour, with two instructors present at all times to provide guidance on exercises and address safety concerns.

For the main exercise in the experimental group, the developed system was utilized to perform 15 repetitions of 5 movements (legs, arms, chest, shoulders, back) in one set. Depending on the proficiency of the instructors, 3-5 Workout of the Day (WOD) routines were created.

As a fundamental framework, Workout of the Day (WOD) sessions were structured around exercises such as squats, box steps, band exercises, arm curls, push-ups, and others. The workout sessions were conducted based on a program that incorporated five foundational movements developed within the system.

To ensure variety and novelty in each workout session, a deliberate effort was made to create different combinations of these basic movements. This approach allowed for a dynamic and diverse set of exercises with unique challenges every time participants engaged in the workout.

During the program's exercises, one person entered each exercise station, and the 5 participants exercised simultaneously. After completing 15 repetitions of a movement, participants rotated clockwise to the next station. Facial recognition was conducted before initiating the exercise to ensure user identification. Once identified, a single movement was performed to assess the user's range of motion. After setting the range of motion, users could observe their projected image on the screen while performing the exercise.

One instructor monitored users' performance through a monitor to provide feedback and guidance, while the other instructor moved around to correct any improper movements.

After the 12-week program, both the experimental group and instructors underwent a usability evaluation. The evaluation included a 5-point scale questionnaire with 10 questions and 5 semi-structured questions, incorporating open-ended opinions.

(a)

(b)

Figure 29 (a) Experimental group, (b) control group

3.5.4 WOD (Workout of the Day) Composition

For each session of WOD, we based the workout on the five program movements we developed. We introduced new exercises in each session to ensure variety. Particularly, in the last 7 rounds (from 18th to 24th), we repeated the same exercises as the initial 1st to 7th rounds but with variations in weights.

Table 8 Workout of the Day

session	Workout of the Day(WOD)
1	5 Round For time 10 squat 10 Box step up 10 band row (Green)
2	EMOM 20min 6~8 Dumbbell Thturster
3	AMRAP 18min 8 deadlift 8 push press 8 farmer's carry
4	AMRAP 16min 6 Shuttle run 10 Dumbbell DEADLIFT 14 Dumbbell SQUAT
5	For time 30 BAND ROW 40 BOX STEP UP 50 AIR SQUAT 40 BOX STEP UP 30 BAND ROW
6	10Round For time 6 BOX STEP OVER 6 SANDBAG CLEAN 6 BURPEE

7	AMRAP 18min 8 Dumbbell THRUSTER 6 SHUTTLE RUN/WALK
8	AMRAP 16min 6 Dumbbell Deadlift 10 Dumbbell Snatch 14 Box step up
9	For time 10 SQUAT With Dumbbell 10 Dumbbell SNATCH 20 SQUAT With Dumbbell 20 Dumbbell SNATCH 30 SQUAT With Dumbbell 30 Dumbbell SNATCH
10	AMRAP 15min 12 Dumbbell SQUAT 8 SIT UP 4 BURPEE
11	For time 30 BAND ROW 30 SANDBAG CLEAN 30 BOX STEP OVER 30 Dumbbell DEADLIFT 30 Dumbbell THRUSTER
12	AMRAP 20min 10 Burpee 10 Shuttle run
13	EMOM 20min ODD : 10 Sit up EVEN : 10 Thruster

14	For time 2 Round 20 Sandbag clean 20 Band row 20 Burpee 20 Wall Push up
15	AMRAP 15min 4 Dumbbell DEADLIFT 4 SQUAT WITH Dumbbell 4 Dumbbell THRUSTER
16	AMRAP 15min 8 SHUTTLE RUN 8 BOX STEP UP WITH Dumbbell 8 Wall Push up
17	AMRAP 18min 8 BURPEE 8 FARMERS CARRY
18	For time 5Round 10 AIR SQUAT 10 BOX STEP UP 10 BAND ROW
19	EMOM 20min 6~8 Dumbbell Thturster
20	AMRAP 18min 8 deadlift 8 push press 8 farmer's carry
21	AMRAP 16min 6 Shuttle run 10 Dumbbell DEADLIFT 14 Dumbbell SQUAT

22	For time 30 BAND ROW 40 BOX STEP UP 50 AIR SQUAT 40 BOX STEP UP 30 BAND ROW
23	10Round For time 6 BOX STEP OVER 6 SANDBAG CLEAN 6 BURPEE
24	AMRAP 18min 8 Dumbbell THRUSTER 6 SHUTTLE RUN/WALK

For time: Complete the given exercises as quickly as possible

AMRAP(As Many Rounds as Possible): Perform as many rounds as possible within the given time.

EMOM(Every Minute On the Minute): Execute the specified movement every minute.

Odd: During odd-numbered minutes

Even: During even-numbered minutes.

3.6 Calorie Calculation

An equation was developed to calculate the calorie consumption of each motion during exercise. Due to the lack of data on the metabolic equivalent (MET) values for band exercises in patients with SCI, the MET values of a band exercise for the upper extremities were developed for the general population in a study by Michael et al., and the resistance values per band color reported in the study by Uchida et al. were applied [49 - 51].

As shown in Table 13, the MET values per band color were induced, and in reference to a study by Eileen G.C. on oxygen consumption by patients with SCI (1 MET = 2.7 mL/kg/min, not 3.5 mL/kg/min), the calorie calculation during exercise was formulated according to the discussions among the researchers of this study [52].

The body weights of the patients with SCI were applied with the MET values per band color (Table 9), and the unit oxygen consumption per minute (resting = 2.7 mL/kg/min) in patients with SCI to the calorie consumption equation per session. The exercise time of 0.33 min was applied based on the assumption that three sessions can be performed for 1 min.

Table 9 MET for each band color

band color	Yellow	Red	Green	Blue	Black
MET	2.77	2.88	2.93	3.1	3.29

$$\text{Calorie consumption per session (kcal)} = \text{band color MET} \times 2.7\text{mL/kg/min} \times \text{body weight(kg)} \times 0.33\text{ min (per session)} \times 0.001\text{(L/mL)} \times 5\text{ (kcal/L)} \times 10\text{ (arbitrary ratio, no unit)}$$

Figure 30 The pragmatic equation of calorie consumption per session.

Additionally, as approximately 5 kcal is generated at 1 L of oxygen consumption, the result was multiplied by 0.001 (to convert L into mL) and 5 (kcal/L). In the process of calculating the calories of a single measurement, the result was multiplied with a 10-fold coefficient after discussions by the research team so as to reflect the recovery from muscle damage, increase the level of scientific evidence, and show the user a numerical value of calorie consumption that could elicit interest in exercise and motivation. The participants were notified before exercising that the calculated calorie consumption would not be an accurate experimental value. The equation of calorie consumption per session is shown in Figure 29.

3.7 Exercise Outcome

The program developed in this study allowed the input of body weight and band color before exercise at the respective predetermined entries.

Upon the completion of an exercise session, a result table was displayed (for example, Figure 30) for the EG subjects. The data, presented next to a character design, included the accuracy of the arbitrary exercise posture feedback (not discussed in this paper), the calorie consumption, and the calculations of cumulative repetition and calories of all sets of the exercise performed.

When it comes to posture accuracy, we look at the number of times you make it to green in the three zones of green, yellow, and red, and mark it as "very accurate" if it's above 70%, "accurate" if it's above 50%, and "good" if it's below.

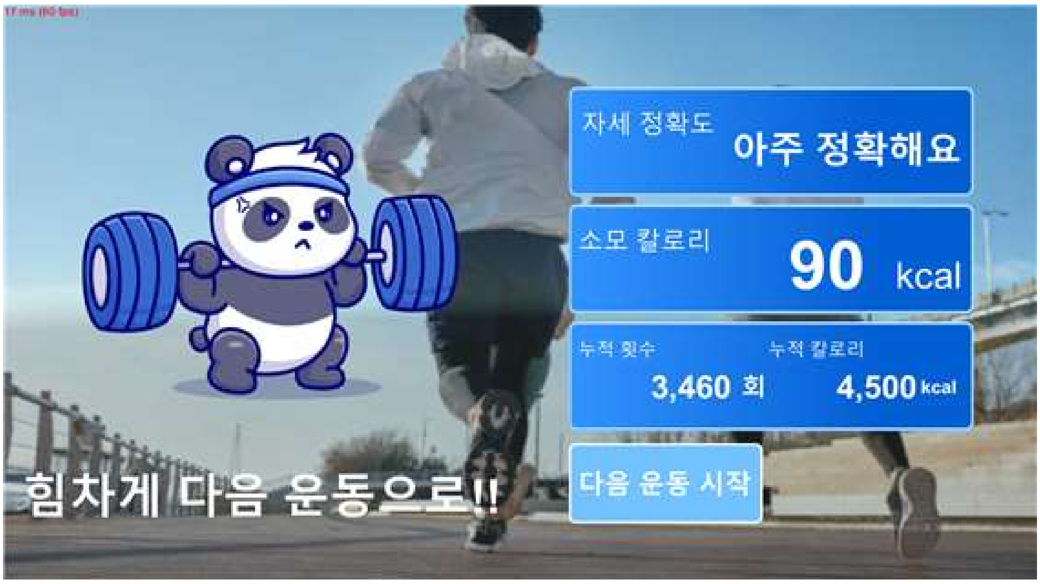


Figure 31 The session ending (result summary) display

* Korean to English translation of the right column: From the top of the right column 자세 정확도 (Postural accuracy), 아주 정확해요 (Very accurate!), 소모 칼로리 (Consumed calorie), 누적횟수 (Cumulative repetition), 누적 칼로리 (Cumulative calorie), 다음 운동 시작 (Start the next set) and at left column 힘차게 다음 운동으로!! (With this energy, let's move on the next!).

3.8 sability Evaluation

After exercise a usability test was conducted on the EG and the instructor to review the benefits and drawbacks, room-for-improvement suggestions, and general opinions of program use. The usability test was a questionnaire containing 10 structured items, rated on a 5-point Likert scale, and 5 semi-structured items. Each free-form interview to record any other opinions was also conducted (table 10) [53].

Regarding the 5-point scale questionnaire, the scores showed: 1 point, complete rejection; 2 points, rejection; 3 points, normal; 4 points, agreement; and 5 points, full agreement was achieved.

Table 10 System Usability Scale

NO	Question	Strongly disagree 1	2	3	4	Strongly agree 5	Short answer
1	I think that I would like to use this system frequently						
2	I found the system unnecessarily complex						
3	I thought the system was easy to use						
4	I think that I would need the support of a technical person to be able to use this system						
5	I found the various functions in this system were well integrated						
6	I thought there was too much inconsistency in this system						
7	I would imagine that most people would learn to use this system very quickly						
8	I found the system very cumbersome to use						
9	I felt very confident using the system						
10	I needed to learn a lot of things before I could get going with this system						

semi-structured question	Answer
Please briefly share your impressions after using the program	
Kindly mention the strengths of the program you used	
Point out any weaknesses or drawbacks you observed in the program	
If there are areas for improvement in the process of using the program, please share your thoughts	
If you were to purchase and use the program, what price range do you think would be reasonable?	
Feel free to provide any additional comments or opinions	

3.9 Statistical Analysis

The results obtained from the pre- and post-intervention physical fitness tests in the EG and CG were compared. The Kolmogorov–Smirnov test was used to verify data normality. Regarding the comparison between the groups, an independent t-test was performed for post-values separately from pre-values within each group, Among the variables of the participants' general characteristics, continuous variables were expressed as means and standard deviations, and categorical variables were expressed as frequencies and percentages. All data analyses were performed using SPSS 26.0 version for Windows (IBM Corp., Armonk, NY, USA), and the level of significance was set at a p-value of 0.05.

Chapter4 Result

4.1 development of an artificial intelligence-based upper limb exercise system for spinal cord injury patients

the 8-week exercise results are shown in Tables 11 and 12. The experimental group exhibits increased values in all tests, while the control group shows either maintained or decreased results

Table 11 Exercise outcome (kg) in the Experimental Group (EG).

	Left Chest Press	Right Chest Press	Shoulder Press	Lat Pull Down	Left Arm Curl	Right Arm Curl
E1						
Pre-test	13.72	10.67	22.08	19.86	54	54
Post-test	24.29	19.75	23.78	38.69	90	120
E2						
Pre-test	28.05	25.79	26.79	28.3	100	96
Post-test	29.27	29.35	30.25	31.64	180	152
E3						
Pre-test	14.64	12.89	20.72	21.84	114	99
Post-test	31.17	36.54	26.94	37.77	183	198
E4						
Pre-test	18.95	22.35	20.87	29.21	130	165
Post-test	22.21	27.65	55.14	34.96	198	258

Table 12 Exercise outcome (kg) in the Control Group (CG).

	Left Chest Press	Right Chest Press	Shoulder Press	Lat Pull Down	Left Arm Curl	Right Arm Curl
C1						
Pre-test	29.01	37.88	39.6	59.55	175	185
Post-test	40.17	50.32	39.52	54.02	240	360
C2						
Pre-test	23.8	32.58	34.9	42.03	148	160
Post-test	28.5	37.73	31.11	34.28	260	300
C3						
Pre-test	17.3	18.21	20.72	6.84	69	108
Post-test	14.38	17.62	16.4	16.9	112	120
C4						
Pre-test	18.18	16.14	27.47	21.76	78	76
Post-test	19.49	23.86	31.17	25.87	177	177
C5						
Pre-test	44.64	44.04	49.67	49.67	240	205
Post-test	46.06	49.69	41.17	53.1	372	432

In the EG, all measured variables increased for all participants. A1, in particular, showed an increase in the chest press from 13.72 kg to 24.29 kg on the left side and from 10.67 kg to 19.75 kg on the right side. Likewise, A3 showed a notable increase from 14.64 kg to 31.17 kg on the left side and from 12.89 kg to 36.54 kg on the right side. A4 exhibited the largest increase in the shoulder press, from 20.87 kg to 55.14 kg. For all tested items, an average increase of 10% was observed in A2, the oldest participant in this study.

Regarding the CG, the overall level of increase was low compared with the EG, and despite an overall increase, several items were found to have decreased. B3, in particular, showed a reduced level across all items except the lat pull-down and arm curl. Addition-ally, B1 and B2 showed a reduced level for the lat pulldown. With the exception of B4, all participants showed reduced levels for the shoulder press. B4 was the only participant exhibiting an increase across all tested items in the CG.

4.1.1 Left chest press Results

The 8-week Left Chest Press experimental results, as shown in Table 13 and Figure 31, indicate an increase of 7.89 kg for the experimental group and 3.13 kg for the control group. However, there was no significant difference between the two groups.

Table 13 Left chest press Results (means ± standard deviation)

	Pre-test	Post-test	Intra-Group changes	p-value
Left chest press (kg)				
Experimental Group	18.84 ± 6.54	26.73 ± 4.18	-7.89 ± 7.01	0.11
Control Group	26.58 ± 11.14	29.72 ± 13.39	-3.13 ± 5.23	0.252

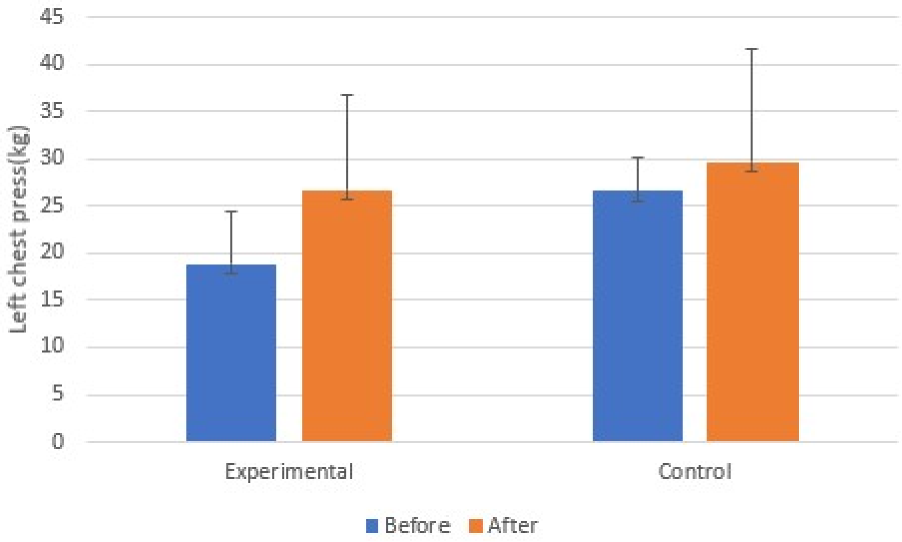


Figure 32 Left chest press Results

4.1.2 Right chest press Results

The 8-week Right Chest Press experimental results, presented in Table 14 and Figure 32, reveal an increase of 10.39 kg for the experimental group and 6.07 kg for the control group. No significant difference was observed between the two groups.

Table 14 Right chest press Results (means ± standard deviation)

	Pre-test	Post-test	Intra-Group changes	p-value
Right chest press (kg)				
Experimental Group	17.92 ± 7.28	28.32 ± 6.89	-10.39 ± 9.13	0.107
Control Group	29.77 ± 12.21	35.84 ± 14.83	-6.07 ± 4.7	0.045

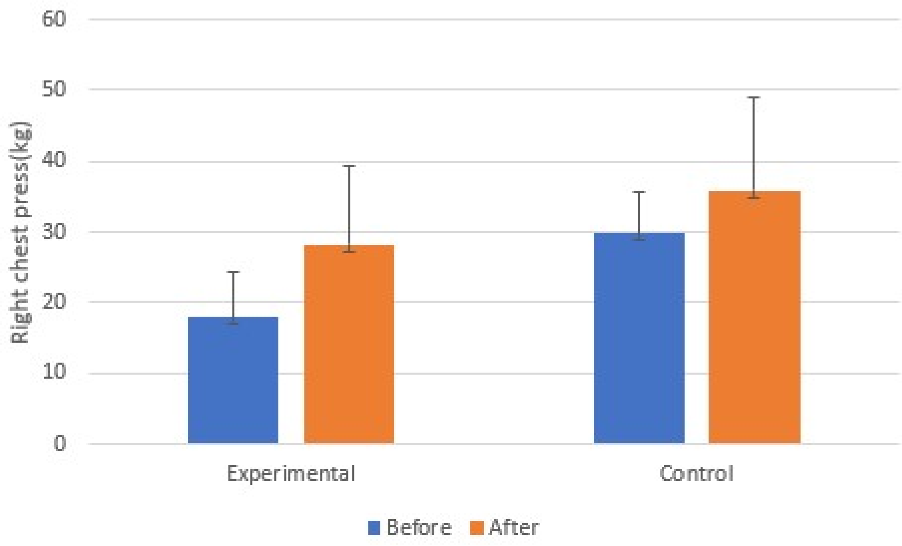


Figure 33 Right chest press Results

4.1.3 Shoulder press Results

The 8-week Shoulder Press experimental results, outlined in Table 15 and Figure 33, demonstrate an increase of 11.41 kg for the experimental group and a decrease of 2.59 kg for the control group. Both groups did not exhibit a significant difference.

Table 15 Shoulder press Results (means ± standard deviation)

	Pre-test	Post-test	Intra-Group changes	p-value
Shoulder press (kg)				
Experimental Group	22.61 ± 2.84	34.02 ± 14.32	-11.41 ± 15.35	0.234
Control Group	34.47 ± 11.13	31.87 ± 9.81	2.59 ± 4.61	0.277

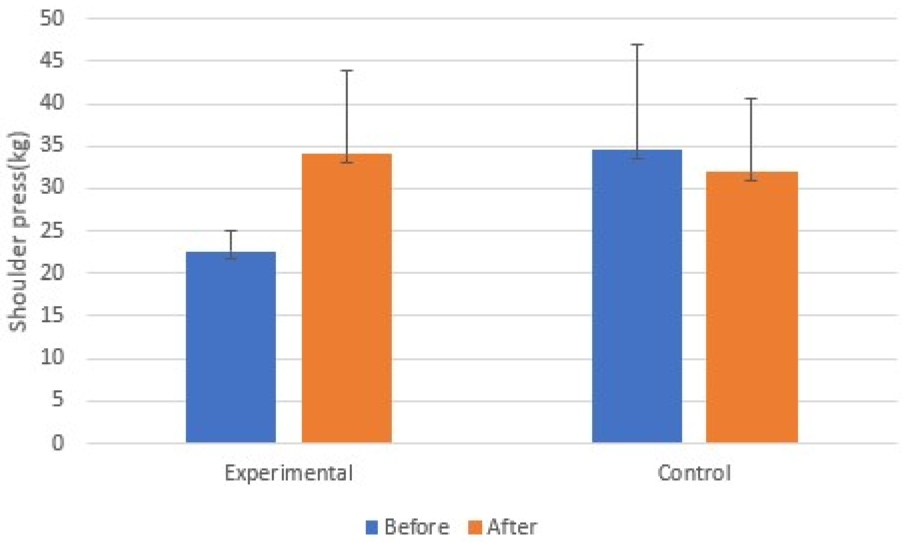


Figure 34 Shoulder press Results

4.1.4 Lat pull down Results

The 8-week Lat Pull Down experimental results, as indicated in Table 16 and Figure 34, exhibit an increase of 10.96 kg for the experimental group and 0.86 kg for the control group. No significant difference was observed between the two groups.

Table 16 Lat pull down Results (means ± standard deviation)

	Pre-test	Post-test	Intra-Group changes	p-value
Lat pull down (kg)				
Experimental Group	24.8 ± 4.64	35.76 ± 3.17	-10.96 ± 7.56	0.063
Control Group	35.97 ± 21.39	36.83 ± 16.46	-0.86 ± 7.36	0.806

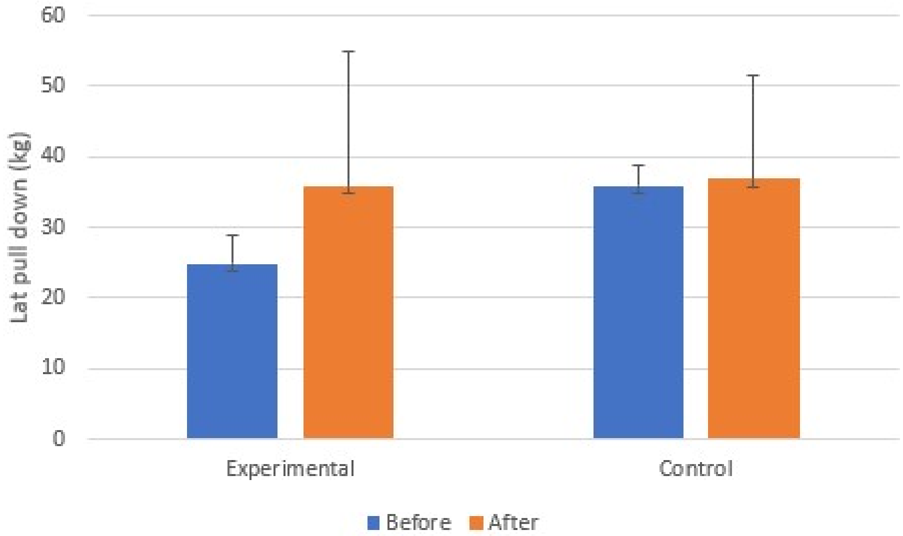


Figure 35 Lat pull down Results

4.1.5 Left arm curl Results

The 8-week Left Arm Curl experimental results, presented in Table 17 and Figure 35, show an increase of 63.25 kg for the experimental group and 90.2 kg for the control group. There was a significant difference between the two groups.

Table 17 Left arm curl Results (means ± standard deviation) (**p<0.01)

	Pre-test	Post-test	Intra-Group changes	p-value
Left arm curl (srore)				
Experimental Group	99.5 ± 32.71	162.75 ± 49.13	-63.25 ± 18.96	0.007**
Control Group	142.0 ± 70.98	232.2 ± 97.3	-90.2 ± 35.92	0.005**

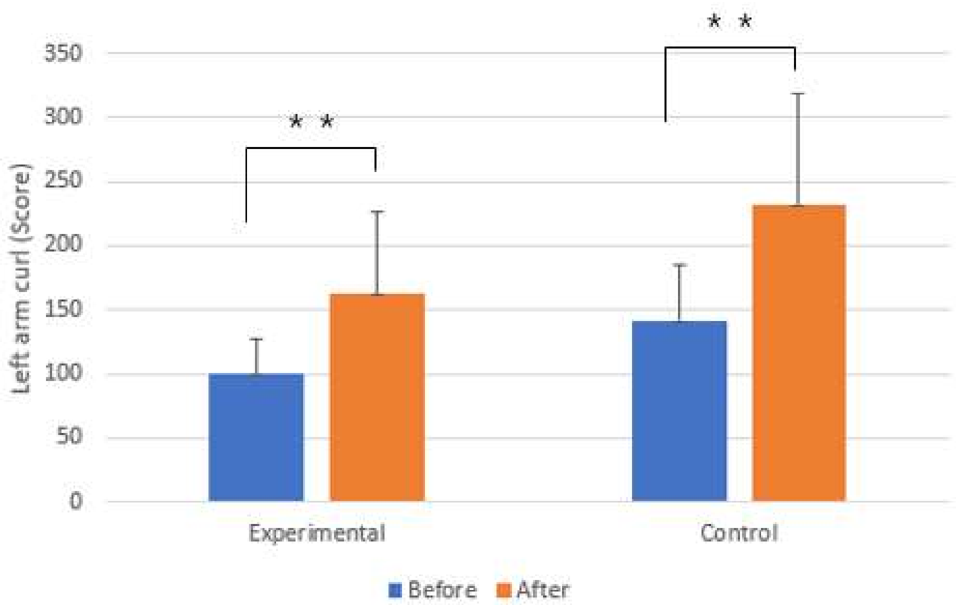


Figure 36 Left arm curl Results (**p<0.01)

4.1.6 Right arm curl Results

The 8-week Right Arm Curl experimental results, outlined in Table 18 and Figure 36, reveal an increase of 63.25 kg for the experimental group and 90.2 kg for the control group. Both groups exhibited a significant difference.

Table 18 Right arm curl Results (means ± standard deviation) (*p<0.05, **p<0.01)

	Pre-test	Post-test	Intra-Group changes	p-value
Right arm curl (score)				
Experimental Group	103.5 ± 45.85	182.0 ± 59.93	-78.5 ± 20.76	0.005**
Control Group	146.8 ± 53.7	276.6 ± 129.73	-129.8 ± 81.67	0.024*

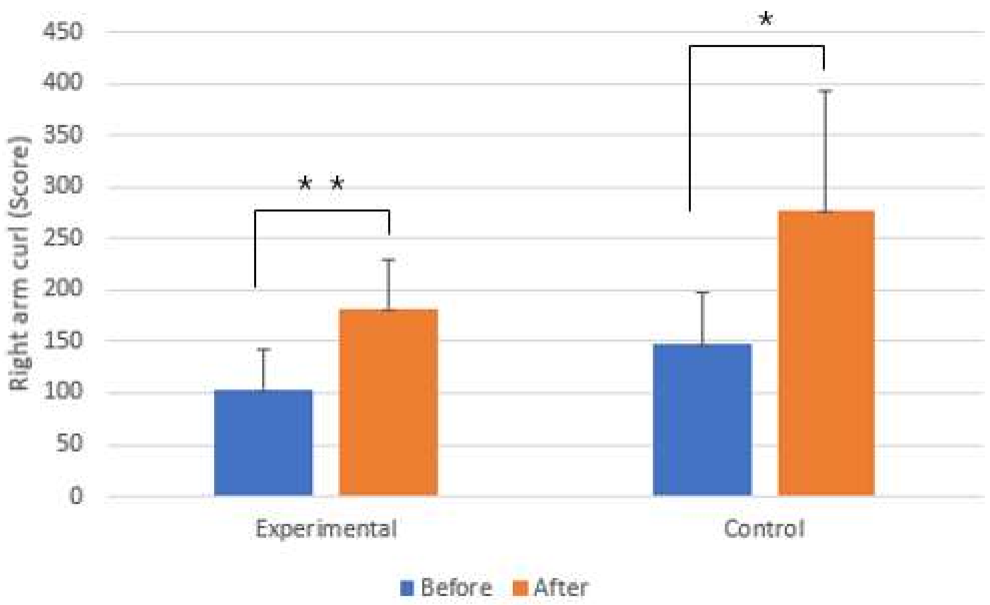


Figure 37 Right arm curl Results (*p<0.05, **p<0.01)

4.1.7 Usability Evaluation Results

In the usability evaluation targeting one instructor and four participants in the experimental group, the results regarding program usage frequency indicated that users gave a score of 5, while the instructor gave a score of 4. Both users and instructors rated the usability of the program with 5 points, considering it easy to use. However, in terms of understanding how to use the program, users scored 3, while the instructor scored 5. Regarding program satisfaction, users gave a score of 5, while the instructor gave a score of 3, showing a difference in perception. In terms of program completeness, both users and instructors gave a score of 2, indicating some shortcomings.

In user feedback, participants expressed satisfaction with the real-time analysis of their movements and having an instructor guide them through the exercises. However, some users mentioned that the program's diversity is currently somewhat lacking. As improvement suggestions, users expressed a desire for a variety of programs and a more stable system that would enable them to exercise at home independently.

From the instructor's perspective, they found the system itself to be user-friendly and not overly complex. However, they acknowledged that there are still many areas that need improvement. The instructor suggested that enhancing the number of programs, improving the design, and incorporating voice feedback could contribute to a better user experience in the future.

4.1.8 Discussion

An AI-based motion analysis system was developed in this study, and the usability and effectiveness of the system for muscle strengthening were evaluated. The results revealed no significant difference between the two groups; however, all tested items showed an improvement in the EG, the users of the computer-aided exercise system, while a constant or reduced level (non-improvement) was observed in the CG, the control exercise without a computer aid.

The biggest issue might have been the insufficient number of participants. The same instructor guided both groups through an identical exercise session. However, the participants in the EG group, having the ability to observe themselves through the motion analysis system during exercise, were presumed to experience increased motivation due to the visual feedback. In contrast, the participants in the CG only watched the instructor during the exercise; therefore, it is possible that they performed the exercise in inaccurate postures in the absence of 1:1 direct guidance. This could have resulted in reduced exercise effectiveness, and the lack of feedback on postural correction could have decreased participant motivation, reducing the effect. Only B4 in the CG exhibited an increase across all tested items, presumably because she could effectively understand the instructor and independently perform the exercises in accurate postures as she had the best physical state with a lumbar injury. Our results are similar to those of a study by Baptista et al., where visual feedback was provided to people without SCI, and of a study by Sayenko et al., where the effect of visual feedback on patients with SCI was investigated [14,16].

In the present study, the four participants in the EG included three males and one female; two had a cervical injury, one had a thoracic injury, and one had a lumbar injury. The participants in the CG included two males and three females;

one had a cervical injury, three had a thoracic injury, and one had a lumbar injury. This indicated a slightly higher proportion of cervical injuries, a relatively more severe condition, in the EG. The mean age of the participants was 68 years in the EG and 59 years in the CG, indicating an age gap of approximately 10 years. Nevertheless, while the exercise effect is generally known to be lower in older adults and severely affected people, the results of this study showed a trend of a quantitatively higher effect in the EG (with higher ages and more severe conditions), which implies that a difference in age and severity did not suppress the effectiveness of the intervention.

The motion analysis system used by the participants in the EG was developed using the MediaPipe algorithm, which is light and rapid in processing, as the system had to provide real-time feedback on participant motions. The animation effect was removed as much as possible, and as an all-in-one, stand-type device was used, the webcam had to be positioned in line with the center of the user. The use of AI technology allowed the two-dimensional image to be analyzed in three dimensions; however, the accuracy of motion detection decreased in the chest press with front-to-back anterior movements. In a follow-up study, an angular zone of motion analysis should be set so that the camera can be installed above and diagonally to the user to increase the accuracy of motion analysis.

The usability test involving the users and the instructor indicated a satisfactory result. The users stated that it was good to watch themselves during exercise, allowing them to recognize their inaccurate postures. The instructor was satisfied that he could guide a number of individuals, not only one at a time, smoothly through the use of the computer system. Both the subjects in the EG and the instructor stated that the system was easy to use; however, there was room for improvement regarding system completeness.

This study has several limitations. As both EG and CG comprised patients with

SCI, not people without physical disability, it was difficult to recruit participants for this clinical study due to the COVID-19 pandemic. Consequently, the low number of participants may have resulted in a decrease in the statistical power and study closure, not reaching intended recruitment. External factors could not be controlled because all participants were chronic free-living outpatients (not inpatients). Therefore, it is difficult to attribute the results in the two groups purely to the use or non-use of these study sessions. Additionally, while efforts were made to involve all participants in all sessions throughout the 8-week intervention period, some participants had to miss one session or more due to illness or personal reasons. Although such participants were instructed to perform the exercise at home using the video recording of the day, this is a factor that could not be controlled by the investigator.

4.2 AI-Based CrossFit Exercise System for Stroke Survivors

4.2.1 Chest Press Results

The 12-week experimental results for Chest Press are presented in the table 19 and figure37. In the experimental group, there was a significant increase in both affected (3.68±4.42 kg) and unaffected sides (2.44±3.03 kg) ($p<0.05$). In the control group, the unaffected side showed an increase of 3.14±6.66 kg, while the affected side decreased by 1.98±2.47 kg, with no significant difference observed.

Table 19 Chest Press Results (means ± standard deviation)(* $p<0.05$)

	Pre-test	Post-test	Intra-Group changes	p-value
Experimental Group				
unaffected side	26.77±13.58	30.45±14.69	-3.68±4.42	0.037*
affected side	18.69±12.71	21.14±14.17	-2.44±3.03	0.042*
Control Group				
unaffected side	28.83±6.01	31.97±7.95	-3.14±6.66	0.258
affected side	20.90±7.65	18.92±9.02	1.98±2.47	0.079

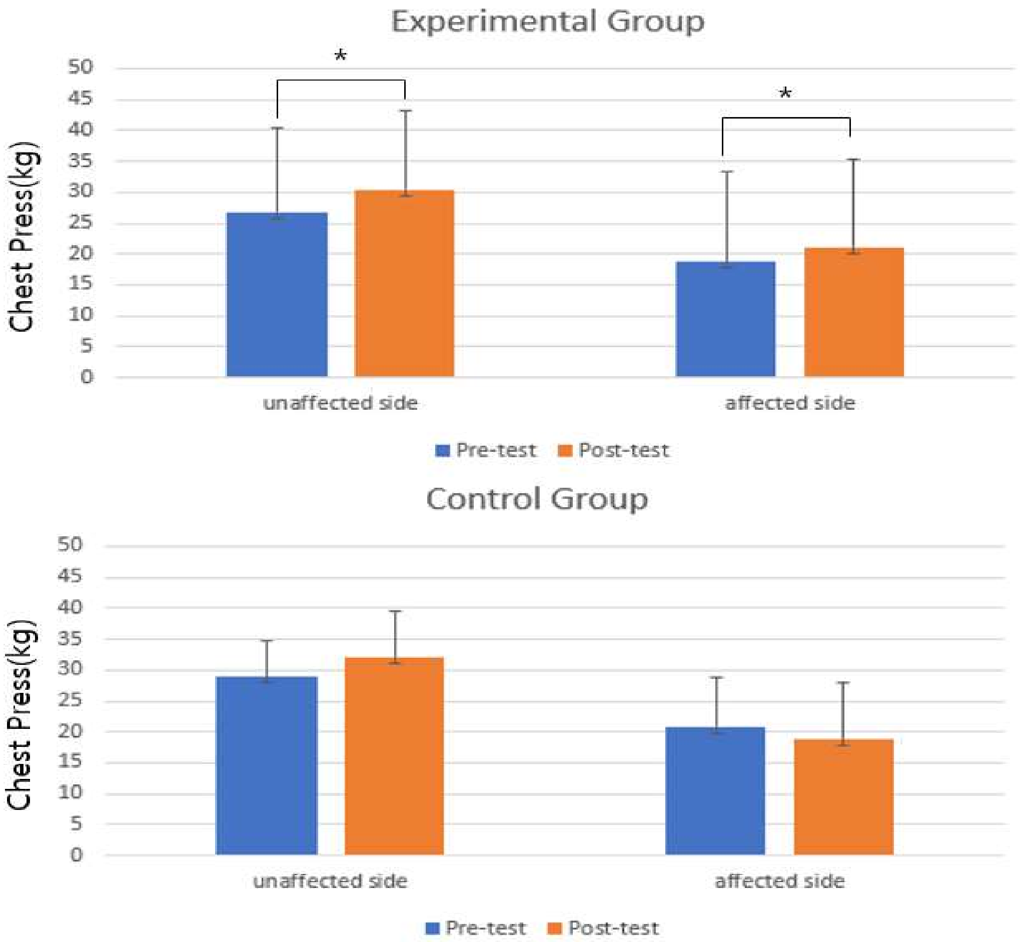


Figure 38 Chest Press Results(*p<0.05)

4.2.2 Arm Curl Results

The 12-week experimental results for Arm Curl are shown in the table 20 and figure 38. In the experimental group, there was a significant increase in the affected side (27.00±31.68 kg) and unaffected side (22.55±32.19 kg) ($p<0.05$). In the control group, the unaffected side increased by 48.14±64.45 kg, and the affected side increased by 2.21±18.16 kg, with no significant difference observed.

Table 20 Arm Curl Results (means ± standard deviation)(*p<0.05)

	Pre-test	Post-test	Intra-Group changes	p-value
Experimental Group				
unaffected side	155.88±62.30	182.88±59.80	-27.00±31.68	0.034*
affected side	85.11±60.11	107.66±81.69	-22.55±32.19	0.069
Control Group				
unaffected side	159.57±60.46	207.71±58.40	-48.14±64.45	0.096
affected side	85.42±62.07	87.64±48.98	-2.21±18.16	0.758

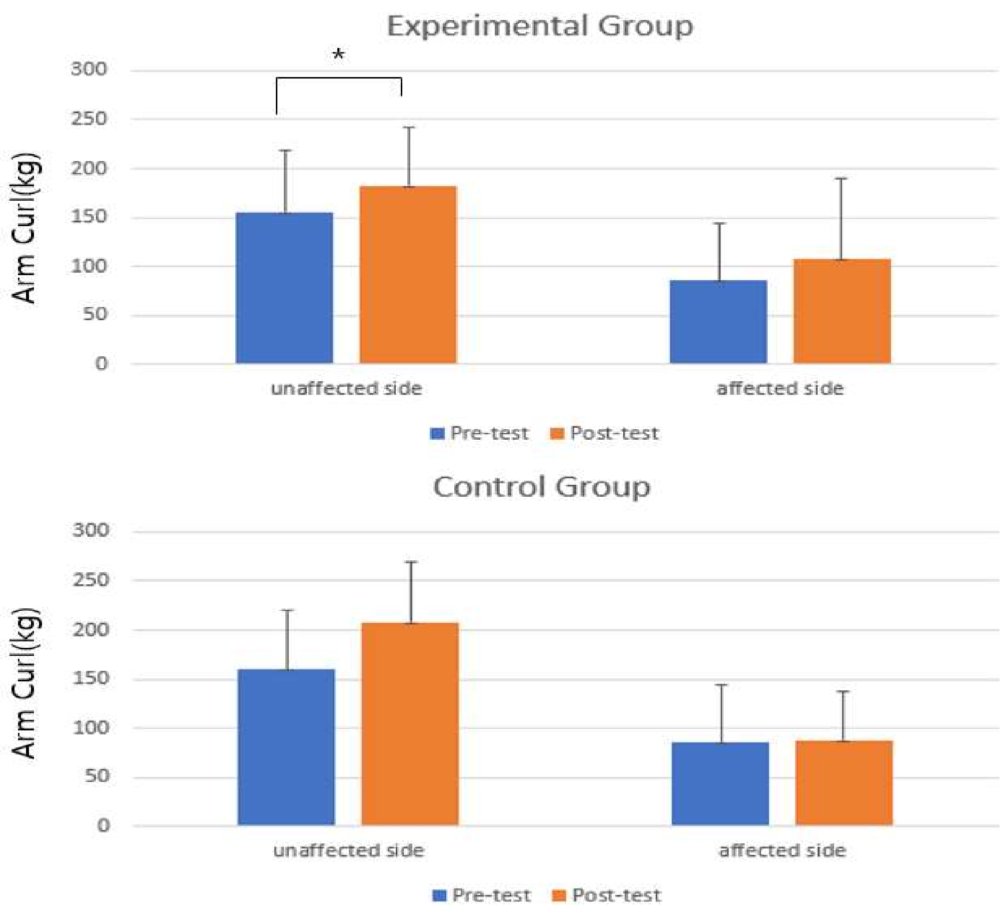


Figure 39 Arm Curl Results(*$p<0.05$)

4.2.3 Leg Extension Results

The 12-week experimental results for Leg Extension are presented in the table 21 and figure39. In the experimental group, there was a non-significant increase in both affected (1.18 kg) and unaffected sides (1.09 kg). In the control group, the unaffected side increased by 3.46 kg, while the affected side decreased by 2.82 kg, with no significant difference observed.

Table 21 Leg Extension Results (means ± standard deviation)

	Pre-test	Post-test	Intra-Group changes	p-value
Experimental Group				
unaffected side	29.53±11.79	30.71±12.89	-1.18±3.10	0.287
affected side	24.51±10.92	25.61±10.65	-1.09±3.97	0.431
Control Group				
unaffected side	33.39±10.23	36.85±7.99	-3.46±7.06	0.243
affected side	29.21±7.05	26.39±8.57	2.82±6.05	0.263

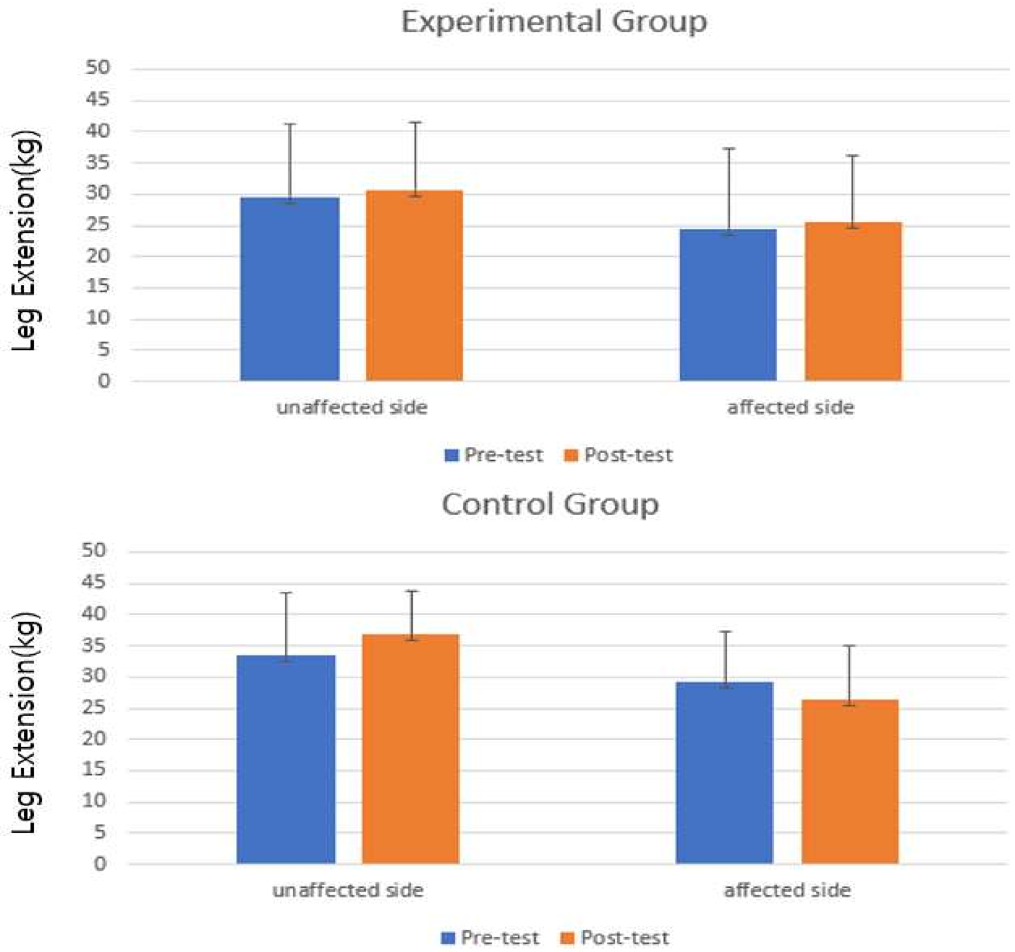


Figure 40 Leg Extension Results

4.2.4 Leg Flexion Results

The 12-week experimental results for Leg Flexion are shown in the table 22 and figure 40. In the experimental group, there was a non-significant increase in both affected (1.57 kg) and unaffected sides (1.64 kg). In the control group, the unaffected side increased by 1.52 kg, while the affected side decreased by 0.61 kg, with no significant difference observed.

Table 22 Leg Flexion Results (means ± standard deviation)

	Pre-test	Post-test	Intra-Group changes	p-value
Experimental Group				
unaffected side	11.72±5.86	13.29±6.73	-1.57±4.39	0.315
affected side	8.44±5.59	10.09±7.74	-1.64±4.90	0.345
Control Group				
unaffected side	18.11±7.50	16.59±7.88	1.52±3.80	0.331
affected side	13.85±8.33	13.23±5.59	0.61±4.45	0.729

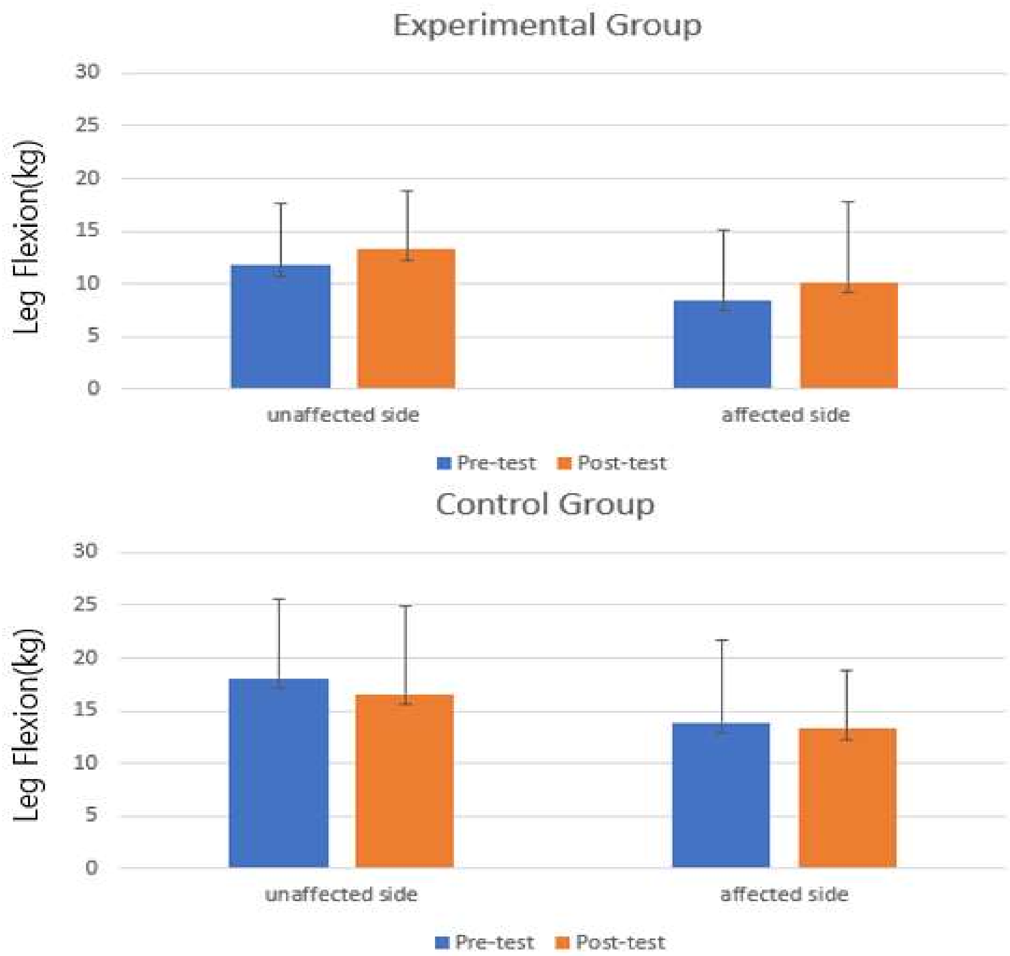


Figure 41 Leg Flexion Results

4.2.5 6-Minute Walk Test Results

The 12-week experimental results for the 6-Minute Walk Test are shown in the table 23 and figure 41. In the experimental group, there was an increase of 8.22 meters, and in the control group, there was an increase of 1.71 meters. Both groups did not show a significant difference.

Table 23 6-Minute Walk Test Results (means ± standard deviation)

	Pre-test	Post-test	Intra-Group changes	p-value
Experimental Group	412.11±129.08	420.33±125.79	-8.22±33.19	0.479
Control Group	441.85±106.12	443.57±91.28	-1.71±36.49	0.905

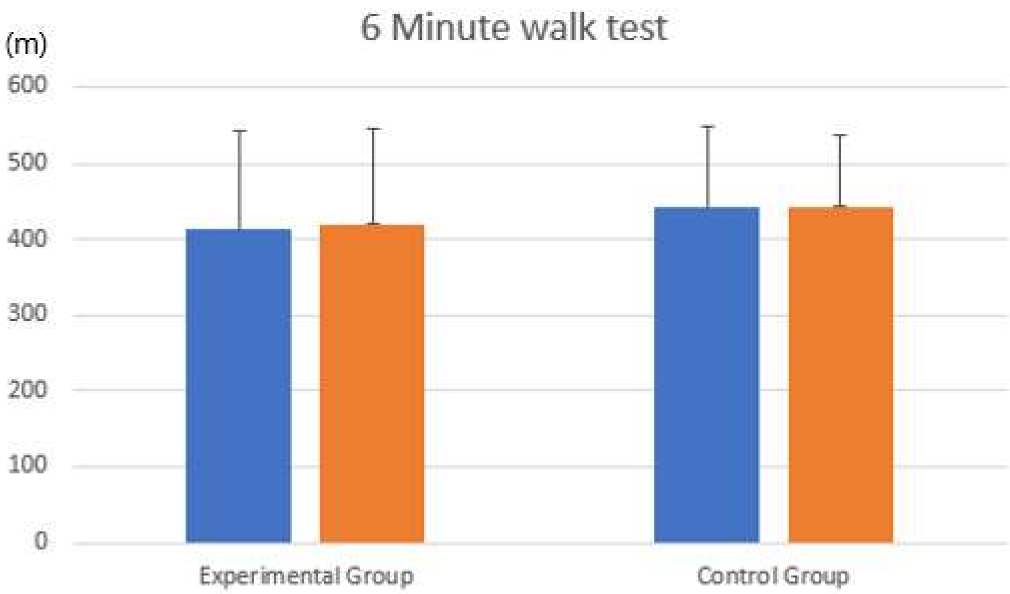


Figure 42 6-Minute Walk Test Results

4.2.6 Percentage Increase by Muscle Group

When representing tthe percentage increase by muscle group in a graph, it appeared as shown in Figure 42. In the experimental group, for chest press, arm curl, leg extension, and flexion, the unaffected side increased by 16%, 21%, 4%, and 18%, respectively, while the affected side increased by 14%, 22%, 7%, and 27%.

In contrast, the control group showed an increase of 12%, 52%, and 16% for the unaffected side in chest press, arm curl, and leg extension, respectively, while leg flexion on the unaffected side decreased by -7%. For the affected side is arm curl and leg flexion increased by 12%, 9% and chest press, leg extension decreased by -12%, -9% respectively.

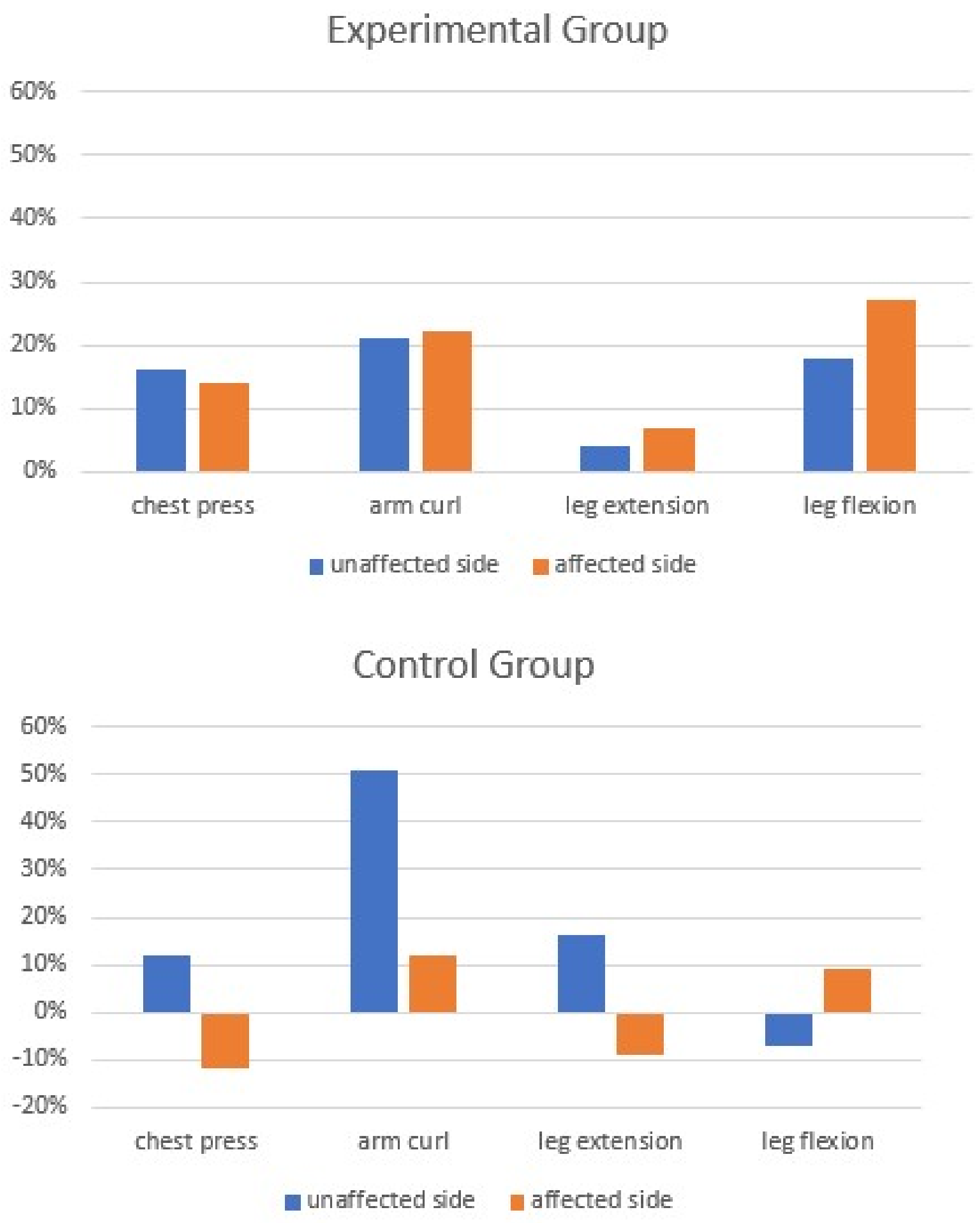


Figure 43 Muscle Group results (a) Experimental group, (b) Control Group

4.2.7 Exercise Effects by Body Part

To assess the exercise effects by body part, we divided the exercises into three categories: Upper Body (chest press, arm curl), Lower Body (leg extension, leg flexion), and Cardiovascular (6-minute walk test). As shown in the graph, the experimental group exhibited an average increase of over 14% on both affected and unaffected sides in the Upper and Lower Body categories, excluding the Cardiovascular part. In contrast, the control group showed an overall increase of 3%, with a significant 21% increase on the unaffected side in the Upper Body category. However, apart from this specific increase, there was minimal or no improvement, and in some cases, a decline was observed. Both groups demonstrated marginal increases in the Cardiovascular category.

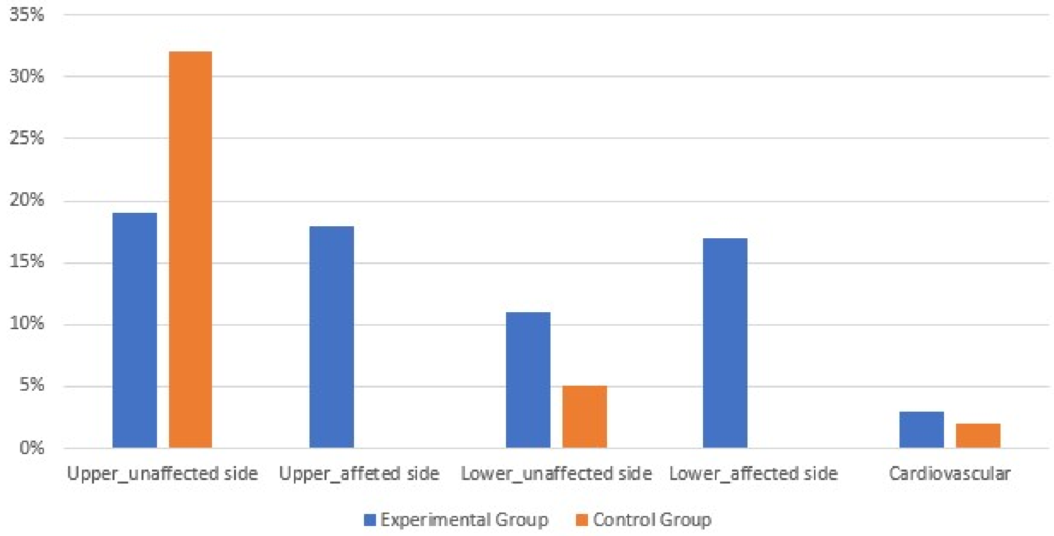


Figure 44 Body Part results

4.2.8 Usability Evaluation Results

We examined the usability of the program through feedback from 10 users and 3 instructors. Users indicated a high likelihood of frequent use with a score of 4.7 for program usage continuity, while user convenience scored 4.4, reflecting ease of use. The program was perceived as not complex 1 point, and its stability scored 2 points, indicating it is not considered unstable.

In terms of expert assistance and program learning ability, users rated them at 3.5 and 4.4, respectively, suggesting a slight need for expert help but confidence in quick learning.

Users expressed positive impressions, finding the experience enjoyable and noting improvements in strength and balance. However, occasional recognition errors were mentioned as a drawback.

From the instructors' perspective, program usage suitability scored 3 points, program complexity 2 points (not complex), and user convenience scored 2.3 points (not user convenience). The necessity of expert assistance from the instructor's viewpoint received a score of 4.3.

Overall, users appreciated the opportunity to discover new exercise methods due to technological advancements, especially the real-time self-monitoring feature. Recognition errors were acknowledged as a notable downside by both users and the instructor.

4.2.9 Discussion

In this study, we compared the differences between CrossFit exercise using a program developed for stroke survivors and conventional gym exercises over a period of 12 weeks. The experimental group showed similar improvements in both affected and unaffected sides. In contrast, the control group exhibited higher improvement on the affected side but tended to show lower or decreased improvement on the unaffected side. Particularly, the experimental group demonstrated significant differences in chest press on both sides and arm curl on the affected side. This could be attributed to the nature of CrossFit exercises, which involve a variety of movements in a group setting, fostering interest in physical activity. This aligns with the findings of Dean's and Shea's studies on the positive impact of group exercises [54-55].

Furthermore, the developed program focused on programming the five fundamental movements crucial for rehabilitation exercises. These movements were personalized for each user by measuring their range of motion, allowing customized exercise for each participant. Unlike simply counting repetitions based on basic movements, setting specific ranges and goals encouraged the experimental group to put in more effort compared to the control group. This outcome resonates with the results of Maghbouli's study on the effectiveness of goal-oriented exercise. The ability to set exercise ranges based on individual capabilities, coupled with real-time feedback on their movements, enabled participants to correct mistakes during the exercise, contributing to its effectiveness [56]. Through this technology, personalized exercise programs for each participant were conducted, allowing them to reach their goals more effectively without straining themselves.

On the other hand, the control group, having exercised independently, likely focused on activities they were already proficient in. Consequently, it is presumed that the amount of exercise on the unaffected side increased compared to the affected side .

Regarding cardiorespiratory function, both groups showed marginal increases, and no significant differences were observed. While previous studies such as Bossmann and Guterrez-Arroyo indicated aerobic effects of high-intensity interval training in CrossFit, this study did not observe significant aerobic effects [57-58]. This discrepancy is attributed to the differences in participants. Previous research primarily involved non-disabled individuals, who could transition quickly between exercises with minimal breaks, given their ease of movement. In contrast, participants in this study, being stroke, faced mobility challenges and required more time to comprehend each movement. Consequently, transitioning between exercises took longer, and the overall exercise intensity may not have been sufficient to elicit a significant cardiovascular response[56-57].

In the real-time motion analysis, specific movements were defined for each region, and cameras were strategically placed in positions that provided optimal visibility, not necessarily facing the front. It was observed that the accuracy of motion analysis significantly improved compared to the existing program.

Furthermore, the personalized system, through the specification of the range of motion, allowed users to visually perceive the extent to which they needed to move. This capability is presumed to have increased interest and motivation in the exercise.

The usability evaluation results indicated satisfaction among both users and instructors regarding the program usage. Participants expressed that the ability to view their movements in real-time and having exercise ranges tailored to their capabilities were particularly positive aspects. Instructors also appreciated the personalized program for users and the ability to guide individuals, even when alone. However, both groups expressed some disappointment with the instability of motion recognition.

Several limitations were noted in this study. Difficulty in recruiting participants, especially stroke survivors, posed a challenge, and the inclusion of chronic outpatient participants in both experimental and control groups made it challenging to control external factors. Additionally, the diverse exercise abilities of stroke survivors made it difficult to provide standardized instructions for the same exercises. While the developed program performed well in tests with non-disabled individuals, occasional difficulties in recognizing the number of movements were observed in individuals with limited exercise ranges. This issue is attributed to the limited information available about the exercise postures of disabled individuals and is expected to be resolved as more experimental data are collected from a broader population in the future.

Chapter5 Conclusion

In this study, we developed a rehabilitation exercise program using an AI-based motion analysis system. A randomized controlled trial (RCT) was conducted with 9 individuals with spinal cord injury and 20 individuals with stroke.

For the upper limb training system targeting individuals with spinal cord injury, there was no significant difference between the experimental and control groups in pre-post comparisons. However, the experimental group showed improved results in all evaluations, while the control group exhibited similar or declining tendencies.

In the case of CrossFit exercise for individuals with stroke, the experimental group showed improvement in all evaluations, with significant differences observed in chest press on the affected side and unaffected side. In contrast, the control group showed improvement only on the affected side, with similar or declining tendencies on the unaffected side.

Based on the results of this study, the AI-based motion analysis system developed was found to be effective in enhancing muscle strength in rehabilitation exercises. However, for cardiovascular fitness, both groups showed minimal improvement, suggesting less effectiveness.

This study presents the results of an examination conducted with a small number of individuals with disabilities. Due to the diverse characteristics of disabilities, even those with similar disabilities exhibit distinct features, making it challenging to represent all individuals with disabilities comprehensively.

The developed programs included a first-phase upper limb training system that measured movement angles to count the user's repetitions and a second-phase CrossFit exercise system that customized workouts by assessing the user's range of motion. The latter, which focused on understanding the range of motion, appeared to engage users more and enable safer exercise from their perspective.

Additionally, while the first phase, using a stand-type device for front-facing filming, showed slightly reduced motion analysis accuracy, the second-phase system improved accuracy by varying camera positions in different areas.

Despite some shortcomings in the number of programs and motion analysis recognition, participants expressed high satisfaction with the new exercise programs and found great satisfaction in being able to exercise when seeing their own movements.

This study, focusing on the effectiveness of AI motion analysis technology in rehabilitation exercises for individuals with disabilities, suggests that the developed system, although limited to 3-5 types, addresses fundamental movements in rehabilitation exercises. In both experiments, the experimental groups outperformed the control groups in evaluations, indicating the effectiveness of the motion analysis system in rehabilitation exercises.

Based on these research findings, we hope to contribute to the future development of AI-based technology for disability rehabilitation exercise systems.

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국문초록

AI기반 동작분석 시스템을 활용한 맞춤형 재활운동 프로그램 개발

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본 연구는 장애인들의 재활운동 시 흥미와 동기부여를 주기위하여 AI기반 동작분석 시스템을 활용하여 맞춤형 재활운동 프로그램을 개발하고자하였다. Mediapipe 알고리즘을 사용하여 동작분석 시스템을 개발하였다. 1차 프로그램은 상지운동을 기반으로 3가지(체스트 프레스, 숄더플레스, 암컬) 동작에 대해 동작횟수를 체크하는 시스템을 개발하였다. 2차 프로그램의 경우 크로스핏 운동으로 재활운동에 있어 기초가 되는 5가지 동작(스쿼트, 암컬, 체스트프레스, 레트럴레이지, 딥)에 대하여 프로그램화하였다. 2차 프로그램에서는 맞춤형 재활운동을 진행 할 수 있도록 운동전 각자의 운동 범위를 파악할 수 있는 시스템을 만들었다. 측정된 운동범위 기반으로 동작의 횟수를 카운트할 수 있도록 하였다. 운동에 흥미를 가질 수 있도록 본인의 모습이 화면이 투영되고 각 동작 횟수를 체크하여 칼로리를 계산할 수 있도록 하였다.

임상시험의 경우 1차 상지운동 시스템은 척수손상환자 9명을 대상으로 8주간 주3회 1시간 운동을 진행하였으며 2차 크로스핏 운동의 경우 뇌졸중 장애인 20명을 대상으로 12주간 주 2회 1시간 운동을 진행하였다. 두 실험 모두 RCT 연구로 실험군 대조군으로 나누어 진행하였고 운동 시작 전, 후로 체력평가를 진행하였다. 실험군의 경우 운동 중에 개발한 프로그램을 보면서 진행하게 하였고 대조군의 경우 프로그램없이 운동을 진행하게 하였다.

실험 결과 상지운동프로그램 실험에서는 실험군은 모든 평가에서 상승하였지만 대조군에는 유지하거나 떨어지는 결과를 보였고 두군 모두 유의한 차이는 보이지 않았다. 크로스핏 운동프로그램 실험에서는 실험군에서 모든 평가가 상승한 결과를 볼 수 있었고 일부평가에서 유의한 차이를 나는 것을 볼 수 있다. 반면 대조군의 경우 건측평가에서만 상승한 결과를 보여주었고 환측에서는 유지하거나 떨어지는 결과를 보였다. 모든 평가에서 유의한 차이는 볼 수 없었다.

본 연구에서 개발된 인공지능기반 동작분석 시스템은 재활운동에 효과적이라고 사료된다. 향후 인공지능기반 재활운동 시스템개발에 있어서 소중한 기초자료가 될 수 있을 것으로 보인다.

Key Words : 재활운동, 인공지능, 동작분석, 척수손상, 뇌졸중