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The effect of leap motion controller based exergame therapy on hand function, cognitive function and quality of life in older adults. A randomised trial

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Objective. To evaluate the effect of leap motion controller based exergame therapy (LMCBET) on hand function, cognitive function and quality of life (QoL) in older adults.
Design. A parallel, double-blind trial with participants allocated (1:1) to one of two groups as the structured exercise (SE) and LMCBET.
Setting. The study was conducted in "Barınyurt Nursing Home and Elderly Care Center" in Istanbul.
Participants. Thirty-two older adults who had adequate hand function, ability to follow commands, 24 points or more in the mini mental state examination (MMSE) were included and 30 were analyzed.
Interventions. SE Group performed a Structured Hand Exercise program while LMCBET group performed "ErgoActive" and "HandROM" exercise apps focusing on hand exercises and fine motor skills along 30-45 minute sessions, 2 days a week, over 8 weeks.
Main outcome measures. Participants were evaluated with box and block test (BBT), Purdue Pegboard test (PPT), hand dynamometer, Duruöz hand index (DHI), stroop test (ST), digit span test (DST), and World Health Organization QoL instrument-older adults module (WHO-QOL-OLD) at the beginning (T0), at 8 (T1), and 16 (T2) weeks after the study started.
Results. There were significant differences in BBT, PPT, DHI, and WHOQOL-OLD in the SE group ($p < 0.05$). BBT, right, left, couple, total scores of PPT, DHI and WHOQOL-OLD were found significant in the LMCBET group ($p < 0.05$). In Time*Group evaluations, there were no differences ($p > 0.05$).
Conclusions. SE and LMCBET were effective on hand function and QoL in healthy older adults.

Key words: exergaming, exercise, hand, quality of life, aged

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Contribution of paper

- LMCBET is a feasible and effective method for healthy older adults to improve the hand function and QoL.
- LMCBET is an alternative to conventional approaches and recommended as home exercises in rehabilitation.
- Further research should be conducted to evaluate the effect of

exergame therapy in adults more focusing on the cognitive improvements.

Abbreviations

ADL: activities of daily living
BBT: box and block test
DHI: Duruöz hand index
DST: digit span test
GDS: geriatric depression scale
LMC: leap motion controller
LMCBET: leap motion controller based exergame therapy
MMSE: mini mental state examination
PPT: Purdue Pegboard test
PRPS: Pittsburgh rehabilitation participation scale
QoL: quality of life
SE: structured exercise
ST: Stroop test
WHOQOL-OLD: World Health Organization quality of life instrument older adults module

INTRODUCTION

Aging is a natural process from adulthood to death, associated with decline in body functions which results in metabolic based diseases while having a remarkable impact on activities of daily living (ADL) and quality of life (QoL) [1]. The functional loss is mainly mediated by a decrease in sensory function, tendon reflexes, motor movements, cognitive function and result in fine and gross motor skill problems in ADL [2]. Hand grip strength is the main indicator of upper extremity strength, guides in evaluating life independence and cognitive aging [3]. The loss of two-way interaction between cognition and motor systems lead to disturbances in hand-eye coordination [4]. Along with physiological changes and cognitive decline, unfavorable alterations in motor planning, muscular endurance, and coordination may become more prominent in aging individuals and subsequently affect ADL [4]. However, the amount of ADL can be preserved by preventing the decrease in cognitive function [4,5]. Depression, another common age-related condition, can be developed via the loss of social communication, decreased self-esteem and courage plus altered biologic or physical function which results in limitation of the daily activities [6]. Due to decreased productivity and economic income, elderly starts dealing with the feel of uselessness which might result in isolated lifestyle or low attendance to the activities which causes other physical limitations in the long term [6]. With an altered neurochemical changes in the brain and the prolonged burden of sleep deprivation, aged individuals seem more prone to depression compared to younger individuals in accordance with decline in cognitive and physical function [6]. Based on this multifactorial disease feature, the rehabilitation process requires a multidisciplinary intervention as well as adapting medication usage, psychotherapy, cognitive approaches, social structure, self-confidence, nutritional support and most importantly, incorporating physical activity into daily routine [6]. While an elderly with a depression is facing with decreased performance due to the laziness and loss of motivation in later stages of the disease, the rehabilitation approaches should mainly focus on improving the function, cognition, motivating the person for social life attendance by incorporating the family and friend support to the process [6].

In parallel with the high impact of physical activity on QoL and cognition, interventions that focus on muscle function and strength are essential [7]. While exercise promotes neuroplasticity, blood circulation, the prevention of the chronic and cognitive diseases, structured exercise (SE) programs which are more preferable as a supervised exercise than a home exercise alone, can be applied in geriatric rehabilitation [8]. In a study examining the effectiveness of physical exercises in conjunction with a mental task, the combination of the cognitive and physical training is emphasized to improve cognition [9]. So focusing on various domains in rehabilitation can provide better outcomes instead of a single intervention alone [9]. It is also suggested that a combination of mobility, endurance, strength and aerobic exercises two/three times a week can improve mental health and QoL, while some studies explain the sedentary lifestyle in older adults as reduced motivation for movement [10,11].

Technology and game-based rehabilitation systems such as exergames can contribute to the development of both motor and cognitive functions with task-specific upper extremity exercises, by providing fun and challenging tasks that enable participants to rehabilitate without being aware of it [12]. The leap motion controller (LMC) can be used for hand exercises with advantages like cheap, no sensor needed, portable, safe and inspiratory environment [13]. The LMC based exergame therapy (LMCBET) is widely used, particularly in pediatric rehabilitation, to evaluate hand fine motor function [14]. Although the LMCBET has been applied for a specific disease group in previous studies [14,15], to our knowledge, there is no study focusing on virtual reality and cognitive function in healthy older adults. This study is intended to be a pioneering study.

The aim of this study was to evaluate the effectiveness of the SE and LMCBET in hand function, cognitive function and QoL in older adults.

METHODS

Study design

This study is a parallel, double-blind (participants and evaluators) trial with participants allocated (1:1) to one of two groups.

Study population

The study was conducted with participants who were living in Nursing Home and Elderly Care Center. The study was conducted between June 2021 and March 2022.

The participants who were ≥ 50 years old, had hand and cognitive function ability to follow commands, and got ≥ 24 points in the mini mental state examination (MMSE) were included in the study. The exclusion criteria were defined as presence of exercise contraindications, getting ≥ 14 points on the geriatric depression scale (GDS), diagnosis of dementia and acute upper extremity injury.

Thirty-nine participants were screened, thirty two participants who met the inclusion criteria were included in the study. During the study process, one is excluded due to not following the exercise sessions and one is dropped out due to the COVID-19 related death. In total, the study was completed with 30 participants. The algorithm for allocation was shown in Figure 1.

The sample size was determined using the "G*power sample size calculator" and was calculated as 30 subjects using "ANOVA: Repeated measures, within-between interaction" design for two groups, with a power of 95% ($\alpha = 0.05$, $\beta = 0.95$) and an effect size of 0.35 [16].

Experimental design

Thirty two participants were included in the study and

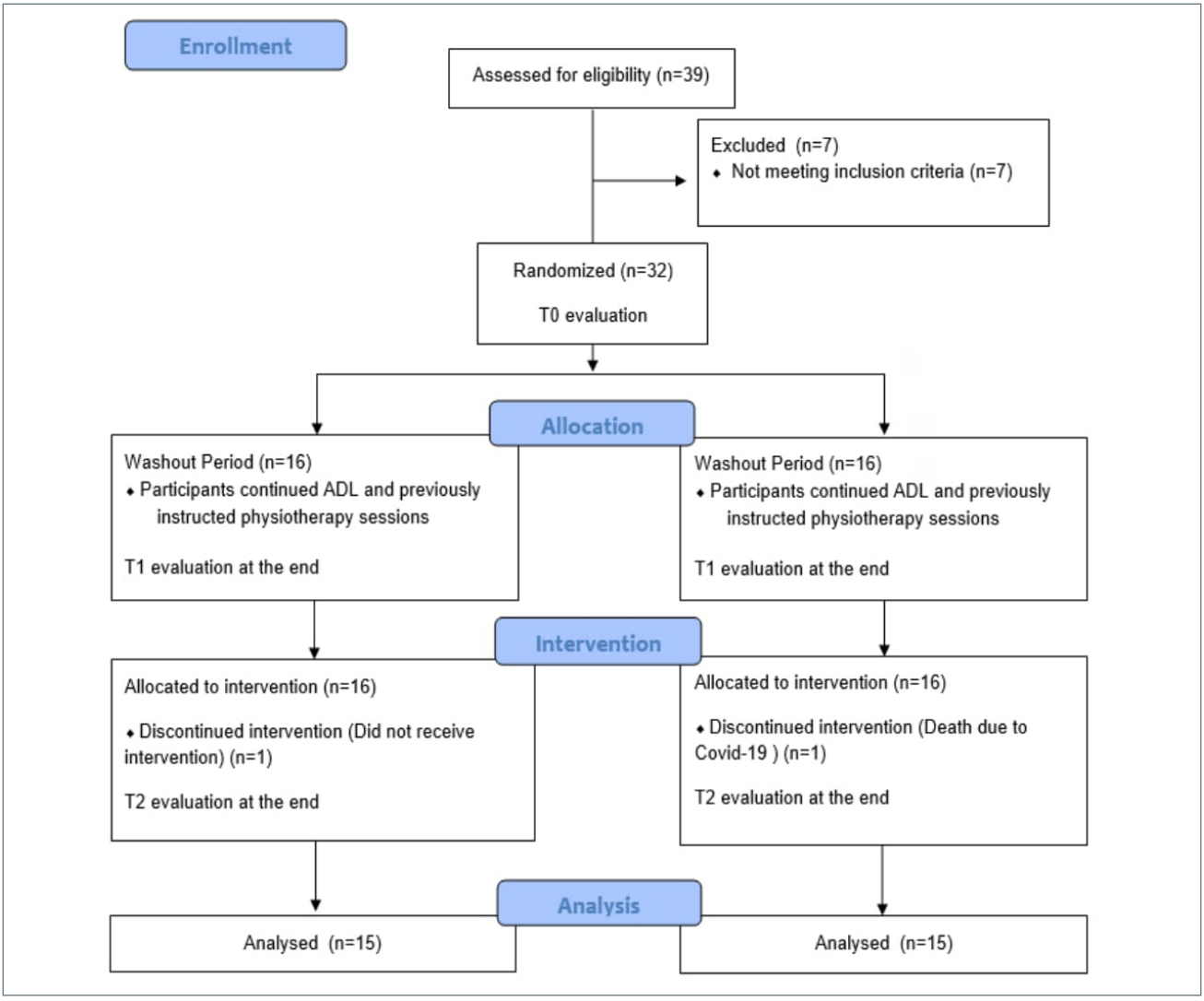


Figure 1. Flow-chart for the participant allocation. RCT: randomized controlled trial.

were randomly divided into two groups using block randomization in Microsoft Excel 'RAND(WS)' function as the SE (n = 16) and LMCBET group (n = 16). Participants were evaluated at the beginning of the study (T0), at 8 (T1), and 16 (T2) weeks after the study started.

T0-T1 period

An 8-week active washout period in which both groups resumed their usual physical activity routines and ADLs. The logic of the active control period was dissociating the affect of the current daily life activities or the experimental intervention prescribed by the study protocol. Because of the participants were already taking a physical therapy or a group exercise session based on balance or postural parameters twice a week in the usual nursing home setting, the continuation of the routine was asked from all participants for the first 8 weeks and then they randomized into two groups. This period was thought-out to answer the question of "Did the development in the outcome measures is occured under favour of the personal daily routine activities or one or two of the structured exercise programs?" to increase the reliability of the achievements. Adding the control group into rehabilitation design was suggested in some other studies which practiced the exergame systems [15].

T1-T2 period

An intervention period in addition to the routine physical activities of participants. Participants in the SE Group performed a structured hand exercise program in the form of 30-45 minute sessions, 2 days a week, over 8 weeks. Participants in the LMCBET Group performed "ErgoActive" and "HandROM" exercise apps in the form of a 30-45 minute session, 2 days a week, over 8 weeks.

SE Protocol

Structured hand exercises were applied in 30-45 minute sessions, 2 days a week, over 8 weeks. They consisted of *warm-up, basic exercise*, and *cognitive exercise phases* (Tab. I). Each exercise was performed as 10 repetitions. The weights were used in the wrist exercises and the difficulty level of the cognitive games were started at the intensity that the participants could tolerate and adapt in the first session, in accordance with the beginner level. Exercise intensity was increased in accordance with the BORG scale [17].

LMCBET protocol

The LMC device, which was the design of the "Becure (formerly Fizyosoft)" system, whose validity and reliability was specified, and which was developed with the cooperation of a physiotherapist and an engineer, was used in this protocol [18].

"ErgoActive" and "HandROM" exercise apps focusing on hand exercises and fine motor skills were performed in the form of an average 30-45 minute session, 2 days a week, over 8 weeks.

"ErgoActive"

It includes 6 different exercises (Master Chef, Key Flip, Piano, Hold Book, Pinch Peg, and Hold And Put) allowing participants to perform similar movements in their ADL (Tab. II).

"HandROM"

It includes 4 different exercises (LeapBall, LeapPong, LeapMaze, CatchaPet) allowing participants to perform exercises and evaluates the range of motion (ROM) of the fingers and wrist (Tab. III).

Each exercise was performed first right and then left hand, respectively together with a certified physiotherapist who is blinded to the group randomisation. The intensity of the sessions and the level of the games were determined according to the cognitive and motor performance of the participants in the first session. After the first session trial, the number of targets or the duration was determined in accordance with the wrist angle values or the time he was able to focus on the task and continue the game. Participants who were successful at the previous level, who could continue this success for a few sessions, and who were able to reach the goal with less verbal cues, were moved to the next level. The participant's ability to easily reach the goal in the game was accepted as the necessary criterion for transitioning to the next level. In case of high difficulty during the session, it was returned to a lower level.

Outcome measurements

Demographic information was taken from participants at the beginning of the study and Pittsburgh rehabilitation participation scale (PRPS) was taken at the end of each session. Participants were evaluated by a physiotherapist in terms of gross motor skills and coordination with box and block test (BBT), in terms of fine motor skills and coordination with Purdue Pegboard test (PPT), in terms of grip strength with hand dynamometer, in terms of hand activity limitation and daily living skills with Duruöz hand index (DHI), in terms of executive functions with Stroop test (ST), in terms of attention with digit span test (DST), and in terms of QoL with World Health Organization QoL instrument-older adults module (WHOQOL-OLD) at the beginning of the study (T0), at 8 (T1), and 16 (T2) weeks after the study started.

Demographic Information Form

It was prepared to record the sociodemographic characteristics of participants.

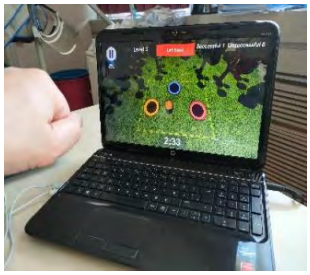
Table I. Structured hand exercise program.

Period	Exercises	Explanation
Warm up exercises	Wrist range of motion (ROM) Exercises 	Wrist flexion, extension, radial, ulnar deviation movements, 10 repetitions
	Finger ROM Exercises	Finger DIP, PIP, MCP joint flexion, extension, abduction, adduction exercises, 10 repetitions
	Stretching exercises	Wrist and finger stretching exercises, 10 repetitions
	Finger-finger exercise	Touching the thumb and other fingertips alternately (straight and reverse), acceleration in movement as you continue, 10 repetitions
	Pencil grip exercise 	Picking up a pencil from the table and dropping it to another spot (relaxation), 10 repetitions
	Pen rotation exercise	Rotating the pen with the thumb and forefinger, 10 repetitions
Basic exercises	Wrist resistance exercises 	Wrist strengthening exercises including flexion, extension, radial and ulnar deviation, pronation and supination movements were performed with the help of a resistance band and/or dumbbells
	Grip exercise	Bottle grip, hold and release exercise with palms facing up, 10 repetitions
	Money stringing exercise 	Exercise to sort coins from largest to smallest, 10 repetitions
	Latch exercise 	Holding the latch with the thumb-index finger, thumb-middle finger, thumb-ring finger and thumb-little fingers, respectively, and latch pinching exercise, 10 repetitions
	Ball exercises 	Power grip, pinch, table roll, thumb roll, finger squeeze, 10 repetitions
	Displacement exercise	Exercise with the command "Take 10 small objects one by one from the table, hold them all in your palm, and then put them on the table one by one"
	Stretching exercise	Reach out, fold and unfold the papers hanging in different spots or held by the physiotherapist and lay them on the table
Cognitive exercises	Box/board game	Box games included the finger, hand movements to place the pins or the objects on the board and tasks that require attention, intelligence and decision making
	Card matching game	Participants were asked to turn and match the same figures or the numbers written on the card. This allowed working on the cognitive function as well as the supination and pronation of the forearm

Table II. LMCBET- "ErgoActive".

Exercises	Explanation
Master chef 	Participants were asked to hold the knife, cut the cheese or tomato on the screen, in addition, in the later stages of the game, break eggs, add salt, stir with a spoon, and eventually make an omelet. Various wrist exercises were aimed
Key flip 	Participants were asked to hold the key, insert it into the door hole, and turn it to open. Supination, pronation and three finger (1, 2, 3 finger) grip movements were aimed
Piano 	Participants were asked to play the piano by pressing the specified number of keys. Finger flexion and extension exercises were aimed
Hold book 	Participants were asked to grasp the book on the table and place it in the indicated compartments by flashing on the shelf. Grip and alignment skills were aimed
Pinch peg 	Participants were asked to grasp the specified sticks with a pinching grip and place them in the specified holes. Game time and number of sticks have been adjusted beforehand. Aimed at improving pinch-type grip and alignment
Hold and put 	The participants were asked to grasp the glass on the table with their palms and to leave it on the shelf by flashing it in the specified area. Cup target amount, elapsed time was adjusted before the game, right or left hand selection was made. Palm grip, alignment and motion control were aimed

Table III. LMCBET- "HandROM".

Exercises	Explanation
Leap ball 	Participants were asked to grasp the ball and throw it to the hole on the screen at the first stage. In the later stages of the game, the size of the ball is minimized and the amount of the balls and the holes is increased up to three with color variations (red, blue, yellow). The participants were asked to match the ball and the hole colors to achieve the combined physical and cognitive tasks
LeapPong 	Participants were asked to hit and direct the ball to the opponent player's side which is controlled by the computer system. The handle is controlled and moved by the wrist flexion, extension, ulnar, radial deviation, supination and pronation
Leap maze 	Participants were asked to place his/her hand 25 cm above with palm down and direct the ball on the narrow roads with obstacles to reach to the maze with the supination, pronation, flexion and extension movements of the hand and forearm. The attention is needed to not let the ball drop in water
CatchaPet 	Participants were asked to hit the rabbits, feed the fish or the dog with the wrist flexion and extension movements. The progression is done with the increase at the joint angles or the target tasks

PRPS

It is a 6-likert scale (1-none/6-excellent) and examines the participation in therapy and motivation. Test duration is 5 minutes [19].

BBT

It examines unilateral gross motor skills [20]. A stopwatch, a wooden box with a middle section, and 150 wooden cubes are the required materials. It lasts 2-5 minutes. BBT can be applied between the ages of 6 and 65. Within 60 seconds, which is kept by the stopwatch, it is requested to pass the cubes one by one from one compartment to the other and the number of cubes is noted. It is applied separately for both extremities [21].

PPT

It consists of a board with holes into which metal pegs are inserted by the patient. It comes with washers and collars to be placed on the pins. PPT measures movements, coordination and speed of hand and finger dexterity [22]. The participant is asked to use their right hand to properly insert as many pins as possible into the holes within 30 sec. Then the same process is repeated for the left hand. The participant is then given 30 sec to simultaneously place the pins, washers and collars using both hands. At the final stage, the participant is asked to perform a combined task with the pins within prescribed 60 sec.

Grip strength.

A hand dynamometer (pinch meter gauge; Jamar®

Hand Dynamometer - Hydraulic - 200 lb Capacity. Patterson Medical Illinois, USA) was used to determine the grip strength. The shoulder was measured in adduction and neutral rotation, the elbow was in 90° flexion, and the forearm and wrist were measured in neutral position. Each test was repeated three times and the average score was obtained for the affected extremity [23].

DHI

It is an 18-item, self-answered scale that assesses hand activity limitations and its effect on ADL. It is scored from 0 to 90, and high scores indicate low functioning [24].

ST

It measures the processing speed, the ability to suppress habitual behavior, focused attention, the ability to do unusual behavior, the ability to change the perceptual setup according to changing demands, and under a disturbing effect [25,26].

DST

It consists of forward and backward number range, and evaluates attention [27]. Numbers 1 to 9 are said in a predetermined and mixed order. In the forward span, it is expected to repeat the numbers in the same order. In the backward span, it is expected to say the numbers from the back to the beginning. The point corresponding to the last correctly known line is recorded as the score.

WHOQOL-OLD

Evaluates QoL in elderly individuals. WHOQOL-OLD consists of 6 sections: sensory skills, autonomy, past-present-future activities, social participation, death and relationships, and each section contains 4 items with a total of 24 questions [28].

Statistical analysis

IBM SPSS (statistical package for social science) version 25.0 was used for statistical analysis. Kolmogrov Smirnov was used for normality assessment and all variables were found in normal distribution. Mean, standard deviation and percentage values were presented in the descriptive statistics of the data. The nominal data of the independent variables were evaluated with the Chi-Square test, and the numerical data were evaluated with the Independent Sample-T Test. Time-dependent differences within groups were analyzed with Two-Way Repeated Measure ANOVA. Intention to treat analysis is performed by adjusting time as dependent and group as independent variable to use Time*Group variable for analysis with intent to view the effect of the interventions. Time*Group interactions between groups were analyzed with MANOVA. Bonferroni correction was used for Post-Hoc tests. The significance value was accepted as $p < 0.05$.

RESULTS

Demographic data

Demographic datas of the participants were shown in Table IV. There was no statistically significant difference in terms of age, gender, MMSE, education, job, history of injury, history of upper extremity surgery, and PRPS between groups ($p > 0.05$).

Within group differences

Within-group differences in the SE Group were shown in Table V. There were significant differences in terms of BBT, PPT, DHI, and WHOQOL-OLD in favor of the T1-T2 period ($p < 0.05$). There were no differences in terms of grip strength, ST and DST ($p > 0.05$).

Within-group differences in the LMCBET group were shown in Table VI. Significant differences in terms of BBT, right, left, couple, and total scores of PPT, DHI, and WHOQOL-OLD were found in favor of the T1-T2 period ($p < 0.05$). There were no differences in terms of grip strength, ST and DST ($p > 0.05$).

Between group differences & time*group interaction

Between-group differences and Time*Group interactions were shown in Table VII. In T0, there were significant differences in terms of PPT-Both hands score and ST-Color time score in favor of the LMCBET Group ($p < 0.05$). In T1, significant differences were found in terms of PPT-Both hands score and DHI in favor of the LMCBET group ($p < 0.05$). In T2, there were no differences between groups ($p > 0.05$). In Time*Group evaluations, no difference was found ($p > 0.05$).

DISCUSSION

In the present study, we investigated the effectiveness of the LMCBET in hand function, cognitive function and QoL in healthy older adults. We observed that SE and LMCBET were effective on hand function and QoL in healthy older adults.

Degeneration in the central nervous system begins to progress with aging, causing loss of muscle mass and strength, decrease in coordination, fine motor skills, hand sensation, and ultimately loss of manual function in ADL [29]. In a study involving 24 older adults to evaluate hand pinch and grip strength, a correlation was found between the DHI and grip strength parameters, and it was suggested that grip strength is the main predictor of manual function [29]. In our study, while there were

Table IV. Demographic data description.

		SE group (n = 15)	LMBET group (n = 15)	x/t	P value
Age (Avg ± SD)		75.93 ± 8.85	73.73 ± 12.46	0.557	0.582
Gender (n / %)	Female	5/33.3	9/60	2.143	0.143
	Male	10/66.7	6/40		
MMSE (Avg ± SD)		25.86 ± 1.68	26.53 ± 1.59	-1.112	0.276
Education (n/%)	Illiterate	0/0	1/6.7	4.154	0.527
	Primary school	7/46.7	1/6.7		
	Middle school	1/6.7	6/40		
	High school	6/40	7/46.7		
	University	1/6.7	0/0		
Job (n/%)	Housewife	10/66.7	2/13.3	11.273	**0.010***
	Officer	1/6.7	0/0		
	Small business	1/6.7	5/33.3		
	Self-employment	3/20	8/53.3		
History of injury (n/%)	No injury	13/86.7	10/66.7	1.725	0.422
	Hand and wrist tendon injury	1/6.7	2/13.3		
	Shoulder fracture, subluxation or frozen shoulder	1/6.7	3/20		
History of surgery (n/%)	Yes	0/0	0/0	--	--
	No	15/100	15/100		
PRPS (n/%)	None	0/0	0/0	5.943	0.114
	Poor	0/0	0/0		
	Fair	3/20	2/13.3		
	Good	6/40	2/13.3		
	Very good	4/26.7	3/20		
	Excellent	2/13.3	8/53.3		

SE: structured exercise; LMCBET: leap motion based exergame; Avg: average; SD: standard deviation; n: number of persons; %: percentage; MMSE: mini-mental state examination; PRPS: Pittsburgh rehabilitation participation scale- *p < 0.05.

Table V. Within group differences in SE Group.

		T0	T1	T2	F	Effect size (Cohen's d)	P value
		Avg ± SD	Avg ± SD	Avg ± SD			
Box and block test	Right	34.00 ± 14.06	32.73 ± 16.98	36.80 ± 16.26	4.421	0.240	**0.025***
	Left	28.06 ± 10.09	28.33 ± 13.49	32.26 ± 14.41	5.529	0.283	**0.015***
Purdue Pegboard test	Right	6.60 ± 2.89	6.13 ± 3.64	7.66 ± 3.47	9.929	0.415	**0.001***
	Left	5.80 ± 2.93	6.00 ± 3.42	7.20 ± 3.52	8.767	0.385	**0.001***
	Both hands	3.20 ± 1.61	3.06 ± 1.62	4.13 ± 2.26	7.655	0.353	**0.006***
	Combined	1.73 ± 1.38	1.80 ± 1.56	2.46 ± 1.84	6.241	0.308	**0.009***
	Total	22.53 ± 12.28	22.53 ± 14.19	28.86 ± 16.06	15.000	0.517	**0.000***
Grip strength	Right	0.37 ± 0.17	0.34 ± 0.18	0.35 ± 0.17	0.491	0.034	0.547
	Left	0.34 ± 0.14	0.32 ± 0.14	0.34 ± 0.16	0.702	0.048	0.462
Duruöz hand Index		25.73 ± 16.93	26.80 ± 17.45	21.46 ± 17.16	15.223	0.521	**0.001***
Stroop test	Reading time	53.15 ± 39.88	53.37 ± 42.19	61.34 ± 49.84	1.806	0.114	0.200
	Colour time	166.69 ± 82.91	160.24 ± 100.65	168.17 ± 120.59	0.068	0.005	0.921
	Time difference	76.59 ± 67.91	63.58 ± 96.72	68.78 ± 117.47	0.300	0.021	0.659
Digit Span test	Forward	5.26 ± 1.48	5.20 ± 1.82	5.06 ± 1.90	0.566	0.039	0.554
	Backward	2.60 ± 1.76	2.66 ± 1.87	2.53 ± 1.92	0.286	0.020	0.726
WHOQOL-OLD		70.80 ± 9.42	69.80 ± 9.95	75.53 ± 11.63	13.401	0.489	**0.001***

SE: structured exercise; Avg: average; SD: standard deviation; n: number of persons; %: percentage; WHOQOL-OLD: World Health Organization quality of life instrument-older adults module. *p < 0.05.

Table VI. Within group differences in LMCBET group.

		T0	T1	T2	F	Effect Size (Cohen's d)	p value
		Avg ± SD	Avg ± SD	Avg ± SD			
Box and block test	**Right**	38.00 ± 10.67	38.33 ± 12.65	45.60 ± 12.79	10.974	0.439	**0.000***
	Left	34.46 ± 11.35	34.66 ± 10.56	39.06 ± 10.50	7.960	0.355	**0.003***
Purdue Pegboard test	**Right**	7.40 ± 2.74	7.86 ± 1.76	9.33 ± 2.25	8.760	0.385	**0.001***
	Left	7.40 ± 2.61	8.06 ± 2.49	8.66 ± 2.25	6.032	0.301	**0.009***
	Both hands	4.60 ± 2.02	4.73 ± 1.57	5.66 ± 2.09	9.333	0.400	**0.002***
	Combined	2.46 ± 0.99	2.44 ± 0.91	2.86 ± 0.99	3.308	0.191	0.054
	Total	29.33 ± 10.65	30.26 ± 8.77	35.13 ± 10.04	8.979	0.391	**0.003***
Grip strength	**Right**	0.39 ± 0.15	0.38 ± 0.14	0.39 ± 0.17	0.223	0.016	0.775
	Left	0.37 ± 0.13	0.36 ± 0.14	0.34 ± 0.14	1.542	0.099	0.232
Duruöz hand index		25.53 ± 10.99	15.73 ± 10.97	11.33 ± 8.84	25.386	0.645	**0.000***
Stroop test	**Reading time**	54.67 ± 48.96	64.81 ± 56.33	55.43 ± 39.62	2.575	0.155	0.101
	Colour time	114.48 ± 50.25	110.60 ± 30.71	103.02 ± 42.69	0.577	0.040	0.517
	Time difference	79.27 ± 64.04	87.75 ± 0.97	56.96 ± 67.19	2.478	0.150	0.131
Digit Span test	**Forward**	4.86 ± 1.59	5.00 ± 1.60	5.06 ± 1.03	0.237	0.017	0.758
	Backward	3.00 ± 1.73	3.00 ± 1.41	2.93 ± 1.33	0.055	0.004	0.899
WHOQOL-OLD		71.13 ± 11.10	69.93 ± 11.24	77.60 ± 7.25	21.832	0.609	**0.000***

LMCBET: leap motion controller based exergame therapy; Avg: average; SD: standard deviation; n: number of persons; %: percentage; WHOQOL-OLD: World Health Organization quality of life ınstrument-older adults module. *p < 0.05.

significant improvements in hand activity limitations after both treatments, we did not find any significant change in hand grip strength [29]. We believe that older adults tolerance to exercises requiring muscular endurance, such as holding the hand 25 cm above the LMC device during playtime, and difficulties during hand resistance training is significantly reduced [29]. With aging, motor deficiencies, cognitive impairments, and impairments in function and QoL can be seen [30]. In particular, functional impairment may affect bilateral and coordinated hand movements more. In our study, we observed that one-handed tasks performed in a shorter time compared to two-handed tasks in PPT [30]. McGrath et al., reported that the amount of grip strength in the elderly with appropriate motor unit and skeletal muscle activation was half that of healthy older adults [31]. It is important to consider a holistic approach in rehabilitation, as hand functions can be affected by dominant hand use, age, gender, and ADL [32].

Cognitive decline, seen in 15-20% of older adults over the age of 65, is another complication associated with aging and is affected by the reduction in ADL [33]. A SE program may result in better improvements in hand and cognitive function in people with cognitive decline [33]. It has been reported that for every 5 kg increase in muscle strength in elderly individuals, the risk of cognitive decline will decrease by 3% [30]. Therefore, engaging in regular physical activity can prevent neurodegeneration and cognitive decline, thereby preventing the consequences of aging on the brain and muscles [30]. In our study, we examined the effects of LMCBET and SE on hand functions and compared their superiority over each other. Participants who underwent SE enjoyed PRPS and showed significant improvements in hand function and QoL outcomes, although there was no significant change in grip strength. We observed that SE is beneficial in improving the QoL secondary to the improvement in hand functions in the elderly.

In recent years, the use of exergames such as LMCBET, which can be used to increase motivation and movement in all age groups, especially for hand functions, is gaining popularity [34]. Yıldırım et al. reported that LMCBET provides improvements in ROM, fine motor skills, hand grip, and compression strength [15]. Similar to studies using LMCBET and reporting improvements in hand function and bilateral coordination, we achieved positive results in the dual task of PPT using LMCBET in older adults [35,36]. We think that this result is due to the fact that exergame includes both cognitive and motor activities. 71.7% of the participants find the exergames easy to use and fun, and want to repeat the game [33]. The similarity of PRPS results in individuals who underwent LMCBET and SE in our study suggests that the use of exergame in rehabilitation may also be preferred by older adults. On the other hand, it is claimed that even though exergames do not include all ADLs, they can improve non-repetitive ADL by improving their general problem-solving skills [32]. We

Table VII. Between group differences and Time*Group interactions.

		Between-groups									Time*Group interactions				
		T0			T1			T2			Mean Difference	CI (lower to upper)	F	Effect Size (Cohen's d)	P value
		SE group (n = 15)	LMCBET group (n = 15)	P value	SE group (n = 15)	LMCBET group (n = 15)	P value	SE group (n = 15)	LMCBET Group (n = 15)	P value					
		Avg ± SD	Avg ± SD		Avg ± SD	Avg ± SD		Avg ± SD	Avg ± SD						
Box and block test	**Right**	34.00 ± 14.06	38.00 ± 10.67	0.388	32.73 ± 16.98	38.33 ± 12.65	0.315	36.80 ± 16.26	45.60 ± 12.79	0.111	6.133	-4.035 to 16.302	2.245	0.074	0.119
	Left	28.06 ± 10.09	34.46 ± 11.35	0.114	28.33 ± 13.49	34.66 ± 10.56	0.163	32.26 ± 14.41	39.06 ± 10.50	0.151	6.511	-2.051 to 15.074	0.034	0.001	0.961
Purdue Pegboard test	**Right**	6.60 ± 2.89	7.40 ± 2.74	0.444	6.13 ± 3.64	7.86 ± 1.76	0.108	7.66 ± 3.47	9.33 ± 2.25	0.131	1.400	-0.629 to 3.429	1.520	0.051	0.229
	Left	5.80 ± 2.93	7.40 ± 2.61	0.126	6.00 ± 3.42	8.06 ± 2.49	0.069	7.20 ± 3.52	8.66 ± 2.25	0.186	1.711	-0.381 to 3.803	0.752	0.026	0.466
	Both hands	3.20 ± 1.61	4.60 ± 2.02	**0.046***	3.06 ± 1.62	4.73 ± 1.57	**0.008***	4.13 ± 2.26	5.66 ± 2.09	0.064	1.533	0.204 to 2.862	0.221	0.008	0.745
	Combined	1.73 ± 1.38	2.46 ± 0.99	0.107	1.80 ± 1.56	2.44 ± 0.91	0.210	2.46 ± 1.84	2.86 ± 0.99	0.466	0.578	-0.349 to 1.505	0.617	0.022	0.531
	Total	22.53 ± 12.28	29.33 ± 10.65	0.117	22.53 ± 14.19	30.26 ± 8.77	0.083	28.86 ± 16.06	35.13 ± 10.04	0.211	6.933	-1.931 to 15.797	0.280	0.010	0.714
Grip strength	**Right**	0.37 ± 0.17	0.39 ± 0.15	0.679	0.34 ± 0.18	0.38 ± 0.14	0.535	0.35 ± 0.17	0.39 ± 0.17	0.595	0.033	-0.090 to 0.155	0.119	0.004	0.888
	Left	0.34 ± 0.14	0.37 ± 0.13	0.653	0.32 ± 0.14	0.36 ± 0.14	0.455	0.34 ± 0.16	0.34 ± 0.14	1.000	0.021	-0.086 to 0.128	1.498	0.051	0.234
Duruöz hand index		25.73 ± 16.93	25.53 ± 10.99	0.061	26.80 ± 17.45	15.73 ± 10.97	**0.047***	21.46 ± 17.16	11.33 ± 8.84	0.052	-10.467	-20.969 to 0.036	0.354	0.012	0.582
Stroop test	**Reading time**	53.15 ± 39.88	54.67 ± 48.96	0.927	53.37 ± 42.19	64.81 ± 56.33	0.534	61.34 ± 49.84	55.43 ± 39.62	0.722	2.346	-31.470 to 36.162	3.100	0.100	0.058
	Colour time	166.69 ± 82.91	114.48 ± 50.25	**0.046***	160.24 ± 100.65	110.60 ± 30.71	0.078	168.17 ± 120.59	103.02 ± 42.69	0.059	-55.669	-106.103 to -5.235	0.217	0.008	0.781
	Time difference	76.59 ± 67.91	79.27 ± 64.04	0.912	63.58 ± 96.72	87.75 ± 0.97	0.442	68.78 ± 117.47	56.96 ± 67.19	0.738	5.009	-51.359 to 61.377	1.339	0.046	0.267
Digit Span test	**Forward**	5.26 ± 1.48	4.86 ± 1.59	0.484	5.20 ± 1.82	5.00 ± 1.60	0.752	5.06 ± 1.90	5.06 ± 1.03	1.000	-0.200	-1.322 to 0.922	0.645	0.023	0.511
	Backward	2.60 ± 1.76	3.00 ± 1.73	0.536	2.66 ± 1.87	3.00 ± 1.41	0.587	2.53 ± 1.92	2.93 ± 1.33	0.513	0.378	-0.838 to 1.593	0.035	0.001	0.955
WHOQOL-OLD		70.80 ± 9.42	71.13 ± 11.10	0.930	69.80 ± 9.95	69.93 ± 11.24	0.973	75.53 ± 11.63	77.60 ± 7.25	0.564	0.844	-6.518 to 8.206	0.764	0.027	0.417

SE: structured exercise; LMCBET: leap motion controller based exergame therapy; Avg: average; SD: standard deviation; n: number of persons; %: percentage; WHOQOL-OLD: World Health Organization quality of life instrument-older adults module. *$p < 0.05$.

found that LMCBET improved QoL and hand function. We are of the opinion that LMCBET in healthy older adults can provide significant improvements in hand function and QoL without major differences in grip strength and cognitive function.

STRENGTHS OF THE STUDY

This study's capacity to evaluate both cognitive and functional outcomes and to compare LMCBET *versus* SE in healthy older adults was one of its great strengths. The second strength of the study was that we added some cognitive tasks to equate the SE group with the LMCBET group to avoid any bias during the study. The third strength of the study was the better results obtained in dominant manual tasks, showing that focusing on ADL in healthy older individuals should be one of the main goals of rehabilitation programs.

LIMITATIONS OF THE STUDY

The limitation of this study is the inability to use an objective neuroimaging tool for cognitive outcome measures. And since the loss of achievements in elderly is expected without the continuation of the intervention, the follow up period might be needed and maybe added into the study design in our future studies.

CONCLUSIONS

In conclusion, SE and LMCBET can be effective in increasing hand function and QoL in healthy older adults. Consequently, LMCBET can be used as an alternative to conventional approaches and recommended as home exercises in rehabilitation.

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Conflict of interest statement
The authors declare no conflict of interest.

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Author contributions
SA: the conception and design of the study, acquisition of data, drafting the article or revising it critically for important intellectual content, final approval of the version to be submitted; DT: the conception and design of the study, acquisition of data, the analysis and interpretation of data, final approval of the version to be submitted; FH: the conception and design of the study, drafting the article or revising it critically for important intellectual content, final approval of the version to be submitted; MB: the analysis and interpretation of data, drafting the article or revising it critically for important intellectual content, final approval of the version to be submitted.

Ethical consideration
The protocol of the study was registered at ClinicalTrials.gov (NCT05317377). This trial was approved by the Non-interventional Ethics Committee at Istanbul Medipol University, Turkey (protocol number: E-10840098-772.02-3137).
The research was conducted ethically, with all study procedures being performed in accordance with the requirements of the World Medical Association's Declaration of Helsinki.
Written informed consent was obtained from each participant/patient for study participation and data publication.

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