



The acute effects of action observation training on upper extremity functions, cognitive processes and reaction times: a randomized controlled trial

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Aim: To investigate the acute effects of action observation training on upper extremity functions, cognitive functions and response time in healthy, young adults. **Materials & methods:** A total of 60 participants were randomly divided into five groups: the self-action observation group, action observation group, action practice group, non-action observation group and control group. The Jebsen–Taylor hand function test (JTHFT), nine-hole peg test, serial reaction time task and d2 test of attention were applied to the participants before and after the interventions. **Results:** JTHFT performance with both non-dominant and dominant hands improved significantly compared with baseline in all groups ($p < 0.001$). JTHFT performance with non-dominant and dominant hands differed between the groups ($p < 0.001$). **Conclusion:** Action observation training seems to enhance the performance of upper extremity-related functions. Observing self-actions resulted in statistically significant positive changes in more variables compared with other methods. However, its clinical effectiveness over the other methods should be investigated in future long-term studies.

Clinical Trial Registration: NCT04932057 (ClinicalTrials.gov)

First draft submitted: 22 April 2022; Accepted for publication: 17 June 2022; Published online: 30 June 2022

Keywords: action observation • neuroscience • reaction time • selective attention • upper extremity

Observing the activities of others engages an extended parieto-premotor brain network known as the action observation network, which overlaps somewhat with the cortical network recruited for action preparation and execution [1,2]. Sensorimotor activity during action observation may enhance action-related perception [3]. Predictive coding is a computational model of cognition and an effort to explain human behaviors and thoughts in terms of calculations performed by the brain [4]. According to the predictive coding hypothesis, other people's action sensory results are compared with sensory predictions created by the same hierarchical neuronal machinery for movement planning and execution [5,6]. Action observation training can be used to create complementary responses in a turn-taking way (for example, in sports) or to synchronize our movements with those of others at the same time (e.g., when handling an object) [7].

The role of attention seems to be a critical issue in converting observation into action. Activation in the brain during action observation is, in a way, automatic; in other words, even if an individual has no intention of acting on the perceived stimuli, this process occurs. On the other hand, when we engage with complicated surroundings to achieve specific activities, our actions must be directed toward the correct task at the right time. Consequently, selection mechanisms have developed to allow goal-directed behavior sequentially [8]. It has been found that diverting attention from an action observation task to a second cognitive task affects different parameters of the resonant response, preserving time course and muscle selection while drastically reducing the excitability of spinal and cortical motor neurons, as well as the kinematic specificity of the response [9]. At the same time, it could be argued that watching goal-directed videos, which is the basis of action observation training, may enhance attention,

an essential cognitive function. Evidence suggests that action observation training can be an effective type of cognitive training to complement physical practice to facilitate desired behavior outcomes [10].

To accomplish everyday functional activities, skilled arm and hand mobility is essential [11], requiring high cognitive processing [12,13]. Most people with neurological conditions have varying degrees of disability related to the upper extremities [14]. Therefore, most rehabilitation programs target improving upper extremity functions. Recent evidence suggests that action observation training is a promising tool for this goal [15,16]. However, the optimal program is not known. Additionally, what should be observed and how the movement should be observed have rarely been studied. While some studies show that it is more effective if people watch their videos [17,18], it is also reported that this is not the case [19]. In addition, even though action observation training can improve upper extremity function [20–21], there is limited evidence of its effects on cognitive functions. Since upper extremity and cognitive functions are associated with each other, and while performing action observation training high cognitive resources are used, the authors speculate that action observation training would improve cognitive functions in parallel with upper extremity function.

Overall, the present study aimed to investigate the acute effects of action observation training on upper extremity functions, cognitive functions and response time in healthy, young adults. It was hypothesized that action observation treatments would improve upper extremity functions compared with watching natural images and controls. The study's second hypothesis was that observing self-videos could improve performance better than observing someone else. The authors thought that if these hypotheses are confirmed even in healthy, young adults, these results will form the basis for full-scale randomized controlled trials in people with different neurological conditions with upper extremity dysfunction.

Materials & methods

Study design & ethical considerations

This study was a randomized controlled trial, and Dokuz Eylul University Ethical Committee approved its protocol (No.: 5845-GOA, Date: 21/12/2020, Clinical Trials ID: NCT04932057). Written informed consent was obtained prior to participation.

Participants

Healthy, young individuals were recruited for this study, which was advertised at three classes at Izmir Katip Celebi University. The researchers explained the study to the students in a course, and the volunteers and eligible students were invited to the laboratory to perform the assessments. Hand dominance was assessed by a modified version of the Edinburgh handedness questionnaire [22]. To minimize the effects of hand dominance, strongly right-handed (>laterality of 80%) healthy adults were included. Exclusion criteria included any neurological, orthopedic or systemic diseases that may affect upper extremity functionality and vision disorders.

Due to a lack of similar research previously, it was planned to include 12 participants per group, for a total of 60 participants, as was recommended by Julious [23].

Procedure

Participants were randomly divided into five groups – the self-action observation group, action observation group, action practice group, non-action observation group and control group – using a simple single sequence randomization method by a researcher (T Kahraman) who did not engage in assessment and intervention procedures. Participants were allocated to the groups according to the numbers 1–5, which they drew. They were allocated to the self-action observation group if they drew 1, the action practice group if they drew 2 and so on. Participants and outcome assessors were blinded to group allocation. Before the assignment, demographic information was gathered, and upper extremity functionality was assessed using the Jebsen-Taylor hand function test (JTHFT) and the nine-hole peg test (NHPT). Reaction time was measured using the serial reaction time task, and cognitive performance was assessed using the d2 test of attention (d2). Tests were administered in random order by using four sealed envelopes. Participants in the self-action observation group watched a video recording that was taken while they were performing JTHFT. The video was watched four times. The JTHFT performance of a third person was shown to participants in the action observation group. Similarly, they watched the video recording four times. Participants in the action practice group performed the JTHFT four more times after the baseline examination. Participants in the non-action observation group watched a slide show of landscape and nature pictures (i.e., motionless images), while participants in the control group waited in a silent and well-lighted room. Table 1 presents

Table 1. The procedure applied to the study groups.

Study groups	Intervention
Self-action observation group	They watched a video recording that was taken while they were performing JTHFT. The video was watched four times.
Action observation group	The participants in the action observation group watched the video recording of a third person's JTHFT performance four times.
Action practice group	They practiced JTHFT four times after the baseline assessment.
Non-action observation group	They watched a slide show of landscape and nature pictures (i.e., motionless images).
Control group	They waited in a silence in a well-lightened room after the baseline assessment.

JTHFT: Jebsen–Taylor hand function test.

the procedure applied to the study groups. All interventions, including the slide show in the non-action observation group and the waiting time of the control group, lasted approximately 25–30 min. After the interventions, the JTHFT, NHPT, serial reaction time task and d2 were applied to all participants. Previously, Schaefer *et al.* [24] investigated the within-session practice effects of JTHFT and indicated that four trials were required to achieve steady-state performance. Therefore, the amount of practice was designated according to their findings.

Outcomes

Upper extremity functions

The study's primary outcomes were upper extremity-related functions evaluated with JTHFT and NHPT. Jebsen *et al.* developed the JTHFT to objectively assess manual dexterity in activities of daily living [25]. The test can be administered quickly and requires only easily available items [26]. Previous research has shown the reliability of the test [27]. JTHFT has seven subtests: handwriting; turning over cards; picking up small, common objects; feeding simulation; stacking checkers; moving large, light objects; and moving large, heavy objects. Due to the large task execution differences between non-dominant and dominant hands, a low reliability writing subtest is commonly excluded [24,28]. Therefore, JTHFT performance was measured as the total completion time of the other six subtests [11]. Subtests were performed first with a non-dominant hand, followed by the dominant hand. A chronometer was used to track task completion.

The NHPT is one of the most commonly used assessment tools to evaluate hand dexterity, and it is found to be reliable and valid in young adults [29]. Nine small pegs are grasped from a container, inserted into a nine-hole grid and replaced in the container during the test. The test is performed first with the non-dominant hand, followed by the dominant hand as rapidly as possible, and a shorter test period implies greater dexterity [30]. A test procedure that was previously used by Oxford Grice *et al.* [30] was implemented.

Cognitive performance

A standard version of the d2 was used to assess some aspects of cognitive function. It examines sustained attention, visual scanning and speed of processing [31]. It is administered with a piece of paper and a pencil; the paper covers 14 rows with 47 'd' and 'p' characters with surrounding vertical dashes placed below or above the character. The target is the cancelation of 'd' characters with two dashes. Both dashes may be placed above, both dashes below, or one dash below and another above. The participant has 20 s for each line and is supposed to cancel the greatest number of target items possible within that time. The test evaluates the performance of the number of items processed, commission errors (canceled non-target items), omission errors (non-canceled target items), overall errors, percentage of errors (given by dividing the number of total errors by the total number of processed characters), total correct cancelation (given by the total number of processed characters – total errors) and fluctuation (the difference between the most character processed line and the least character processed line). The rationale for choosing the d2 was the possible effect of attention on action observation training performance. The test was found to be valid and reliable [32].

Reaction time

A serial reaction time task assesses participants' response times [33]. Four gray squares appear horizontally over a black background on a computer screen during the test. One of the squares becomes red for each trial, which indicates that it is the target square for the response. Participants placed four fingers of their right hands (starting

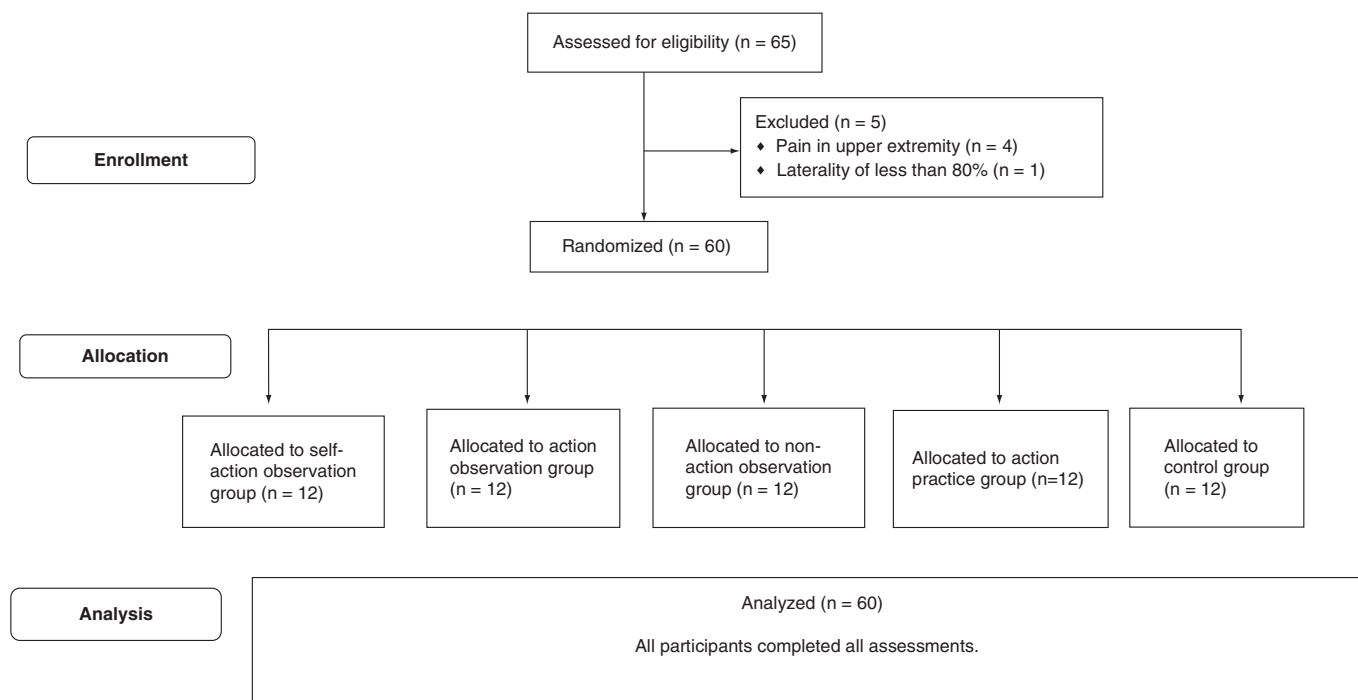


Figure 1. Flow diagram of the study participants.

from index to little finger) on the ‘V’, ‘B’, ‘N’, and ‘M’ letters of a keyboard. They were instructed to press the corresponding button when they saw the square turn red. Overall, mean reaction times were recorded [34].

Statistical analyses

The statistical analyses were performed using IBM SPSS Statistics for Windows (version 25.0, IBM Corp., NY, USA). The distribution of the collected data was checked by the Shapiro–Wilk test and by investigating distribution graphs. Due to the normal distribution, parametric tests were applied. Descriptive statistics were presented with mean and standard deviation. The paired-samples t-test was used to assess the difference between the baseline performance and the performance after the intervention within the groups. Delta values were calculated to analyze the difference by subtracting the baseline assessment value from the final assessment value. Continuous baseline variables and delta values were compared using one-way analysis of variance with a Bonferroni correction between the groups. The gender difference was analyzed using the chi-square test. The significance level was set at $p < 0.05$, and adjusted p-values are presented.

Results

A total of 60 healthy right-handed participants (32 female and 28 male; mean age: 21.32 ± 1.07 years) were included in the study (Figure 1). No significant difference was found in age, gender, height, weight and baseline test performances between the groups ($p > 0.05$). The demographic characteristics of the participants of the groups and baseline test performances are shown in Table 2.

The JTHFT performance with non-dominant and dominant hands improved significantly compared with baseline in all groups ($p < 0.001$). While there were significant decreases in the NHPT completion time with dominant and non-dominant hands in the self-action observation group (sAOG), the action observation group (AOG) and the action practice group (APG; $p < 0.05$), no significant difference was observed in the non-action observation group (nAOG) and control group (CG; $p > 0.05$). Significant improvements were observed in all variables of the d2 test of attention except errors of commission ($p = 0.809$) in the sAOG. Only the total correct variables significantly increased in the nAOG and CG (Table 3).

Delta values differed considerably between the groups in JTHFT performance with non-dominant and dominant hands ($p < 0.001$). In the non-dominant hand, significant differences were observed between the sAOG and nAOG ($p < 0.001$), the sAOG and CG ($p = 0.022$), the AOG and nAOG ($p = 0.004$), the APG and nAOG ($p < 0.001$)

Table 2. Demographic characteristics of and baseline performance between the study groups.

	sAOG	AOG	APG	nAOG	CG	F/ χ^2	p-value
Age (years)	21.42 $\pm$ 1.00	21.58 $\pm$ 1.17	21.59 $\pm$ 1.00	21.33 $\pm$ 1.07	21.17 $\pm$ 1.19	0.401	0.807
Height (m)	1.67 $\pm$ 1.05	1.72 $\pm$ 0.96	1.73 $\pm$ 0.88	1.69 $\pm$ 0.59	1.71 $\pm$ 0.91	0.766	0.552
Weight (kg)	61.58 $\pm$ 13.29	67.54 $\pm$ 13.17	70.92 $\pm$ 14.37	62.00 $\pm$ 9.81	66.33 $\pm$ 11.63	1.173	0.333
BMI (kg/m ²)	21.75 $\pm$ 2.79	22.75 $\pm$ 3.09	23.43 $\pm$ 2.98	21.51 $\pm$ 2.28	22.70 $\pm$ 3.16	0.898	0.472
Sex, n (%)							
Female	9 (75)	5 (42)	4 (33)	8 (67)	6 (50)	5.76	0.218
Male	3 (25)	7 (58)	8 (67)	4 (33)	6 (50)		
Upper extremity functionality							
JTHFT_Left (s)	31.57 $\pm$ 3.57	30.75 $\pm$ 2.36	30.91 $\pm$ 3.55	31.01 $\pm$ 2.80	31.94 $\pm$ 3.57	0.295	0.880
JTHFT_Right (s)	35.67 $\pm$ 3.63	32.96 $\pm$ 2.76	32.60 $\pm$ 2.19	33.08 $\pm$ 2.39	33.95 $\pm$ 2.19	2.527	0.051
NHPT_Right (s)	17.52 $\pm$ 2.03	17.32 $\pm$ 1.57	16.61 $\pm$ 1.34	17.02 $\pm$ 1.41	17.15 $\pm$ 1.49	0.567	0.687
NHPT_Left (s)	18.33 $\pm$ 1.50	18.94 $\pm$ 1.79	18.94 $\pm$ 2.32	18.97 $\pm$ 1.63	18.98 $\pm$ 1.58	0.301	0.876
d2 test of attention variables							
Total characters processed	555.58 $\pm$ 67.21	563.75 $\pm$ 32.02	540.50 $\pm$ 71.72	557.42 $\pm$ 60.14	531.75 $\pm$ 59.11	0.589	0.672
Errors of commission	3.25 $\pm$ 2.26	5.67 $\pm$ 4.54	5.75 $\pm$ 4.05	4.33 $\pm$ 3.68	7.58 $\pm$ 4.10	2.213	0.079
Errors of omission	27.33 $\pm$ 16.00	35.50 $\pm$ 21.65	30.17 $\pm$ 18.70	32.50 $\pm$ 24.03	27.67 $\pm$ 16.65	0.366	0.832
Total errors	30.58 $\pm$ 16.14	41.17 $\pm$ 23.26	35.92 $\pm$ 20.63	36.83 $\pm$ 25.50	35.25 $\pm$ 17.43	0.394	0.812
Percentage of errors	5.50 $\pm$ 2.83	7.36 $\pm$ 4.46	6.68 $\pm$ 3.5	6.41 $\pm$ 4.09	6.50 $\pm$ 2.65	0.416	0.797
Total correct	525.00 $\pm$ 65.68	522.42 $\pm$ 43.69	504.58 $\pm$ 70.81	520.58 $\pm$ 50.61	496.50 $\pm$ 48.97	0.583	0.676
Fluctuation	12.42 $\pm$ 6.88	13.67 $\pm$ 4.58	13.00 $\pm$ 4.33	11.75 $\pm$ 3.41	15.75 $\pm$ 4.96	1.145	0.345
Reaction time							
Serial reaction time task (milliseconds)	419.15 $\pm$ 59.99	440.44 $\pm$ 44.33	418.89 $\pm$ 56.14	426.09 $\pm$ 68.89	439.58 $\pm$ 74.82	0.355	0.840

Values are presented as mean $\pm$ standard deviation unless specified.

AOG: Action observation group; APG: Action practice group; CG: Control group; F: F-value; JTHFT: Jebsen–Taylor hand function test; nAOG: Non-action observation group; NHPT: Nine-hole peg test; sAOG: Self-action observation group; χ^2 : Chi-square value.

and the APG and CG ($p < 0.001$). While the JTHFT was performed with the dominant hand, delta values varied significantly between the sAOG and AOG, nAOG and CG ($p = 0.004$; $p < 0.001$; $p = 0.020$; respectively). Additionally, while there were significant differences in delta values of the NHPT completion time with the dominant hand between the sAOG and nAOG ($p = 0.048$), significant differences were observed in the non-dominant hand between the APG and CG ($p = 0.024$). No significant difference was observed in any variable of the d2 test of attention and reaction time between the groups ($p > 0.05$) (Table 4).

Discussion

This study aimed to examine the acute effects of action observation training on upper extremity functions, cognitive processes and response times in young, healthy adults. It was hypothesized that action observation interventions would enhance upper extremity functions compared with natural image watching and controls. The second hypothesis was that observing self-actions would be more effective than watching another person. While all participants improved the total JTHFT performance, only participants in the action observation groups (the self-action observation group and action observation group) and participants who practiced the test four more times (the action practice group) decreased the nine-hole peg test completion time significantly compared with the baseline. Also, there was no statistically significant difference between the groups, but the d2 test of attention (d2) showed that the people in the self-action observation group had better cognitive performance.

Previously, several studies examined the effects of action observation training on upper extremity functions (reaching, grasping, object manipulation etc.) in both healthy participants [35–38] and people with various diseases [15,20,21]. Sakaguchi and Yamasaki combined action observation with motor imagery and compared the effectiveness of this method with the physical training group [38]. Sport stacking, an upper extremity functionality test, was chosen as the main outcome, and both groups completed 20 min of practice per day for 3 days. After the training, both groups improved their test completion performance, and there was no significant difference between them. Although the researchers did not include any neurophysiological tests in the research design, they have attributed that performance improvement to the activation of greater motor areas and the corticospinal tract

Table 3. Within-group changes in the study outcome measures.

	SAOG			AOG			APG			nAOG			CG		
	Before (mean ± SD)	After (mean ± SD)	p-value	Before (mean ± SD)	After (mean ± SD)	p-value	Before (mean ± SD)	After (mean ± SD)	p-value	Before (mean ± SD)	After (mean ± SD)	p-value	Before (mean ± SD)	After (mean ± SD)	p-value
JTHFT_Left (s)	31.57 ± 3.57	25.14 ± 3.31	<0.001 [†]	30.75 ± 2.36	25.08 ± 1.72	<0.001 [†]	30.91 ± 3.55	24.43 ± 2.07	<0.001 [†]	31.01 ± 2.80	29.11 ± 2.95	0.040 [†]	31.94 ± 3.57	28.74 ± 3.27	<0.001 [†]
JTHFT_Right (s)	35.67 ± 3.63	21.74 ± 2.16	<0.001 [†]	32.96 ± 2.76	22.50 ± 2.24	<0.001 [†]	32.60 ± 2.19	21.70 ± 1.61	<0.001 [†]	33.08 ± 2.39	24.90 ± 2.38	<0.001 [†]	33.95 ± 2.19	25.23 ± 2.11	<0.001 [†]
NHPT_Right (s)	17.52 ± 2.03	15.56 ± 1.90	<0.001 [†]	17.32 ± 1.57	15.72 ± 0.82	0.002 [†]	16.61 ± 1.34	15.49 ± 1.39	<0.001 [†]	17.02 ± 1.41	16.60 ± 1.48	0.228	17.15 ± 1.49	16.62 ± 1.09	0.233
NHPT_Left (s)	18.33 ± 1.50	17.07 ± 1.75	0.001 [†]	18.94 ± 1.79	17.44 ± 1.16	0.002 [†]	18.94 ± 2.32	17.13 ± 1.75	<0.001 [†]	18.97 ± 1.63	18.24 ± 1.37	0.182	18.98 ± 1.58	19.08 ± 3.17	0.868
Total characters processed	555.58 ± 67.21	601.08 ± 53.91	0.017 [†]	563.75 ± 32.02	612.92 ± 19.23	<0.001 [†]	540.50 ± 71.72	592.17 ± 56.79	<0.001 [†]	557.42 ± 60.14	595.00 ± 62.29	<0.001 [†]	531.75 ± 59.11	600.08 ± 37.93	<0.001 [†]
Errors of commission	3.25 ± 2.26	3.00 ± 2.22	0.809	5.67 ± 4.54	5.67 ± 4.31	1.000	5.75 ± 4.05	6.83 ± 2.98	0.285	4.33 ± 3.68	7.42 ± 8.43	0.084	7.58 ± 4.10	8.33 ± 4.62	0.616
Errors of omission	27.33 ± 16.00	18.08 ± 12.16	0.017 [†]	35.50 ± 21.65	26.25 ± 27.81	0.057	30.17 ± 18.70	20.67 ± 15.27	0.025 [†]	32.50 ± 24.03	26.37 ± 23.82	0.147	27.67 ± 16.65	25.67 ± 10.27	0.575
Total errors	30.58 ± 16.14	21.08 ± 12.59	0.033 [†]	41.17 ± 23.26	31.92 ± 28.38	0.070	35.92 ± 20.63	27.50 ± 16.10	0.061	36.83 ± 25.50	33.78 ± 28.01	0.480	35.25 ± 17.43	34.00 ± 11.79	0.780
Percentage of errors	5.50 ± 2.83	3.60 ± 2.22	0.013 [†]	7.36 ± 4.46	5.21 ± 4.60	0.008 [†]	6.68 ± 3.5	4.66 ± 2.64	0.018 [†]	6.41 ± 4.09	5.53 ± 4.20	0.215	6.50 ± 2.65	5.71 ± 2.06	0.298
Total correct	525.00 ± 65.68	580.00 ± 58.96	0.003 [†]	522.42 ± 43.69	581.00 ± 33.72	<0.001 [†]	504.58 ± 70.81	564.50 ± 57.72	<0.001 [†]	520.58 ± 50.61	561.33 ± 57.48	<0.001 [†]	496.50 ± 48.97	566.08 ± 42.14	<0.001 [†]
Fluctuation	12.42 ± 6.88	7.83 ± 6.26	0.008 [†]	13.67 ± 4.58	8.92 ± 2.23	0.007 [†]	13.00 ± 4.33	8.83 ± 2.41	0.005 [†]	11.75 ± 3.41	8.50 ± 4.12	0.001 [†]	15.75 ± 4.96	11.00 ± 4.82	0.026 [†]
Serial reaction time task (milliseconds)	419.15 ± 59.99	341.56 ± 61.87	<0.001 [†]	440.44 ± 44.33	347.00 ± 36.40	<0.001 [†]	418.89 ± 56.14	324.66 ± 57.10	<0.001 [†]	426.09 ± 68.89	346.02 ± 59.69	<0.001 [†]	439.58 ± 74.82	349.19 ± 61.91	<0.001 [†]

Values are presented as mean ± SD.
† p < 0.05.
AOG: Action observation group; APG: Action practice group; CG: Control group; JTHFT: Jebsen-Taylor hand function test; nAOG: Non-action observation group; NHPT: Nine-hole peg test; SAOG: Self-action observation group; SD: Standard deviation.

Table 4. Between-group changes in the study outcome measures.

	sAOG	AOG	APG	nAOG	CG	ηp^2	F	p-value	Post hoc comparisons with Bonferroni corrections
Δ JTHFT_Right (s)	-7.51 (-8.65, -6.37)	-5.04 (-7.02, -3.06)	-5.39 (-7.09, -3.69)	-2.55 (-4.56, -0.54)	-2.05 (-2.99, -1.12)	0.381	8.466	<0.001 [†]	sAOG>nAOG (p < 0.001 [†]), sAOG>CG (p = 0.022 [†]), AOG>nAOG (p = 0.004 [†]), APG>nAOG (p < 0.001 [†]), APG>CG (p = 0.020 [†])
Δ JTHFT_Left (s)	-13.74 (-15.64, -11.83)	-14.27 (-19.17, -9.37)	-14.94 (-18.21, -11.68)	-6.26 (-9.72, -2.79)	-5.61 (-7.40, -3.82)	0.357	7.624	<0.001 [†]	sAOG>AOG (p = 0.04 [†]), sAOG>nAOG (p < 0.001 [†]), sAOG>CG (p < 0.001 [†])
Δ NHPT_Right (s)	-1.96 (-2.78, -1.152)	-1.60 (-2.48, -0.71)	-1.12 (-1.84, -0.40)	-0.421 (-1.15, 0.30)	-0.53 (-1.45, 0.39)	0.190	3.230	0.019 [†]	sAOG>nAOG (p = 0.048 [†])
Δ NHPT_Left (s)	-1.26 (-1.88, -0.64)	-1.51 (-2.33, -0.69)	-1.81 (-2.49, -1.13)	-0.73 (-1.86, 0.40)	0.09 (-1.14, 1.33)	0.186	3.135	0.022 [†]	APG>CG (p = 0.024 [†])
Δ Total characters processed	45.50 (9.83, 81.17)	49.17 (28.06, 70.27)	51.67 (31.53, 71.80)	51.67 (31.53, 71.80)	68.33 (42.80, 93.87)	0.071	1.048	0.391	–
Δ Errors of commission	-0.25 (-2.47, 1.97)	0.00 (-2.39, 2.39)	1.08 (-1.04, 3.21)	1.08 (-1.04, 3.21)	0.75 (-2.45, 3.95)	0.074	1.102	0.365	–
Δ Errors of omission	-9.25 (-16.46, -2.03)	-9.25 (-18.82, 0.32)	-9.50 (-17.56, -1.44)	-9.50 (-17.56, -1.44)	-2.00 (-9.62, 5.62)	0.051	0.742	0.568	–
Δ Total errors	-9.50 (-18.06, -0.94)	-9.25 (-19.38, 0.88)	-8.42 (-17.31, 0.47)	-8.42 (-17.30, 0.47)	-1.25 (-10.86, 8.36)	0.057	0.835	0.509	–
Δ Percentage of errors	-1.90 (-3.30, -0.48)	-2.16 (-3.61, -0.70)	-2.02 (-3.63, 0.41)	-2.02 (-3.63, -0.41)	-0.79 (-2.37, 0.80)	0.063	0.932	0.452	–
Δ Total correct	55.00 (22.61, 87.39)	58.58 (40.92, 76.24)	59.92 (42.64, 77.19)	59.92 (42.64, 77.19)	69.58 (46.45, 92.71)	0.075	1.107	0.363	–
Δ Fluctuation	-4.58 (-7.68, -1.49)	-4.75 (-7.95, -1.55)	-4.17 (-6.76, -1.57)	-4.17 (-6.76, -1.57)	-4.75 (-8.82, -0.68)	0.015	0.213	0.930	–
Δ Serial reaction time task (milliseconds)	-76.79 (-92.18, -61.40)	-91.17 (-109.65, -72.68)	-91.50 (-111.89, -71.11)	-80.75 (-96.58, -64.92)	-85.79 (-105.84, -65.74)	0.058	0.844	0.503	–

[†]p < 0.05
 Values are presented as means (95% CI).
 AOG: Action observation group; APG: Action practice group; CG: Control group; Δ : Delta; F: Test statistic for F-test; JTHFT: Jebsen–Taylor hand function test; ηp^2 : Partial eta squared;
 nAOG: Non-action observation group; NHPT: Nine-hole peg test; sAOG: Self-action observation group.

based on previous findings. Romano Smith *et al.* [39] investigated the effects of motor imagery, action observation and a combination of motor imagery and action observation on dart-throwing performance. The groups practiced the interventions three times a week for 6 weeks, and pre-training and post-training dart-throwing performances were compared. After the interventions, it was found that while there was no improvement in the control group, participants in the action observation, motor imagery and a combination of motor imagery and action observation groups improved their performance significantly. Moreover, improvement in the combination of motor imagery and action observation was greater than in the action observation and motor imagery groups. The researchers argued that the difference had arisen from the production of more effective visuomotor command encoding by adding motor imagery to action observation. In the current study, the authors did not add any motor imagery practice, and they observed that the observation of action alone is an effective way to improve upper extremity functions, even with a single 20 min session. Similarly, Adhikari *et al.* [16] examined the impact of a single session of action observation training on improving upper extremity functions in subacute stroke patients. The study's primary outcomes included hand performance-related subtests of the Wolf motor function test and Stroke Impact Scale. They reported significant improvements in action observation training, including group compared with usual care. Furthermore, improvements were sustained for 7 days after the intervention. Even though the authors of the current study did not reassess the participants to report long-term effects, which was not in the scope of this study, the findings are in parallel with theirs. Additionally, participants in action observation groups only watched the JTHFT in the videos; however, their nine-hole peg test performance was significantly enhanced compared with baseline. So, after action observation training, an improvement in performance on a specific task that was observed could be transferred to another task involving the upper extremities.

One main concern regarding the effects of action observation training is focus and attention issues. Emerson *et al.* argued that practitioners seldom teach participants how to observe the desired activity or what elements to focus on, which is a drawback in the present delivery technique for action observation training [40]. In the present study, participants in the action observation groups were instructed to “*focus on the nature of movement in the video and try to find cues on how to perform faster when you practice the test*” to eliminate the disadvantage of the action observation technique. Furthermore, the authors evaluated sustained attention and working memory, which are essential elements of cognitive functions [41], using the d2. Although the difference between the groups was not statistically significant, participants scored better in almost all the d2 variables.

Additionally, while participants in the self-action observation group and action practice group significantly reduced the number of errors in the d2 at the final assessment, there was no significant difference in the final assessment compared with baseline in the remaining three groups. An increase in attention level may be one possible cause of better performance in both upper extremity-related tasks. In a recent study by Kemmerer, the literature was reviewed, and it has been concluded that mirror neuron system responses are enhanced when people's attention is drawn to the mechanical components of observed actions [42]. The findings of the present study are thereby in parallel with previous conclusions.

One interesting finding of the present study was that participants watched their videos and performed observed actions better than those who watched someone else's actions. Several mechanisms could be suggested in that regard. First, the participants may have focused more on the actor on the screen, which greatly impacts action observation performance [42]. Ste-Marie *et al.* discussed the issue in depth and stated that there is insufficient evidence to decide which observation technique (self-action or a model's actions) is more effective, and both observation procedures have different benefits for the observers [43]. Holmes and Calmels have indicated that when viewing self-generated actions as opposed to other people's actions, there may be a stronger functional resemblance of brain activity to that during motor execution [18]. Second, another reason might be the impact of different perspectives. As studied by Ge *et al.*, the first-person perspective causes more massive and greater activation compared with the third-person perspective [44]. In that regard, Nagai and Tanaka investigated event-related desynchronization responses under three conditions: motor imagery + self-action observation, motor imagery + observation of another person's action and motor imagery only; like the findings of the present study, they found that participants who observed their hand movements with motor imagery had greater event-related desynchronization [36]. In the present study, the authors also say that observing one's own actions improves performance on a simple hand-opening-and-closing task and on the JTHFT, which is a much more difficult hand-functioning test.

There are some limitations to the present study. First, the sample size per group seems too small; however, post-analysis revealed that the study achieved a power of at least 0.97 for the main outcomes. Therefore, the authors believe that these findings have not been found by chance, which is supported by the evidence in the literature. Second, the data of any high-tech devices could not be included as an outcome. Nevertheless, using easily applicable outcome measurements such as JTHFT and the nine-hole peg test is valuable for researchers and may be used in daily practice by clinicians. Third, the learning effect is generally a problem in acute effect studies. Even though the authors tried to decrease the learning effect by applying a literature-recommended number of trials before each test, it is obvious that the learning effect and/or placebo effect might still be present, as significant improvements were observed in the control groups (i.e., the non-action observation group and control group). This point should indicate cautiousness when interpreting the results of this study. Finally, the hypotheses were tested only on a healthy population. However, the study's results from a group of people who were healthy could have a big effect on neuroscience research.

Conclusion

In conclusion, action observation training seems to enhance the performance of upper extremity-related functions. Moreover, observing self-actions resulted in statistically significant positive changes in more variables compared with other methods. However, future long-term studies should investigate its clinical effectiveness over the other methods. This study's observed performance improvements might be attributed to both neurophysiological and behavioral mechanisms.

Future perspective

In the future, researchers should use high-tech outcome measures to find out more about these mechanisms and look at how different action observation techniques affect people with neurological conditions.

Summary points

- Action observation training can be used to create complementary responses in a turn-taking way or to synchronize movements with those of others at the same time.
- Activation in the brain during action observation is, in a way, automatic; in other words, even if an individual has no intention of acting on the perceived stimuli, this process occurs.
- A single-session action observation training may enhance upper extremity functions.
- After action observation training, an improvement in performance on a specific task that was observed could be transferred to another task involving the upper extremities.
- Observing self-videos may improve performance to a greater extent compared with observing another person.
- Performance improvements might be attributed to both neurophysiological and behavioral mechanisms.

Author contributions

Y Emuk, T Kahraman and Y Sengul contributed to the design and implementation of the research, the analysis of the results and the writing of the manuscript.

Acknowledgments

The authors sincerely thank the participants of the study.

Financial & competing interests disclosure

The authors have no relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript. This includes employment, consultancies, honoraria, stock ownership or options, expert testimony, grants or patents received or pending or royalties.

No writing assistance was utilized in the production of this manuscript.

Ethical conduct of research

The authors state that they have obtained appropriate institutional review board approval or have followed the principles outlined in the Declaration of Helsinki for all human or animal experimental investigations. In addition, for investigations involving human subjects, informed consent has been obtained from the participants involved.

Data sharing statement

The authors certify that this manuscript reports original clinical trial data. Individual participant data that underlie the results reported in this article after deidentification (text, tables and figures) will be shared immediately following the publication. Proposals should be directed to yusufemk@gmail.com. To gain access, data requesters will need to sign a data access agreement. Clinical trial identifier: NCT04932057.

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