Paresis of an upper extremity. Action observation and motor imagery in recovery of patients with chronic stroke

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Introduction. Action observation (AO) and motor imagery (MI) are considered functionally equivalent forms of motor representation related to movement execution (ME). Because of their characteristics, AO and MI have been proposed as techniques to facilitate the recovery of post-stroke hemiparesis in the upper extremities.

Patients and methods. An experimental, longitudinal, prospective, single-blinded design was undertaken. Eleven patients participated, and were randomly assigned to each study group. Both groups received 10 to 12 sessions of physical therapy. Five patients were assigned to the control treatment group, and six patients to the experimental treatment group (AO + MI). All were assessed before and after treatment for function, strength (newtons) and mobility (percentage) in the affected limb, as well as alpha desynchronisation (8-13 Hz) in the supplementary motor area, the premotor cortex and primary motor cortex while performing AO + MI tasks and action observation plus motor execution (AO + ME).

Results. The experimental group presented improvement in function and strength. A negative correlation was found between desynchronisation in the supplementary motor area and function, as well as a post-treatment increase in desynchronisation in the premotor cortex of the injured hemisphere in the experimental group only.

Conclusions. An AO + MI-based intervention positively impacts recovery of the paretic upper extremity by stimulating the supplementary motor area, a cortex involved in movement preparation and learning. AO + MI therapy can be used as adjunctive treatment in patients with upper extremity paresis following chronic stroke.

Key words. Action observation. Alpha desynchronisation. Motor execution. Motor imagery. Paresis of the upper extremity. Stroke.

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Introduction

Action observation (AO) [1,2] and motor imagery (MI) [3] are considered functionally equivalent forms of motor representation related to movement execution (ME) [4,5]. According to neuroimaging evidence, both the supplementary motor area and the premotor cortex are activated in similar ways during AO and MI tasks [6]. Both regions interact with the primary motor cortex in the planning and initiation of sequenced movements [7,8]. Because of their functional characteristics, AO and MI have been proposed as techniques to facilitate recovery from post-stroke hemiparesis in the upper extremities [9-13].

Several studies of the effects of interventions based on AO for stroke patients report improvements in clinical motor function scales compared to a baseline or controls [14-18]. Treatments focusing on MI have also been administered in order to evaluate their clinical effects [19,20] (for a review, see Fernández-Gómez and Sánchez-Cabeza [21]) involving reducing the degree of involvement of the paretic limb, increasing its use and maintaining the positive effects [22-25]. However, some studies have reported contrary results for AO- and MI-based interventions with stroke patients; in their respective studies, Ietswaart et al [26] and Braun et al [27] conclude that treatments do not lead to motor recovery in these cases.

Although AO- and MI-based interventions for patients with paresis of an upper extremity as a sequela of stroke have been shown to lead to clinical improvement [28,29], Vogt et al [9] note that 'Typically only one form of treatment, either MI or AO, has been used as an intervention', and argue that this approach ignores the potential benefits of multimodal motor training with both AO and MI (AO + MI). Research with healthy subjects by Conson et al [30] supports this proposition by demonstrating

Figure 1. a) Evaluation using the AMADEO® system; b) Electroencephalographic recording; c) Intervention focused on AO + MI.

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that AO has facilitation effects for MI, while Sun et al [31] claim that an AO- + MI-focused intervention improves activation in the sensorimotor cortex, and facilitates recovery of the paretic upper extremity in stroke patients.

The present study aimed to investigate the effects of an AO- + MI-based intervention complementing physical rehabilitation in patients with chronic stroke, based on the hypothesis that AO + MI stimulation enhances the recovery of strength, mobility and function of the paretic upper extremity. The following steps were taken to overcome some of the limitations presented by the state of the art: the intervention was based on AO and MI together (AO + MI) [32]; clinical strength and mobility were measured using a computerised robotic device; the patients had a time to progression of at least 12 months, so that the expected recovery in the first six months would have reached a plateau [33-35]; and electroencephalographic recordings were performed to determine whether stimulation via AO + MI led to long-term (6 weeks) changes in brain electrical activity in the motor areas [32,36].

Patients and methods

Study design

An experimental, longitudinal, prospective design was undertaken. Each patient was assigned to a group by randomisation by a draw. The study was single-blinded, with third-party blinded evaluation; neither the evaluators nor the patients knew which group they belonged to.

Patients

The patients were recruited from the acquired brain injury service of the Luis Guillermo Ibarra Ibarra National Rehabilitation Institute (INR-LGII) in Mexico City, and had to meet the following inclusion criteria: a) first stroke with time to progression of more than 12 months; b) right-handed; c) over 18 years of age; and d) Mini-Mental test score of 20 or over. Patients were excluded: a) if they had a stroke secondary to traumatic brain injury; b) if they were in concurrent treatment for paresis of the upper extremity; c) if they had quadriparesis; d) if they were visually impaired; and e) if they had an uncontrolled chronic condition. The sociodemographic characteristics of the sample are shown in Table I.

The study was approved by the Research and Ethics Committee of the INR-LGII. The patients gave their written informed consent in accordance with the standards of the Declaration of Helsinki.

Study variables

Primary

The variable of interest function is derived from the domain known as motor function according to the Fugl-Meyer assessment scale, which clinically determines post-stroke recovery by directly observing performance. The Fugl-Meyer assessment scale also measures other domains, including sensation, balance, joint motion and joint pain, rating them on an ordinal scale with three possible answers (0 = none; 1 = partial; and 2 = full) [37,38]. In accordance with the objectives of this study, the evaluation focused only on the items related to movement of the upper extremity (the shoulder, elbow and wrist), considering changes in reflex activity and volitional movement in relation to motor synergies.

The AMADEO® robot-assisted rehabilitation system was used for measurement, control and intervention. The patient's arm and hand is fastened to a device composed of levers, to which the fingers are attached by means of magnets (Fig. 1a). The robot applies various flexion and extension resistances to each finger, and measures the ranges of mobility, forces received and power of mobility. The variables of interest were the combined force (newtons) of flexion and extension of the fingers, and the range of motion (percentage) of the hand. The AMADEO® physical therapy programme was also applied [39].

Secondary

Electroencephalographic recording was performed in a lit, semi-soundproofed room, with the patients seated comfortably and their arms resting on the armrests of a padded armchair (Fig. 1b), using a

Figure 2. a) Structure of the electroencephalographic trials; b) position of the electroencephalogram electrodes.

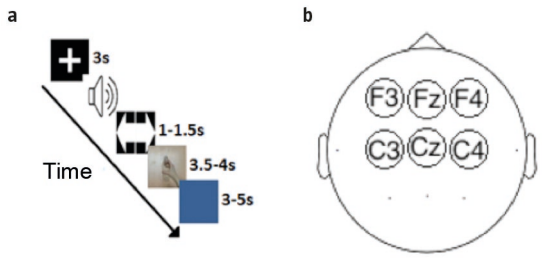


Table I. Sociodemographic characteristics of the total sample and for each group.

	Age in years	Time to progression (weeks)	Sex	Paresis	Type of stroke	Injured hemisphere
Total sample (*N* = 11)	50.4 (±10.6)	141 (±92.2)	M = 6. F = 5	R = 6 L = 5	Isq = 8 Hem = 3	R = 5 L = 6
Experimental group (*n* = 6)	53.1 (±11.1)	136.8 (±107)	M = 4. F = 2	R = 3 L = 3	Isq = 3 Hem = 3	R = 3 L = 3
Control group (*n* = 5)	47.2 (±10)	146.2 (±82.8)	M = 2. F = 3	R = 3 L = 2	Isq = 5 Hem = 0	R = 2 L = 3

Hem: haemorrhagic; Isch: ischemic; L: left; R: right; M: male; F: female.

g.USBamp model g.TEC 16-channel biosignal amplifier with a sampling frequency of 256 Hz and active electrodes. The data for the quantitative electroencephalographic analysis were obtained during three tasks: resting with eyes open (baseline), AO + MI and action observation plus movement execution (AO + ME). The movements shown on video (lifting a bottle and lifting a spoon) were presented on a 50-centimetre monitor placed on a table one metre in front of the patients.

The trials had the following structure (Fig. 2a): a) a fixed white cross appeared in the centre of the monitor for three seconds; b) a beep and an arrow pointed randomly to the left or right for 1-1.5 seconds to indicate which hand should be used for the task; c) a short video randomly showed a first-person perspective of a hand lifting a bottle or spoon for 3.5-4 seconds; and d) a blue screen for 3-5 seconds indicated the end of the test. Fluctuations in the display times of the arrow, video and blue screen stimuli were randomly distributed among trials, and all patients were subjected to them in equal proportion. All the patients performed all the tasks. For control purposes, half of the trials were performed with the paretic upper extremity and the other half with the non-paretic upper extremity.

While the video was displayed, the patients had to imagine (AO + MI) or perform (AO + ME) the movement they saw, as instructed at the beginning of each series of trials. The order of the AO + IM and AO + EM series was randomised in order to prevent carryover effects. Eight series of 20 tests were performed for each patient, with rest periods of 3-5 minutes after every two series. Four series (80 trials) were for AO + MI, and another four for AO + ME. Each series lasted for approximately 4-5 minutes, and the recording had a total duration of 35-45 minutes.

The AO + EM task was included in the electroencephalographic recording due to evidence for the functional equivalence and involvement of similar neural substrates during motor representation (AO and MI) and motor execution (ME), which would enable training in the former to facilitate the latter [4-6,9,31].

The electroencephalographic analysis focused on one-second windows during the first three seconds of the video for each condition, separating the paretic upper extremity and non-paretic upper extremity trials. Six surface electrodes arranged according to the international 10-20 system and located over the supplementary motor area (Fz and Cz), the premotor cortex (F3 and F4) and the primary motor cortex (C3 and C4) were recorded (Fig. 2b). The quantitative electroencephalographic variable of interest for this study was event-related desynchronisation of the alpha rhythm (8-13 Hz) [40-42].

Intervention

The patients who met the inclusion criteria were evaluated using the Fugl-Meyer assessment scale, AMADEO® and a quantitative electroencephalogram prior to their randomisation to the groups. During the intervention, both the patients and the professionals responsible for the physical therapy and evaluations were unaware of the group which the patients belonged to. At the conclusion of the treatment, the patients were re-evaluated using the Fugl-Meyer assessment scale, AMADEO® and a quantitative electroencephalogram.

The experimental group received 10-12 treatment sessions, consisting of 10-12 minutes of physical therapy plus 25-30 minutes of AO + MI, focused exclusively on the paretic upper extremity.

Table II. Comparison of pre-treatment variables.

	Control (MR)	Experimental (MR)	U	Z	*p*
Age (years)	5	6.83	10	–0.913	0.361
Time to progression (weeks)	6.6	5.5	12	–0.548	0.584
Cognitive status	6.8	5.33	11	–0.746	0.456
Functionality PRE	6.5	5.58	12.5	–0.457	0.647
Strength PRE	6.4	5.67	13	–0.369	0.712
Mobility PRE	4.8	7	9	–1.095	0.273
Desynchronisation					
Fz AO + ME NP PRE	5.8	6.17	14	–0.183	0.855
Fz AO + ME PA PRE	5.4	6.5	12	–0.548	0.584
F INJ AO + ME PA PRE	7	5.17	10	–0.913	0.855

AO + ME: action observation plus motor execution; F: frontal; Fz: medial frontal; INJ: injured; MR: mean range; NP: not paretic; PA: paretic; PRE: pre-treatment.

Two sessions were administered per week, on Mondays and Thursdays, for six weeks. The physical therapy consisted of continuous flexion and extension movements of the fingers at a frequency of 0.5 Hz. Exercises involving stretching of the hand (flexion and extension of the fingers and wrist) and arm (flexion and extension of the elbow and shoulder) were performed before each session as a warm-up to prevent injuries, as specified by a physiotherapist specialising in neurorehabilitation. The AO + MI intervention consisted of watching videos showing repetitive hand movements in daily life actions (lifting a bottle and lifting a spoon), from a first-person perspective, presented on a computer screen at a distance of 50 centimetres from the patient (Fig. 1c). While watching the movements, the patients were instructed to imagine themselves performing them with the paretic upper limb, but keeping it immobile, evoking how it would feel to touch the bottle or spoon (the temperature and texture), the force and tension they would have to exert on the arm and hand, the position of the arm and fingers needed to perform the task, and the feeling of completing the movement (drinking from the bottle or eating from the spoon). Each task was displayed with the same frequency (50% lifting the bottle and 50% lifting the spoon).

The control group received from 10 to 12 sessions of physical therapy, with parameters identical to those of the experimental treatment. In order to ensure consistency between conditions, after the physical therapy, 25-30 minutes were allocated to an informal interview between the experimenter and patient, during which the same videos used for the experimental intervention were presented at a distance of 50 cm in the patient's field of vision, with no cues provided, so that both groups were exposed to the same stimuli, with the difference that the experimental group was trained in AO + MI.

During the intervention, neither group performed the AO + EM task required for electroencephalographic recordings, in order to prevent any possible interference between the treatments.

Statistics

Version 22.0 of the SPSS® statistical package (IBM Corp., New York, United States) was used to analyse the variables studied. The equivalence of the groups was initially established for the variables age, time to progression and cognitive status (Mini-Mental test) using the Mann-Whitney U test. The same analysis was subsequently performed with the variables of interest function, strength, mobility and desynchronisation.

The measurements of function, strength, mobility and desynchronisation before (PRE) and after (POS) treatment were compared using the Wilcoxon test to determine the effect of the intervention in the overall sample and for each group. The POS measurements of the same variables were then compared between the groups using the Mann-Whitney U test to determine whether the experimental group presented a greater degree of improvement. Effect sizes were calculated for all the comparisons using Cohen's d or Hedges' g as appropriate.

Finally, the main variables that presented significant changes were correlated with desynchronisation using Spearman's rho test to ascertain whether the clinical improvement was related to brain electrical activity in any specific region (the supplementary motor area, premotor cortex or primary motor cortex). The level of significance established for all the analyses was alpha < 0.05.

Results

Fourteen patients were recruited. Three of them

Figure 3. Comparison of pre-treatment (PRE) versus post-treatment (POS) clinical variables in the total sample, the control group and the experimental group.

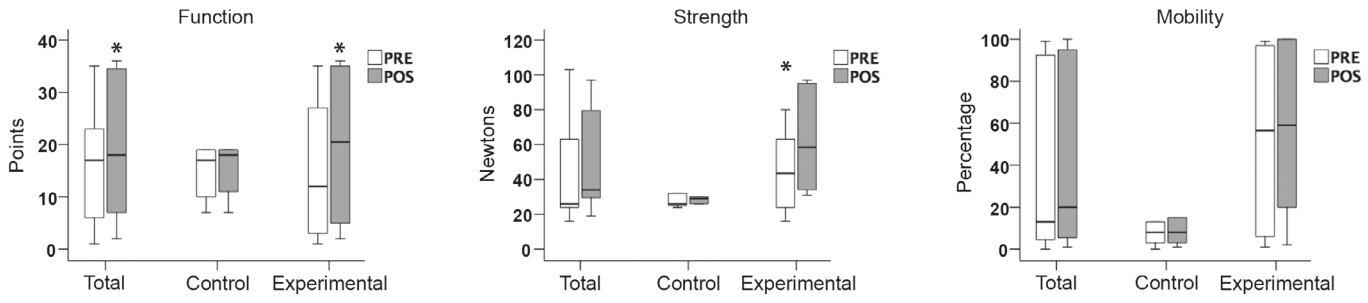
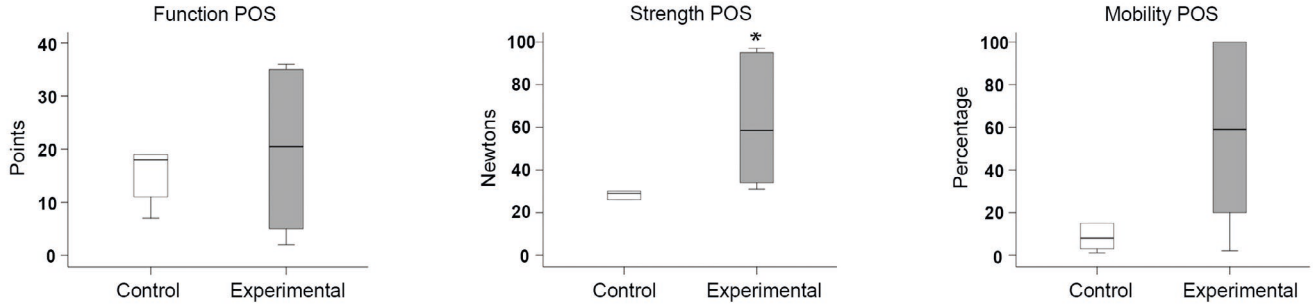


Figure 4. Comparison of post-treatment clinical variables (POS) between the control group and the experimental group.



were excluded, as two did not meet the inclusion criteria and one refused to participate.

The groups were considered equivalent, as none of the variables measured before treatment showed any significant differences ($p < 0.05$) (Table II).

Function, strength and mobility

PRE vs. POS comparison of the total sample showed significant differences in function (PRE, median 17 and range 34, vs. POS, median 18 and range 34; Z = -2.546, p = 0.011 and d = 0.234), but not in strength or mobility. When comparing the changes by group, there were significant increases in function in the experimental group (PRE, median 12 and range 34, vs. POS, median 20.5 and range 34; Z = –2.032, p = 0.042 and d = 0.312) and strength (PRE, median 43.5 and range 64, vs. POS, median 58.5 and range 66; Z = –2.201, p = 0.028 and d = 0.599), while there were no significant changes in any of the variables in the control group (Fig. 3).

POS comparison between groups revealed significantly greater strength in the experimental group (experimental, median 58.5 and range 66, versus control, median 29 and range 68; U = 4, p = 0.045 and g = 0.824), and no significant differences in function or mobility (Fig. 4).

Desynchronisation

Significant changes were found during AO + ME, but not during AO + MI. PRE vs. POS comparison of the total sample at Fz during AO + ME of the paretic upper extremity (AO + ME PA) showed a significant increase in POS desynchronisation (PRE, median 0.059 and range 0.346, vs. POS, median –0.183 and range 0.344; Z = –2.49, p = 0.013 and d = 1.399). When the groups were compared, this difference remained significant in the experimental group (PRE, median 0.042 and range 0.237, vs. POS, median –0.188 and range 0.181; Z = –2.201, p = 0.028 and d = 2.819), but not in the control group. A significant increase at the same elec-

Figure 5. Pre-treatment (PRE) versus post-treatment (POS) desynchronisation at the medial frontal electrode (Fz) during action observation plus motor execution (AO + ME) of the non-paretic upper extremity (NP) and paretic upper extremity (PA) in the total sample, the control group and the experimental group.

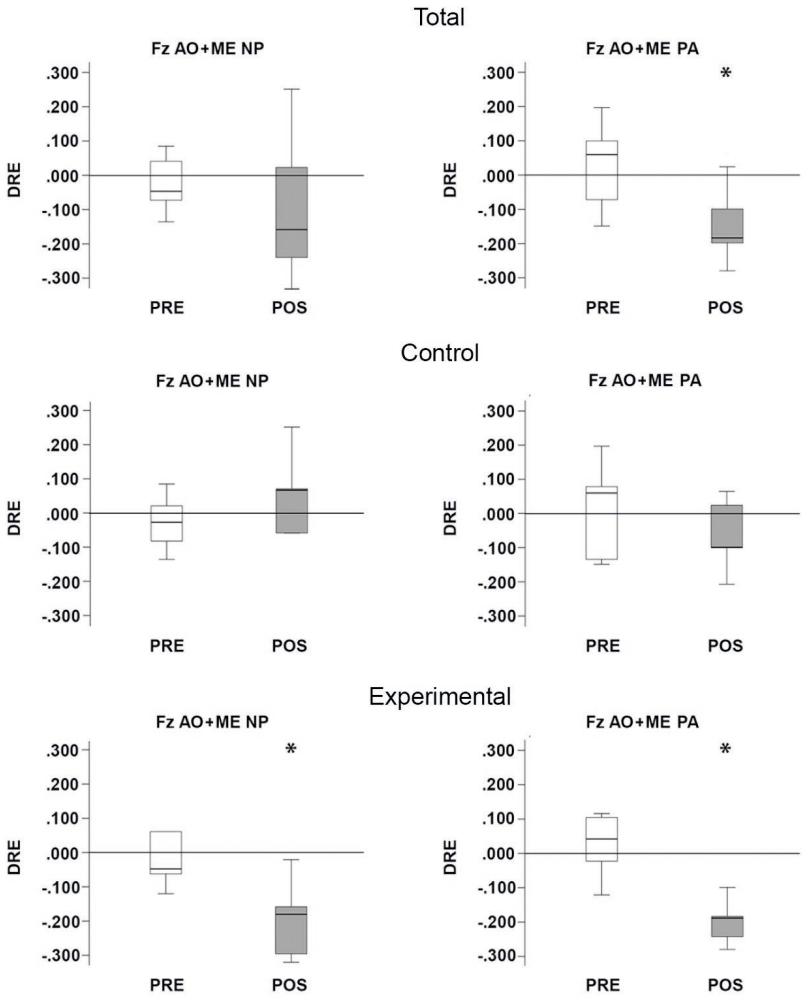
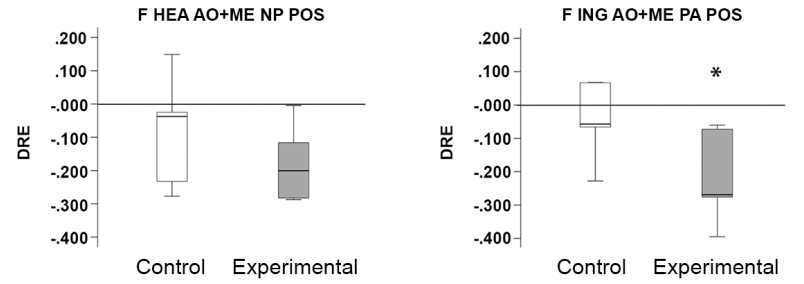


Figure 6. Comparison between the control and experimental groups of post-treatment desynchronisation (POS) in healthy frontal cortex (F HEA) and injured frontal cortex (F INJ) during action observation plus motor execution (AO + ME) of the non-paretic upper extremity (NP) and paretic upper extremity (PA).



trode (Fz) during AO + ME of the non-paretic upper extremity (AO + ME NP) was also found for the experimental group (PRE, median –0.047 and range 0.375, vs. POS, median –0.18 and range 0.3; Z = –1.992, p = 0.046 and d = 1.628) (Fig. 5).

The only significant difference in POS desynchronisation between the groups was in the frontal electrode of the injured hemisphere (F INJ) during AO + ME PA, in which the experimental group presented greater POS desynchronisation (experimental, median –0.057 and range 0.296, vs. control, median –0.269 and range 0.335; U = 3, p = 0.03 and g = 1.421) (Fig. 6).

Correlation between recovery in the paretic upper extremity and desynchronisation

Correlations were performed for the total sample, between function, strength and POS desynchronisation at Fz during AO + ME PA and AO + ME NP, with no significant results. We then performed the same analysis for each group, and found a significant strong positive correlation between function and strength (rho(4) = 0.829 and p = 0.042), as well as a significant strong negative correlation between function and POS desynchronisation at Fz during AO + ME PA (rho(4) = –0.829 and p = 0.042) for the experimental group, but not for the control group.

Discussion

Our findings show that an AO- + MI-based intervention facilitates recovery of the paretic upper extremity in chronic stroke patients in terms of function and strength, which is consistent with the suggestions of Vogt et al [9] and Eaves et al [13], concerning the benefits of multimodal motor training in these cases; this is partially consistent with the results reported by Sun et al [31], who reported an increase in function related to greater activation of the primary motor cortex, whereas in our study the relationship was between function and greater activation of the supplementary motor area; a possible explanation for this difference could be the time to progression, since our chronic patients are less likely to present changes in areas directly related to movement.

Likewise, the increased desynchronisation in the supplementary motor area during movement of both upper limbs (AO + ME PA and AO + ME NP) after treatment in the experimental group suggests a bilateral facilitating effect that is consistent with

the findings of Welniarz et al [43], who refer to a modulatory function of the supplementary motor area during movement preparation, while the increased desynchronisation in the injured premotor cortex (F INJ) during movement of the paretic upper limb (AO + ME PA) in the experimental group indicates neuroplastic processes related to recovery in movement planning [44] and even reorganisation for control of the basic movement parameters usually assigned to the primary motor cortex, consistent with that described by Fridman et al [45].

With regard to increased strength, the study by Scott et al [46] is the only precedent reporting an improvement related to AO + MI. Taken together, the findings could indicate a facilitating effect on intramuscular tension; however, these authors focused on the hamstring muscles, so the results should be considered with caution, as these are very different muscle groups and movements. The correlation between function and strength is also expected, as the former includes aspects of motion for which the latter is necessary [38].

An interesting but nevertheless logical result was that during the AO + ME task and not during the AO + MI task, the most post-treatment changes were observed in the experimental group, which seems to be consistent with Jeannerod's proposal [4,5] concerning AO and MI as functionally equivalent phenomena, and hidden constituents of movement execution.

Conclusions

In this study, we examined the effects of an AO- + MI-based intervention for chronic stroke patients on the assumption that it enhances recovery of strength, mobility, and function of the paretic upper extremity. According to the results, the treatment favoured improvement in strength and function, but not directly in mobility.

It is likely that the AO + MI-based intervention had an overall impact on the recovery of the paretic upper extremity by stimulating the supplementary motor area, a region involved in the preparation, initiation, control and learning of movement [6,47-49]. This would indicate that it has an indirect positive effect on the generation of movement, which only the primary motor cortex is capable of [50], and the latter showed no changes in desynchronisation. No changes in the mobility variable were detected either.

In the authors' opinion, this is complemented by the fact that the changes in desynchronisation occurred during motor execution tasks (AO + ME), and that the function variable is in turn made up of both reflex movements and voluntary movements related to motor synergies, i.e. the effects of the intervention could affect some motion parameters without necessarily favouring the recovery of the primary motor cortex.

In summary, our findings indicate that AO + MI-focused therapy as a complement to physical rehabilitation can be used as a treatment for patients with post-stroke paresis in the upper extremity, and that its effects are positive even in chronic cases.

It is important to note that although the effect sizes were moderate to high for the clinical variables and very high for cortical activation, the results should be considered with caution, as the study had important limitations, such as the size and heterogeneity of the sample, in addition to the low level of spatial resolution in the electroencephalogram. In future research, we recommend increasing the sample size and homogenising its characteristics in order to increase the robustness of the statistical analysis, and including functional imaging studies during the tasks to establish the cortical areas involved more precisely. Finally, we suggest administering different versions of the AO + MI based treatment to determine the effects of duration, frequency and time of exposure on recovery.

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Paresia de una extremidad superior. Recuperación mediante observación de la acción más imaginería motora en pacientes con ictus crónico

Introducción. La observación de la acción (OA) y la imaginería motora (IM) se consideran formas de representación motora funcionalmente equivalentes, relacionadas con la ejecución del movimiento (EM). Debido a sus características, la OA y la IM se han propuesto como técnicas para facilitar la recuperación de las hemiparesias de la extremidad superior posterior a ictus.

Pacientes y métodos. Se realizó un diseño experimental, longitudinal y prospectivo simple ciego. Participaron 11 pacientes, quienes fueron asignados aleatoriamente a cada grupo de estudio. Ambos grupos recibieron de 10 a 12 sesiones de terapia física. Cinco pacientes fueron asignados al grupo de tratamiento control y seis pacientes al grupo de tratamiento experimental (OA + IM). A todos se les evaluó antes y después del tratamiento para determinar la función, la fuerza (newtons) y la movilidad (porcentaje) de la extremidad afectada, así como la desincronización de alfa (8-13 Hz) en el área motora suplementaria, la corteza premotora y la corteza motora primaria durante tareas de OA + IM y observación de la acción más ejecución motora (OA + EM).

Resultados. El grupo experimental presentó mejoría en la función y la fuerza. Se encontró correlación negativa entre la desincronización en el área motora suplementaria y la función, así como incremento postratamiento de la desincronización en la corteza premotora del hemisferio lesionado únicamente para el grupo experimental.

Conclusiones. Una intervención basada en OA + IM impacta positivamente en la recuperación de la extremidad superior parética mediante la estimulación del área motora suplementaria, corteza involucrada en la preparación y aprendizaje del movimiento. La terapia OA + IM puede usarse como tratamiento complementario en pacientes con paresia de una extremidad superior posterior a un ictus crónico.

Palabras clave. Desincronización de alfa. Ejecución motora. Ictus. Imaginería motora. Observación de la acción. Paresia de extremidad superior.