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Aphasia improvement without logotherapy during motor neurorehabilitation of post-stroke hemiparesis using virtual reality or modified constraint-induced movement therapy: A retrospective cohort

María del Carmen Rojas-Sosa[a,1], José Antonio Zárate[b,2], Norma de la Rosa-Peña[c,3], José Luis Olvera-Gómez[d,4], David Rojano-Mejía[e,5], José Delgado-García[a,6] and Juan Garduño-Espinosa[f,*]
[a]*Rehabilitation Units and Services Division, Mexican Institute of Social Security (IMSS), Mexico City, Mexico*
[b]*External Consultation Service, XXI Century Physical Medicine and Rehabilitation Unit, Mexican Institute of Social Security (IMSS), Mexico City, Mexico*
[c]*Psychology Department, XXI Century Physical Medicine and Rehabilitation Unit, Mexican Institute of Social Security (IMSS), Mexico City, Mexico*
[d]*Planning and Institutional Liaison Directorate, South Delegation, Mexican Institute of Social Security (IMSS), Mexico City, Mexico*
[e]*Health Research Coordination, Mexican Institute of Social Security (IMSS), Mexico City, Mexico*
[f]*Secretariat of Health, Federico Gómez Children's Hospital of Mexico, Mexico City, Mexico*

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Abstract.
BACKGROUND: Some research suggests that post-stroke aphasia can recover "on its own", however, there is evidence of a common neural substrate for motor and language systems. We hypothesize, that motor neurorehabilitation of hemiparesis could be related to simultaneous improvement in aphasia.
OBJECTIVE: To measure changes in post-stroke aphasia and its relation with hemiparesis treated with different therapies.

[1]ORCID: 0000-0002-5924-5454
[2]ORCID: 0000-0001-6822-5183
[3]ORCID: 0009-0008-1215-330X
[4]ORCID: 0000-0001-5932-8578
[5]ORCID: 0000-0002-6340-8463
[6]ORCID: 0009-0003-7804-5073
*Address for correspondence: Juan Garduño-Espinosa, Head of the Research Directorate, Secretariat of Health, Federico Gómez Children's Hospital of Mexico, Calle Doctor Márquez # 162, Colonia Doctores, Alcaldía Cuauhtémoc, 06720, Mexico City, Mexico. E-mail: juan.gardunoe@gmail.com; ORCID: 0000-0002-3000-4948.

METHODS: Database information ($n = 32$) on post-stroke hemiparesis (Fugl-Meyer Scale evaluated) managed with virtual reality (VR) versus modified constraint-induced movement therapy (mCIMT) or regular therapy (rPT/OT) was analyzed. None received logotherapy (LT) by appointment at four months. Inclusion criteria: < 3 months after the stroke, aphasia severe (Boston Aphasia Intensity Scale), and all three evaluations.

RESULTS: Twenty-one patient records met inclusion criteria (71,4% women and mean age 66,67 ± 3,13 years) who received VR, mCIMT, or rPT/OT ($n = 6$, 8, and 7, respectively). There was continuous intra-groups improvement in aphasia ($p < 0.05$), but inter-groups the greater aphasia recovery ($p = 0.05$) and hemiparesis ($p = 0.02$) were in VR, with a high correlation in evolution between them ($r = 0.73$; $p = 0.047$).

CONCLUSION: High clinical correlation between aphasia, without LT, and hemiparesis evolution during motor neurorehabilitation would support common neural connections stimulation. We will conduct a clinical trial, with a larger sample size to contrast our hypothesis.

Keywords: Aphasia, hemiparesis, modified constraint-induced movement therapy, neurorehabilitation, satisfaction, virtual reality

1. Introduction

Cerebrovascular event (CVE) or stroke are one of the main causes of acquired disability in adults (Feigin et al., 2022). As 50%–80% of cases occur in the middle cerebral artery (MCA) (Pineda-Sanabria & Tolosa-Cubillos, 2022) and the most frequent neurological disorders are hemiplegia/hemiparesis and aphasia (Choreño-Parra et al., 2019). Given that restoring movement is essential for patients' daily life, different techniques for the rehabilitation of motor sequelae have been widely studied (Wang et al., 2022), including virtual reality (VR) (da Silva-Ribero et al., 2015; Anwar et al., 2021) and modified constraint-induced movement therapy (mCIMT) (Bani-Ahmed, 2019). Likewise, post-stroke aphasia is also highly incapacitating in terms of social activities and quality of life (Marshall et al., 2020).

The VR provides multisensory stimulation to the brain and is currently considered an therapeutic alternative for sequelae of stroke, showing positive effects on active neurorehabilitation by stimulating neural pathway restoration and motor function, observed using functional magnetic resonance imaging, as activation of ipsilesional primary sensorimotor cortex, increased bilateral activation supplementary motor area and changes contralesional premotor cortex; also, at synaptic level: changes in the strength of synaptic connections, axonal remodeling of the cortical pathways and the rearrangements of cortical mapping occurring disease recovery (Hao et al., 2022).

On the other hand, mCIMT has been shown to favour ipsilateral and contralateral sensory–motor plasticity as a way of restoring movement right from the first post-stroke stages (Treger et al., 2012; Hu et al., 2020), with the recruitment of additional neural sites (Bani-Ahmed et al., 2019). These techniques could be exerted clinical effects on other affected neurological functions, as motor training appears to determine the reorganisation of associated cortical networks, which are restored via the activation of cerebral plasticity, very early (even the first week), after the event (Zeiler et al., 2016).

Neural language substrates damaged by a stroke could be among the sites recruited during motor neurorehabilitation, as distribution of perception circuits has been observed in auditory and motor pathways. Considering that language processing is based on action (Schomers & Pulvermüller, 2016), this finding suggests a perceptual-motor interaction and, therefore, the motor system would be involved in language generation (Stokes et al., 2019).

A previous study involving VR and mCIMT showed improvement in patients with post-stroke hemiparesis (Rojas-Sosa et al., 2021), and positive changes were reported for initial aphasia without logotherapy as well as a high satisfaction level towards VR; however, these two variables were not measured. Hence, this study aimed to measure the changes aphasia post-stroke and relation with hemiparesis, as well as satisfaction levels in patient records with sequelae CVE who participated in a previously carry out clinical trial, in which had undergone motor neurorehabilitation with VR or mCIMT or regular therapy. This research was based on the hypothesis that general neural stimulation associated with motor training would improve aphasia without language therapy, during the first months of post-stroke evolution, which is the time of greatest brain plasticity.

Table 1
General characteristics of the 21 patients with aphasia secondary to a cerebrovascular event (CVE) per motor rehabilitation group

Characteristic		Groups			
		Virtual Reality ($n = 6$)	Modified Constraint-Induced Movement Therapy ($n = 8$)	Usual Physical and Occupational Therapy ($n = 7$)	Significance (p)
Sex	Female	4 (66.7%)	5 (62.5%)	6 (85.7%)	0.58; X^2
	Male	2 (33.3%)	3 (37.5%)	1 (14.3%)	
Age (years)	(X ± SD)	68.3 ± 2.1	65.38 ± 3.1	66.7 ± 3.6	0.17; KW
Progress time since CVE (months)	(X ± SD)	2.37 ± 0.30	2.43 ± 0.38	2.5 ± 0.31	0.58; KW
Comorbidities	None	0	3	3	0.068; X^2
	Arterial Hypertension	3	3	3	
	Diabetes mellitus 2	0	2	1	
	Arterial Hypertension plus Diabetes mellitus 2	3	0	0	

n = Number of patients; p = Level of statistical significance; X ± SD = Mean and standard deviation; X^2 = Chi-squared test; KW = Kruskal–Wallis test.

2. Materials and methods

2.1. Subjects

Data were collected from a previously carried out single blind (examiner) randomized clinical trial database from August 2021 to July 2022. Information from 21 adults (71.4% women and mean age 66.67 ± 3.13 years) who had undergone motor neurorehabilitation with VR, mCIMT or fisical therapy/occupational therapy regular (rPT/OT) ($n = 6$, 8 and 7, respectively) for management post-stroke hemiparesis were analyzed. All participants were right-handed and had suffered a first CVE in the left MCA, as determined using computed tomography. Inclusion criteria were < 3 months of progression, severe aphasia (a score of 0–2 on the Boston Aphasia Intensity Scale (BAISc)), hemiparesis assessed with Fugl-Meyer scale and Table 1 lists the characteristics of the population in each group.

Ethical considerations: The study adhered to the tenets of the Declaration of Helsinki of 1964 and its latest amendment in Fortaleza, Brazil (2013) as well as the Rules of the General Health Act on Health Research Matters of Mexico (Reglamento de la Ley General de Salud en Materia de Investigación, 2022). This study is part of the research to obtain the degree of doctorate in Medical Sciences from the Master's and Doctorate Program in Medical, Dental, and Health Sciences of the National Autonomous University of Mexico (UNAM, for its acronym in Spanish), and approved by the Local Ethics and Research Ethics Committee (number 3702), pertain to the Mexican Social Security Institute (with the Spanish acronym IMSS), recorded under number R 2016-3702-44. Informed consent was not requested as it was a descriptive study in which stored information was used.

2.2. Methods

To achieve the objective of this work, a study with retrospective cohort design was carried out. The analyzed database included 32 patients who had undergone post-stroke hemiparesis therapy supported by VR or mCIMT in IMSS rehabilitation centres. Eleven patients were excluded because they did not meet the selection criteria.

The 21 patients corresponded to the groups as follows: Group I = VR ($n = 6$), Group II = mCIMT ($n = 8$) and Group III = rPhT/oT ($n = 7$). In each group, patients with hemiparesis had received management with motor neurorehabilitation described in a prior study involving a similar population (Rojas-Sosa et al., 2021) and general procedure of different treatments is described later, in the neuro-rehabilitation section. Patients underwent therapy two times a week, for 1 h each, over 6 weeks (12 sessions). Baseline evaluation (Bas. Eval.), intermediate evaluation (Interm. Eval.) after 3 weeks (six sessions), and ending evaluation (End. Eval.) after 6 weeks (12 sessions) were analyzed.

All patients reinforced the corresponding therapy at home, daily, for at least one hour a day. Details of clinical measurements are described below.

2.3. Hemiparesis/hemiplegia

A physical medicine and rehabilitation specialist, blinded to treatment, evaluated and recorded the patient's affected hemibody with the Fugl-Meyer Scale (F-MSc). Recorded scores that corresponded to the motor functions were analyzed, of the upper limb (UL –66 points-) and the lower limb (LL –34 points-) with a total qualification of 100 points (UL+LLqual.). The classification proposed by Duncan et al. for disability (1994) was used to determine the functionality in the following manner: 0–35 = highly severe; 36–55 = severe; 56–79 = moderate and >79 = mild (Duncan et al., 1994).

2.4. Aphasia

BAISc is validated for a simple language test in patients with neurological damage. A neuropsychologist, blinded to treatment, measured degree of aphasia using a structured interview. The following scores were considered: 0: The patient cannot speak or lacks listening comprehension. 1: The patient only utters incomplete phrases, and the examiner needs to infer the meaning, ask questions or guess based on what is uttered; information exchange is highly limited, and the conversation is led by the listener. 2: The patient can follow a conversation on familiar topics but requires support by the examiner and frequently fails to express an idea, although the conversation is led equally by the patient and the examiner. 3: The patient can talk about any daily subject, with very little or no help; however, the deterioration in speech and/or understanding makes it highly difficult or impossible to talk about complex subjects. 4: The patient shows some evident loss of fluency or ability to understand, and the ideas uttered are slightly limited. 5: The patient shows minimum speech deterioration (Moreno-Ramos et al., 2008).

2.5. Satisfaction

In experiments, the intrinsic motivation inventory is considered a satisfaction equivalent. The Task Assessment version was used, which included the following domains: 1. Interest and satisfaction with therapy (7 items); 2. Competence perception (in the face of therapy) (5 items); 3. Effort and importance of therapy (5 items); and 4. Pressure or tension (because of the therapy) (5 items) (Self-determination theory, 2020). In each item the patient scored from 1 (no satisfaction) to 7 (maximum satisfaction).

2.6. Hemiparesis neurorehabilitation

The programmes followed by each group have been described in a previous original paper (Rojas-Sosa et al., 2021). In general terms, for VR, Xbox-One and sensor Kinect® equipment, was used to carry out the actions indicated in the software: Tennis® and Ski® used for UL, Covering Cracks® was used for UL and LL and Star Wars: battles in the galaxy® software was used for hand and precision grip; patients repeated the activities at home with identical or similar equipment and software, for at least one hour a day, all week. Regarding mCIMT, PT/OT tasks were conducted with the healthy UL attached to the patient's chest during the session and they repeated the therapy at home for at least one hour a day, all week; furthermore, as part of the type of therapy, they had to fix the healthy arm for 5 h of the patient's daily life, using the paretic hand to carry out their activities. As regards rPT/OT, the same mCIMT programme was followed, but the healthy UL was not restricted and they repeated the therapy at home for at least one hour a day, all week. The physical and occupational therapy program included: tasks to promote mobility of the UL and LL by segments with transfers, volitional movements, visual-motor coordination, fine grip and gait (motor management) and deep sensitivity, stereognosia, sensory discrimination, graphesthesias, topognosias and proprioception (sensory training).

2.7. Statistics

Inferential analysis was performed using chi-squared test for qualitative variables, Friedman test for intra-group differences (post-hoc Wilcoxon), Kruskal–Wallis for inter-group differences (post-hoc Mann–Whitney) and Pearson's correlation coefficient for the association among hemiparesis, aphasia and satisfaction. The correlation equivalence proposed by Martínez-Ortega et al. (2009) was used. A p value of ≤ 0.05 was considered significant.

Table 2
Comparison of the scores obtained in the different measurements of motor progress of the affected hemibody, in language and satisfaction, for the 21 patients with hemiparesis and aphasia secondary to cerebrovascular event per motor rehabilitation group

		Groups			
		Virtual Reality ($n=6$)	Modified Constraint-Induced Movement Therapy ($n=8$)	Regular Physical Therapy/Occupational Therapy ($n=7$)	Significance (p)
Instrument	Score	X ± SD	X ± SD	X ± SD	KW*
Fugl-Meyer Scale (UL+LLqual.)	Initial	20.33 ± 6.68	23.88 ± 4.25	23.86 ± 6.33	0.49
	Intermediate	36.83 ± 9.98	36.38 ± 9.39	35.71 ± 11.01	0.91
	Ending	80 ± 13.94	60 ± 13.93	57.86 ± 10.22	0.02
Boston Aphasia Severity scale	Initial	1.17 ± 0.98	1.13 ± 0.83	1.14 ± 0.90	0.99
	Intermediate	3.67 ± 0.81	3.63 ± 1.5	3.57 ± 0.97	0.92
	Ending	4.83 ± 0.40	4.25 ± 0.70	4.0 ± 0.57	0.05
Intrinsic Motivation Inventory	Initial	50.8 ± 7.4	95.25 ± 7.88	93 ± 2.88	0.001
	Intermediate	115.17 ± 3.31	109.25 ± 5.47	106.14 ± 3.38	0.01
	Ending	150.17 ± 2.639	115.75 ± 12.56	125.71 ± 6.921	0.001

n = Number of patients; p = Level of statistical significance; KW* = Kruskal–Wallis test; X ± SD = Mean and standard deviation; UL = Upper limb; LL = Lower limb; UL+LLqual. = Upper Limb plus Lower Limb total qualification.

Table 3
Significantly related variables, per treatment group, correlation and magnitude of correlation

Group	Related Variables	Correlation (r)	Magnitude	Significance (p)
GI = VR	UL+LLqual. with Aphasia	0.73	High	0.047
GII = mCIMT	UL+LLqual. with Satisfaction	0.77	High	0.012
GIII = rPT/OT	UL+LLqual. with Satisfaction	0.81	High	0.014

Correlation (r) = Pearson's correlation coefficient; p = Level of statistical significance; (GI = VR): Group I, virtual reality; (GII = mCIMT): Group II, modified constraint-induced movement therapy; (GIII = rPT/OT): Group III, regular physical therapy and occupational therapy; UL+LLqual. = Upper Limb plus Lower Limb total qualification.

3. Results

3.1. Hemiparesis/hemiplegia

The intra-group comparison showed a continuous increase in motor skills during the treatment, with statistically significant differences in all group comparisons (Bas. Eval. - Interm. Eval., Bas. Eval. - End. Eval. and Interm. Eval. - End. Eval.) ($p = 0.002$). However, inter-group differences demonstrated significance only in the End. Eval. and were observed between VR and mCIMT ($p = 0.05$) and between VR and rPT/OT ($p = 0.02$) (Table 2). From a clinical perspective, all patients in all groups had a severe disability at baseline, and at the end, GI = VR improved towards mild disability and GII = mCIMT, and GIII = rPT/OT improved towards moderate disability.

3.2. Aphasia

In the three groups and in all comparisons, the BAISc yielded significant continuous intra-group improvement in language as motor training progressed ($p = 0.003$). Inter-group aphasia changes were significantly different in the End. Eval. between VR and rPT/OT ($p = 0.035$). From a clinical perspective, patients using VR showed almost optimal language skills, but more alterations were observed in the mCIMT and rPT/OT groups (Table 2).

3.3. Satisfaction

Intra-group changes in satisfaction towards management were significant for all three therapies ($p = 0.0001$), and the satisfaction increased after each measurement. Regarding inter-group changes, satisfaction was lower at baseline in GI = VR ($p = 0.001$). However, VR showed the highest scores in the Interm. Eval. and in the End. Eval., as opposed to mCIMT and rPT/OT ($p < 0.01$). Differences were observed in the End. Eval. of GII = mCIMT and GIII = rPT/OT ($p = 0.02$), with better scores being observed in regular therapy (Table 2).

3.4. Relationships

The GI = VR showed a high correlation between aphasia qualification and UL+LLqual. ($r = 0.73$; $p = 0.047$). Table 3 shows other significant relationships observed in GII = mCIMT and GIII = rPT/OT at end of treatment. There were other low relationships between aphasia improvement and motor recovery in the other 2 groups (mCIMT and rPT/OT), but they were not significant ($p > 0.05$).

4. Discussion

4.1. Hemiparesis/hemiplegia

Consistent with the analysis of 21 clinical trials that showed the positive effect of VR on post-stroke paretic limbs ($p < 0.001$), according to the F–MSc analysis (Zhang et al., 2021), our findings indicated a significant intra-group improvement for the three treatments. However, the inter-group comparison showed that VR resulted in the highest scores in the last two measurements (Table 2). This finding is congruent with the statement that when patients with CVE engage in virtual games and notice improvements in their hemiparesis, their trust and self-efficacy increases, which positively affects their learning and plasticity. As a result, an effect on brain remodelling and reorganisation is felt (Anwar et al., 2022).

4.2. Aphasia

Our study evidenced a significant and continuous intra-group change in aphasia (Table 2) in patients who had only undergone motor rehabilitation for hemiparesis using techniques that have been proven to provide generalised brain stimulation and whose feedback promotes use-dependent cortical plasticity (Bani-Ahmed, 2019; Anwar, 2022) with no logotherapy involved, due to a delay of more than 4 months in the medical appointment in the language therapy service. Improvements in aphasia during motor training are consistent with evidence of the participation of specific motor circuits in the perceptive speech process (Pulvermüller et al., 2006). Hence, the idea that language is restored “on its own” is still under debate as it may be being stimulated during motor neurorehabilitation, activation of the auditory pathway or via music, such as the one used in VR games (Panouillères et al., 2018; Venezia et al., 2021; Nuttall et al., 2022), at least during the first months, where brain plasticity is greater. The idea that VR favours a progressive and continuous learning process that permits the brain neurons to remain active for a longer time to restore functions and form new connections (Valentin L. S. S., 2017) would support the fact that language scores were better with VR in our study (Table 2). This idea further supports the high correlation between improvements in aphasia and hemiparesis (Table 3). The above considers the assessment of neural plasticity in stroke survivors managed with VR using functional Magnetic Resonance (fMRI), Electroencephalography (EEG), and Transcranial Magnetic Stimulation (TMS) (Hao et al., 2022). Specifically, with fMRI, the main findings after undergoing VR management included: greater activation of the ipsilesional primary sensorimotor cortex and contralesional activation of the primary motor area, activation in bilateral supplementary motor cortex, as well as, changes generalized bilateral activation along with the contralesional premotor cortex, among other variations in brain activity. The evidence of these modifications in cortical areas function would support that the VR intervention increased task-evoked brain capacity in an extended network during attention cues (Xiao et al., 2017; Saleh et al., 2017; Hao et al., 2022).

Although mCIMT tends to be used for UL, it exerts a positive effect on general motor recovery and additional network recruitment (Bani-Ahmed et al., 2019), which could be consistent with the improvements in aphasia observed in this group, since, in particular, the ventral premotor cortex is involved in various aspects of motor learning in healthy individuals and with recovery after injury in both humans and animals. TMS studies suggest that the ventral premotor cortex (VPC) contributes to functional motor recovery in persons with CVE, well, with intact premotor cortex they have better functional independence than those in whom the premotor cortex was damaged, hence the findings suggest that reorganization in non-primary cortical motor areas, such as the VPC, which has been proposed as a neural substrate that contributes to the recovery motor after stroke related to “forced use” therapy (Frost et al., 2022). This could be consistent with the improvements in aphasia observed in the mCIMT group, because this therapy has been associated with the reorganization of premotor maps, evaluated using intracortical microstimulation (ICMS) techniques in monkeys (Frost et al., 2022) and with TMS in humans (Fridman et al., 2004) which are, in turn, related to the activation of brain functions (Arya et al., 2011) and associated with language processing since some fMRI studies have detected activation of the premotor cortex involved in the somatotopic representation of the hands, legs, and mouth when subjects heard to speech and move these parts of the body. Therefore, these results suggest that premotor areas would support a relation between the linguistic information with physical movement (hands, legs, or mouth) (Onmyoji et al., 2015).

4.3. Satisfaction

The lowest baseline satisfaction score corresponded to VR (Table 2) probably because the patients doubted the fact that "videogames" could be considered a form of "rehabilitation" (Tieri et al., 2018). Subsequently, satisfaction significantly increased in the GI = VR (Table 2) together with motor improvement (Table 2) probably because the patients' perception of their reduced disability motivated them and increased their satisfaction levels (Colombo et al., 2007). When participants "feel" a natural interaction in interactive VR scenarios, the brain receives multisensory stimulation, as well as an increase in enjoyment and fun, at the cognitive and physical levels. This augments the benefits of neurorehabilitation in terms of motor and cognitive re-learning (Leeb R & Pérez-Marcos, 2020), which would explain the high scores achieved by the VR group.

4.4. Relationship between hemiparesis recovery and aphasia

Up to 20 years ago, aphasia and hemiplegia were said to be related because of neural connections and irrigation as a single CVE affected several functions (Anderlini et al., 2019). Moreover, several aspects of speech motor control are involved in perception because of the presence of non-identical subpopulations of neurons that codify auditory and cognitive functions, such as in the brain areas of sensory–motor integration (Nuttall et al., 2022). We found a high coefficient correlation when establishing a possible clinical connection ($r = 0.73$; $p = 0.047$) between aphasia and post-stroke hemiparesis, only in the VR group, but this may be due a small sample size since in all groups both variables always showed positive changes. Our findings agree with the proposal that motor and language systems may share a common neural substrate as, from the functional perspective, they appear to have a similar objective (Anderlini et al., 2019). Considering the above, it seems that comprehensive neurorehabilitation could be possible, so the measurement of aphasia during motor rehabilitation of stroke sequelae should be taken into account, as well as satisfaction with the treatment, since it can contribute to the final clinical result.

Although the post-stroke clinical evolution could be moderately influenced by some clinical factors, such as sex, age, time of evolution, and location or size of the infarct, especially during the first 3 to 6 months (Prabhakaran et al., 2008), spontaneous recovery or "proportional recovery" in this period, it has currently been questioned as a valid recovery model after EVC due to possible mathematical coupling errors and ceiling effects. However, it is still considered useful (Chong et al., 2023) and the measurement of clinical predictors in various studies would be important. Although it was not part of the objective of this work, its measurement could be considered in the following investigations.

However, current research separates stroke assessment and rehabilitation in patients with aphasia or patients with hemiparesis, without taking neural organization and neuroplasticity into consideration (Anderlini et al., 2019). Therefore, our study could add to the few investigations of its kind to resume the global assessment approach for the rehabilitation of CVE sequelae using unconventional therapies, such as VR and mCIMT, and would provide further evidence for the utility and feasibility of VR therapy as a neurorehabilitation technique to favor hemiparesis recovery and language improvement after stroke (Anderlini et al., 2019; Vilageliu-Jordà et al., 2022) during the first months post-stroke.

5. Conclusions

The main finding of this study was to document evidence for the continuous improvement in the level of after-stroke aphasia of patients that received motor neurorehabilitation to improve their hemiparesis and with no language therapy. Improvements were significantly higher in the group that performed VR activities compared to the mCIMT and rPT/OT groups. Similarly, patients' satisfaction level was significantly greatest in those who performed VR activities. Furthermore, a high correlation between positive changes in hemiparesis and aphasia at the end of the treatment was observed only in the VR group. The findings of our study are consistent with the idea that there is a common neural motor and language substrate and that motor restoration optimized by brain plasticity stimulated with motor neurorehabilitation could favor recovery in post-stroke aphasia, at least during the first 3 months after stroke. Global assessment in patients with post-stroke motor sequelae, including aphasia and satisfaction, is hence important, which would be further will be investigated as a line of research.

Study limitations: The study population is small. However, the findings constitute a basis for starting a randomized clinical trial in which all the relevant variables detected are measured, such as hemiparesis, aphasia, satisfaction, number of hours of reinforcement at home, and even the influence of the therapist's or doctor's "conduct".

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Declaration of interest

The authors have no conflict of interest to declare.

Ethics statement

This study is part of the research approved by the IMSS's Local Ethics and Research Ethics Committee (number 3702).

Informed consent

As this is a descriptive study, informed consent was not required.

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