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ORIGINAL RESEARCH

Effects of virtual reality training in the upper limb motor coordination of individuals post- stroke: a systematic review with meta-analysis

Efeitos do treino de realidade virtual na coordenação motora dos membros superiores de indivíduos após acidente vascular encefálico: uma revisão sistemática com meta-análise

Efectos del entrenamiento de realidad virtual en la coordinación motora de miembros superiores de individuos después de un accidente cerebrovascular: una revisión sistemática con metaanálisis

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ABSTRACT | After a stroke, 75% of people are affected in their upper limbs, remaining with sequelae at these limbs. Results from recent clinical trials have been contradictory regarding the effectiveness of Virtual Reality (VR) therapy in rehabilitating upper limb motor coordination in this population. This study aimed to perform a systematic literature review with meta-analysis to investigate the effects of VR training on upper limb motor coordination in patients post-stroke. Searches were performed in the electronic databases PubMed, LILACS, SciELO, PEDro, in addition to manual searches. The whole process was performed by two independent raters. The methodological quality of the studies was assessed by the PEDro scale. In total, we selected 18 studies, out of which only 13 were included in the meta-analysis. In general, VR training was effective in improving upper limb motor coordination (SMD 0.32; 95% CI 0.08–0.56; I^2=42%; p<0.01). When subgroup analysis assessed control group type, VR training was superior than no intervention (SMD 0.36; 95% CI: 0.06–0.66; p<0.05). However, when compared to other interventions, we found no significant difference (SMD 0.26; 95% CI: −0.12–0.64; p=0.18). Overall, VR training is effective in improving upper limb motor coordination in post-stroke individuals compared to no intervention. However, it shows no superiority when compared to other types of intervention used in the rehabilitation of upper limb motor coordination in these patients.

Keywords | Virtual Reality; Motor Skills; Upper Extremity; Stroke; Systematic Review.

RESUMO | Após um acidente vascular encefálico (AVE), 75% das pessoas tem o membro superior acometido, permanecendo com sequelas nessa extremidade. Resultados de ensaios clínicos recentes são contraditórios quanto à eficácia da terapia de realidade virtual (RV) na reabilitação da coordenação motora dos membros superiores dessa população. Assim, o objetivo deste trabalho foi realizar uma revisão sistemática da literatura, com meta-análise, a fim de investigar os efeitos do treinamento com RV na coordenação motora dos membros superiores em pacientes pós-AVE. Para isso, foram feitas buscas nas bases de dados PubMed, LILACS, SciELO, PEDro e buscas manuais. Esse processo foi realizado por dois avaliadores independentes, e a qualidade metodológica dos estudos foi avaliada pela escala PEDro. Foram selecionados 18 estudos, sendo que apenas 13 foram incluídos na meta-análise. De forma geral, o treino de RV se mostrou eficaz na melhora da coordenação motora dos membros superiores da população (SMD 0,32; IC95% 0,08 a 0,56; I^2=42%; p<0,01). Após uma análise de subgrupos, o treino de RV demonstrou ser superior quando comparado a nenhuma intervenção (SMD 0,36; IC95% 0,06 a 0,66; p<0,05). No entanto, quando comparado a outras

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intervenções, não houve diferença significativa (SMD 0,26; IC95% −0,12 a 0,64; p=0,18). De forma geral, o treino de RV é eficaz na melhora da coordenação motora dos membros superiores de indivíduos pós-AVE em comparação a nenhuma intervenção. No entanto, não é superior quando comparado a outros tipos de intervenção utilizados na reabilitação da coordenação motora dos membros superiores dos pacientes.
Descritores | Realidade Virtual; Destreza Motora; Extremidade Superior; Acidente Vascular Cerebral; Revisão Sistemática.

RESUMEN | El 75% de las personas que son acometidas por un accidente cerebrovascular (ACV) presentan secuelas en el miembro superior acometido. Los resultados de ensayos clínicos recientes son contradictorios con respecto a la efectividad de la terapia de realidad virtual (RV) en la rehabilitación de la coordinación motora de los miembros superiores en esta población. Por lo tanto, el objetivo de este trabajo fue realizar una revisión sistemática de la literatura, con metaanálisis, para investigar los efectos del entrenamiento con RV en la coordinación motora de los miembros superiores en pacientes post-ACV. Para ello, se realizaron búsquedas en las bases de datos PubMed, LILACS, SciELO, PEDro y búsquedas manuales. Este proceso fue realizado por dos evaluadores independientes, y la calidad metodológica de los estudios se evaluó mediante la escala PEDro. Se seleccionaron 18 estudios, de los cuales solo 13 se incluyeron en el metaanálisis. En general, el entrenamiento con RV demostró ser efectivo para mejorar la coordinación motora de los miembros superiores de la población (SMD 0,32; IC95% 0,08 a 0,56; I^2=42%; p<0,01). Después de un análisis de subgrupos, el entrenamiento de RV fue superior cuando no estuvo comparado con otras intervenciones (SMD 0,36; IC95% 0,06 a 0,66; p<0,05). Sin embargo, no hubo diferencias significativas en la comparación con otras intervenciones (SMD 0,26; IC95% −0,12 a 0,64; p=0,18). En general, el entrenamiento con RV es eficaz para mejorar la coordinación motora de los miembros superiores en personas post-ACV cuando esta intervención no estuvo comparada con otras. Sin embargo, no es superior en comparación con otros tipos de intervención que se aplican en la rehabilitación de la coordinación motora de los miembros superiores de los pacientes.
Palabras clave | Realidad Virtual; Destreza Motora; Extremidad Superior; Accidente Cerebrovascular; Revisión Sistemática.

INTRODUCTION

Stroke is the obstruction (ischemia) or blood extravasation (hemorrhage) of a certain area of the brain, resulting in neurological and/or motor loss[1], which may lead to hemiparesis or hemiplegia in the opposite side of the lesion[2]. Currently, this is one of the conditions that most affect the population, showing the highest prevalence among neurological pathologies[3], causes of death, and temporary or permanent disabilities worldwide[3]. Data indicate that 70% of patients after stroke show some kind of difficulty in performing daily activities and limitations to functioning and oral communication[4]. These individuals show muscle weakness, changes in motor control, balance, proprioception, sensitivity, and spasticity, explaining the limitations that impair their performance at work and in basic daily activities, thus restricting their social participation[5].

After a stroke, 75% of people are affected in an upper limb and, of these, 30 to 66% remain with sequelae at this extremity[6]. In addition to the aforementioned motor disabilities, another common characteristic of affected upper limbs is their flexor pattern, in which patients adopt digital, wrist and elbow flexion, forearm pronation, and shoulder adduction and internal rotation[7], preventing adequate coordinated movements for feeding, self-care, and hygiene[8]. Motor coordination or dexterity can be defined as the ability to perform motor tasks in an accurate, fast, and controlled manner[9]. In post-stroke individuals, loss of motor coordination significantly contributes to disability[10] due to uncoordinated muscle activity to achieve task and environment demands[10]. Such impairment can lead to inadequate positioning of affected upper limbs, and difficulties with reach-to-grasp, object manipulation, and combined muscle movements in the affected limb[11].

Currently, physical therapists use several treatments in patients post-stroke, of which virtual reality (VR) is one option. VR is an interactive computerized technology that encourages patients, even those with physical and cognitive disabilities, to simulate tasks aiming at neurological rehabilitation[12]. This method simulates real environments, making individuals participate in realistically and interactively built scenes[13,14]. Patients are represented in game by an avatar that can capture the movements of the entire body, identifying changes in speed, direction, and acceleration[14]. Moreover, since VR displays movements in real time, it enables accurate feedback and activity improvement[14].

Recent studies show contradictory results regarding the efficacy of VR in rehabilitating upper limb motor coordination in post-stroke individuals. Givon et al., conducted a randomized clinical trial with 47 post-stroke individuals and reported no significant effects on the upper limb motor coordination of the group which received VR training, in comparison to control, which received conventional physical therapy[15]. Kong et al., also compared the effects of VR to conventional physical therapy and no treatment in 105 patients who were randomized into one of these groups, finding no significant differences in the improvement of upper limb motor coordination among groups[16]. On the other hand, Afsar et al. conducted a randomized clinical trial with 43 post-stroke individuals and reported significantly improved motor coordination in the RV therapy group associated with conventional therapy, compared to the control which only received conventional therapy[17]. Another clinical trial also randomly distributed 18 patients in an experimental group which received VR training and the control group, which performed bilateral upper limb training without VR, reporting significant improvement in the motor coordination of the former group[18].

Thus, although previous randomized clinical trials have investigated the effects of VR training on the upper limb motor coordination of post-stroke individuals, their results are contradictory. In this context, a systematic, structured, analytical, and critical review is the best way to synthesize existing information[19]. Moreover, whenever possible, systematic reviews should include a meta-analysis[20], quantifying the results of several studies in a standard metric[19]. Systematic reviews with meta-analyses provide greater accuracy for the information related to the effect of a given intervention[20]. Thus, researchers should summarize evidence from clinical trials via systematic reviews with meta-analyses to provide immediate responses to researchers, clinicians, and patients. However, we found no systematic meta-analysis reviews investigating the effects of VR training on upper limb motor coordination in post-stroke individuals.

Thus, this study aimed to conduct a systematic review, associated with a meta-analysis, of the literature to investigate the effects of VR training on upper limb motor coordination in patients post-stroke.

METHODOLOGY

Selection of studies

Between June and August 2019, searches were conducted in the electronic databases PubMed, Latin American and Caribbean Literature in Health Sciences (LILACS), Scientific Electronic Library Online (SciELO), and Physiotherapy Evidence Database (PEDro). The descriptors used for specific searches related to stroke, motor coordination, upper limb, and virtual reality in both Portuguese and English. The specific research strategies on each basis can be found in Appendix 1. No restriction was applied regarding language and publication year. Article search and selection was conducted by two independent raters (CVM and SFF). A third rater was consulted (KKPM) to solve any disagreements. Finally, a manual search was also performed in the reference lists of all included articles to identify other relevant studies.

Inclusion and exclusion criteria

Only randomized clinical trials dealing with VR training in patients post-stroke of any age, gender, and time elapsed after lesion were included. Studies that failed to meet the inclusion criteria, with incomplete data or conducted with less than five participants were excluded. The outcome of interest was upper limb motor coordination, mandatorily evaluated by tests that involved fast and alternating movements and simultaneously considered movement speed and quality as scoring criteria[21]. Incomplete studies, feasibility studies without previous results, pilot studies, those including other pathologies or another intervention in the experimental group were also excluded.

Data extraction

Sample characteristics (size, age, time elapsed after stroke), study aim, training protocol (type of VR used; comparison performed; and training duration, frequency, and intensity), tests used to evaluate upper limb motor coordination, and results were extracted from the selected studies.

Methodological quality

The methodological quality of the studies was evaluated by the PEDro scale, which assesses bias risks, internal validity, and whether statistical information is sufficient for interpretability. The scale has eleven items, the first of which, unscored, relates to external validity. Scores range from zero to 10; the higher the score, the better the methodological quality of the study[22]. The scores provided by the PEDro database were used in this study. When studies were absent in the PEDro database, methodological quality assessment was performed by the researchers.

Data analysis

All information on the studies was extracted by two raters (CVM and SFF) and verified by a third evaluator (KKPM). Post-intervention measures (mean and standard deviation) were used since these values were unavailable for all studies. Moreover, the fixed effects model was preferably used and, in cases of statistically significant heterogeneity ($I^2>40\%$), effect size was analyzed by the random effects model. The data grouped for all results were reported as standard mean differences (SMD), along with their respective 95% confidence intervals (95% CI). A 0.10 SMD was considered small; 0.30, average; and 0.50, large[23]. Analyses were carried out in Comprehensive Meta-Analysis, version 3.0. The critical value to reject H_0 was set at a 5% significance level (two-tailed). When the published studies did not present necessary information, additional details were requested, by e-mail, to the corresponding authors. When data were unavailable for meta-analysis inclusion, the differences between comparison groups were just described.

RESULTS

Our electronic search produced 577 articles. Out of these, we excluded 340 after reading their titles and 187, after reading their abstracts, thus leaving us 50 articles to full-reading. After reading them, we selected 18 studies according to previously determined inclusion criteria[15-18,24-37]. Figure 1 shows our article inclusion flowchart.

Table 1 describes the 18 included studies. The methodological quality of the clinical trials ranged from 4 to 8, with an average of 6.4 (SD 1.2) (Table 2). Studies included from 18 to 235 participants with a mean age of 62.6 years (SD 4.8), and three studies (17%) included subjects in the acute, three (17%) in the subacute, and 12 (66%) in the chronic post-stroke phases. VR interventions lasted from 30 to 60 minutes, two to seven times a week for three to 12 weeks. Regarding comparisons, six studies (33%) compared VR with no treatment17,25,29-31,36; whereas 11 (61%), with another type of treatment15,18,24,26-28,32-35,37. Only one (6%) used two experimental groups, comparing VR with no treatment and another type of treatment16. Note that, when studies administered the same intervention in both groups and, additionally, VR in the experimental group, we considered the comparisons between VR and no treatment. In studies comparing VR with other treatments, the administered interventions were upper limb exercises to be done at home, conventional therapy, specific exercise protocols for upper limb rehabilitation, induced containment therapy, recreational games, and the same exercise protocol for the VR group without the interface. In relation to the reported tests to evaluate upper limb motor coordination, studies used action research arm, box and blocks, wolf motor function, and Jebsen-Taylor hand function tests.

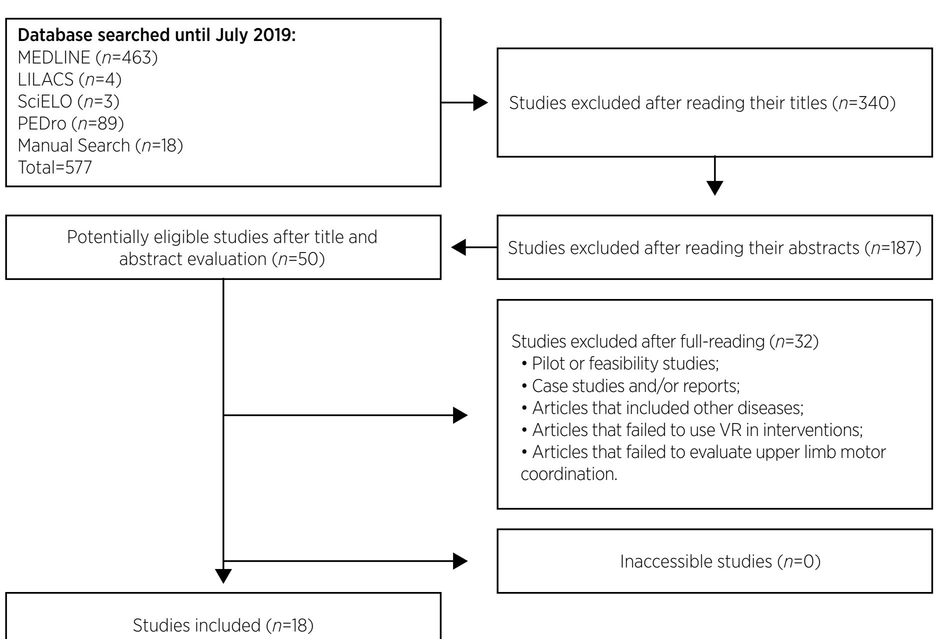

Figure 1. Article selection flowchart

Table 1. Characteristics of the included studies (n=18)

STUDY	PARTICIPANTS	PROTOCOL	MOTOR COORDINATION TEST	RESULTS
Adie et al. (2016)	235 participants Age: 67.4±13.3 Experimental group (n=117) Control group (n=118) Acute stroke	**Experimental group**: performed 45 minutes of exercise at home, sitting, with Nintendo Wii Sports™ every day for six weeks. **Control group:** performed 45 minutes of upper limb exercises, sitting, every day for six weeks at home.	action research arm test	There was no significant difference between the experimental and control groups. Both groups improved.
Afsar et al. (2018)	35 participantes Age: 66.4±8.1 Experimental group (n=19) Control group (n=16) Subacute stroke	**Experimental group**: 30-minute VR training with Microsoft Xbox 360 Kinect five times a week for four weeks + 60-minute conventional therapy five times a week for four weeks. **Control group:** 60-minute conventional therapy five times a week for four weeks.	box and blocks test	There was a significant improvement in the experimental group when compared to the control group.
Askin et al. (2018)	40 participants Age: 54.9±10.5 Experimental group (n=20) Control group (n=20) Chronic stroke	**Experimental group**: 20 one-hour VR training sessions with Microsoft Xbox 360 Kinect five times a week for four weeks + 20 physical therapy sessions five days a week for four weeks. **Control group:** 20 conventional therapy sessions, five days a week for four weeks.	box and blocks test	Both groups improved significantly. There was no between-group analysis.
Brunner et al. (2017)	120 participantes Age: 62 Experimental group (n=62) Control group (n=58) Subacute stroke	**Experimental group**: 60-minute VR training with Microsoft Xbox 60 Kinect from four to five times a week for four weeks + conventional therapy. **Control group**: 60-minute standardized exercises with emphasis on task-oriented practice four to five times a week for four weeks + conventional therapy.	action research arm test and box and blocks test	There was no significant difference between the experimental and control groups. Both groups improved.
Choi et al. (2014)	20 participants Age: 64.5±10.8 Experimental group (n=10) Control group (n=10) Subacute stroke	**Experimental group**: VR training with the Nintendo *Wii game* for 30 minutes a day five times a week for four weeks. **Control group:** conventional therapy five times a week for 30 minutes for four weeks.	box and blocks test	Both groups significantly improved. There was no analysis between groups.
Givon et al. (2015)	47 participants Age: 59.4±9.3 Experimental group (n=23) Control group (n=24) Chronic stroke	**Experimental group:** VR training with Microsoft Xbox Kinect, Sony PlayStation 2 Eye Toy, Sony PlayStation 3 Move, Nintendo Wii Fit, and the SeeMe VR system with two one-hour sessions per week for three months. **Control group:** conventional therapy with two one-hour sessions per week for three months.	action research arm test	There was no significant difference between the experimental and control groups. Both groups improved.
Hung et al. (2019)	33 participants Age: 59 Experimental group (n=17) Control group (n=16) Chronic stroke	**Experimental group:** VR training with Kinect 2 Scratch with 30-minute 24 sessions for 12 weeks + 45 minutes of manual function training and daily activities. **Control group:** 24 30-minute conventional therapy sessions for 12 weeks + 45 minutes of manual function training and daily activities.	wolf motor function test	There was no significant difference between experimental and control groups. Both groups improved.
In et al. (2012)	19 participants Age: 64±12.2 Experimental group (n=11) Control group (n=8) Chronic stroke	**Experimental group**: 30-minute VR training five days a week for four weeks + conventional therapy. **Control group**: conventional therapy.	box and blocks test	There was no significant difference between the experimental and control groups. Both groups improved.
Jo et al. (2012)	29 participants Age: 64±7.1 Experimental group (n=15) Control group (n=14) Chronic stroke	**Experimental group:** VR training with the game Interactive Rehabilitation and Exercise System for 60 minutes a day five times a week for four weeks + conventional therapy three times a week for 30 minutes for four weeks. **Control group:** conventional therapy three times a week for 30 minutes for four weeks.	wolf motor function test	No group improved significantly. There was no analysis between groups.

(continues)

Table 1. Continuation

STUDY	PARTICIPANTS	PROTOCOL	MOTOR COORDINATION TEST	RESULTS
Kong et al. (2016)	105 participants Mean age: 57.6±11.4 Experimental group 1 (n=35) Experimental group 2 (n=35) Control group (n=35) Acute stroke	**Experimental group 1:** VR training with the Nintendo Wii Sports game™ for 12 60-minute sessions four times a week for three weeks + one hour of conventional therapy daily. **Experimental group 2**: 12 60-minute stretching, strengthening, and range of motion exercises; task-specific training; and upper limb skill training sessions four times a week for three weeks + one hour of conventional therapy daily. **Control group:** one hour of conventional therapy daily.	action research arm test	There was no significant differences among experimental and control groups. All groups improved.
Lee et al. (2013)	24 participants Age: 61.9±10 Experimental group (n=12) Control group (n=12) Chronic stroke	**Experimental group:** VR asymmetric training 30 minutes a day, five days a week for four weeks + 30-minute conventional therapy twice a day, five days a week for four weeks. **Control group:** conventional therapy twice a day, five times a week for 30 minutes for four weeks.	box and blocks test	There was a significant improvement in the experimental group when compared to control.
Lee et al. (2016)	18 participants Age: 71.3±7.3 Experimental group (n=10) Control group (n=8) Chronic stroke	**Experimental group:** upper extremity bilateral exercises in a VR environment in 30-minute sessions thrice a week for six weeks. **Experimental group:** upper extremity bilateral exercises in 30-minute sessions thrice a week for six weeks.	box and blocks test	There was a significant improvement in the experimental group when compared to control.
McNulty et al. (2015)	41 participants Age: 58 ± 15.4 Experimental group (n=21) Control group (n=20) Chronic stroke	**Experimental group:** VR training with *Nintendo Wii* for 10 consecutive 60-minute sessions. **Control group:** induced containment therapy with containment for 90% of the day and continuous activity training of 15 to 20 minutes.	wolf motor function test	There was no significant difference between the experimental and control groups. Both groups improved.
Saposnik et al. (2016)	141 participants Age: 62±12.5 Experimental group (n=71) Control group (n=70) Acute stroke	**Experimental group:** non-immersive VR training with *Nintendo Wii* for 10 60-minute sessions. **Control group:** recreational games (card games or bingo, for example) for 10 60-minute sessions for two weeks.	wolf motor function test	There was no significant difference between the experimental and control groups. Both groups improved.
Schuster-Amft et al. (2018)	54 participants Age: 61.3±12.3 Experimental group (n=22) Control group (n=32) Chronic stroke	**Experimental group:** 45-minute VR training four days a week for four weeks + conventional therapy. **Control group:** 45-minute conventional therapy four times a week for four weeks.	box and blocks test	There was no significant difference between the experimental and control groups. Both groups improved.
Shin et al. (2016)	46 patients Age: 58.5±11.7 Experimental group (n=24) Control group (n=22) Chronic stroke	**Experimental group:** VR training with RAPAEL Smart Glove™, with 20 30-minute sessions for four weeks + conventional therapy for 30 minutes. **Control group:** same category of movements without VR, with 20 30-minute sessions for four weeks + conventional therapy for 30 minutes.	Jebsen-Taylor hand function test	There was a significant improvement in the experimental group when compared to control.
Sin & Lee (2013)	40 participants Age: 73.7±7.5 Experimental group (n=20) Control group (n=20) Chronic stroke	**Experimental group:** VR training with Microsoft Xbox Kinect thrice a week for 30 minutes for six weeks + conventional therapy thrice a week for 30 minutes for six weeks. **Control group:** conventional therapy three times a week for 30 minutes for six weeks.	box and blocks test	There was a significant improvement in the experimental group when compared to control.
Subramanian et al. (2013)	32 participants Age: 61±10.4 Experimental group (n=16) Control group (n=16) Chronic stroke	**Experimental group:** VR training with Computer Assisted Rehabilitation Environment for 45 minutes thrice a week for four weeks. **Control group:** same category of movements without VR for 45 minutes thrice a week for four weeks.	wolf motor function test	There was a significant improvement in the experimental group when compared to control.

* VR: virtual reality.

Table 2. Study detailing on the PEDro scale (*n*=18)

Study	Randomization	Blinded participant distribution	Initial similarity between groups	Participant blinding	Therapist blinding	Evaluator blinding	Measures of primary outcome	"Intent to treat"	Intergroup comparison of primary outcome	Accuracy and variability measures for at least one outcome	Total
Adie et al. (2016)	Y	Y	Y	N	N	N	Y	Y	Y	Y	7/10
Afsar et al. (2018)	Y	Y	Y	N	N	Y	N	N	Y	Y	6/10
Askin et al. (2018)	Y	N	Y	N	N	Y	Y	N	Y	Y	6/10
Brunner et al. (2017)	Y	N	Y	N	N	Y	Y	Y	Y	Y	7/10
Choi et al. (2014)	Y	N	Y	N	N	Y	Y	Y	Y	Y	7/10
Givon et al. (2015)	Y	N	Y	N	N	Y	Y	Y	Y	Y	7/10
Hung et al. (2019)	Y	Y	Y	N	N	Y	Y	Y	Y	Y	8/10
In et al. (2012)	Y	N	Y	N	N	N	N	N	Y	Y	4/10
Jo et al. (2012)	Y	N	Y	N	N	N	Y	N	Y	Y	5/10
Kong et al. (2016)	Y	N	Y	N	N	N	Y	N	Y	Y	5/10
Lee et al. (2013)	Y	N	Y	N	N	Y	N	N	Y	Y	5/10
Lee et al. (2016)	Y	N	Y	N	N	Y	Y	N	Y	Y	6/10
McNulty et al. (2015)	Y	Y	Y	N	N	Y	Y	Y	Y	Y	8/10
Saposnik et al. (2016)	Y	N	Y	N	N	Y	Y	Y	Y	Y	7/10
Schuster-Amft et al. (2018)	Y	Y	Y	N	N	Y	Y	Y	Y	Y	8/10
Shin et al. (2016)	Y	Y	Y	N	N	Y	N	Y	Y	Y	7/10
Sin & Lee (2013)	Y	N	Y	N	N	Y	Y	N	Y	Y	6/10
Subramanian et al. (2013)	Y	Y	Y	N	N	Y	Y	N	Y	Y	7/10

VR effects on upper limb motor coordination in post-stroke individuals

Regarding meta-analysis, we included 13 studies that evaluated VR effects on upper limb motor coordination in post-stroke individuals. Moreover, one study assessed upper limb motor coordination with two instruments, and another included two intervention groups, resulting in a total of 15 comparisons (Figure 2). In general, VR training was moderately effective in improving this population's upper limb motor coordination (SMD 0.32; 95% CI: 0.08–0.56; I^2=42%; p<0.01). When subgroup analyses were performed regarding type of control group, VR training was higher than no intervention, also with a moderate effect (SMD 0.36; 95% CI: 0.06–0.66; I^2=42%; p<0.05). However, when compared to other interventions, there was no significant difference (SMD 0.26; 95% CI −0.12–0.64; p=0.18). Five studies could not be included in our meta-analysis since they showed insufficient data[25,28,32,34,37]. Table 2 describes their results and those of other studies individually.

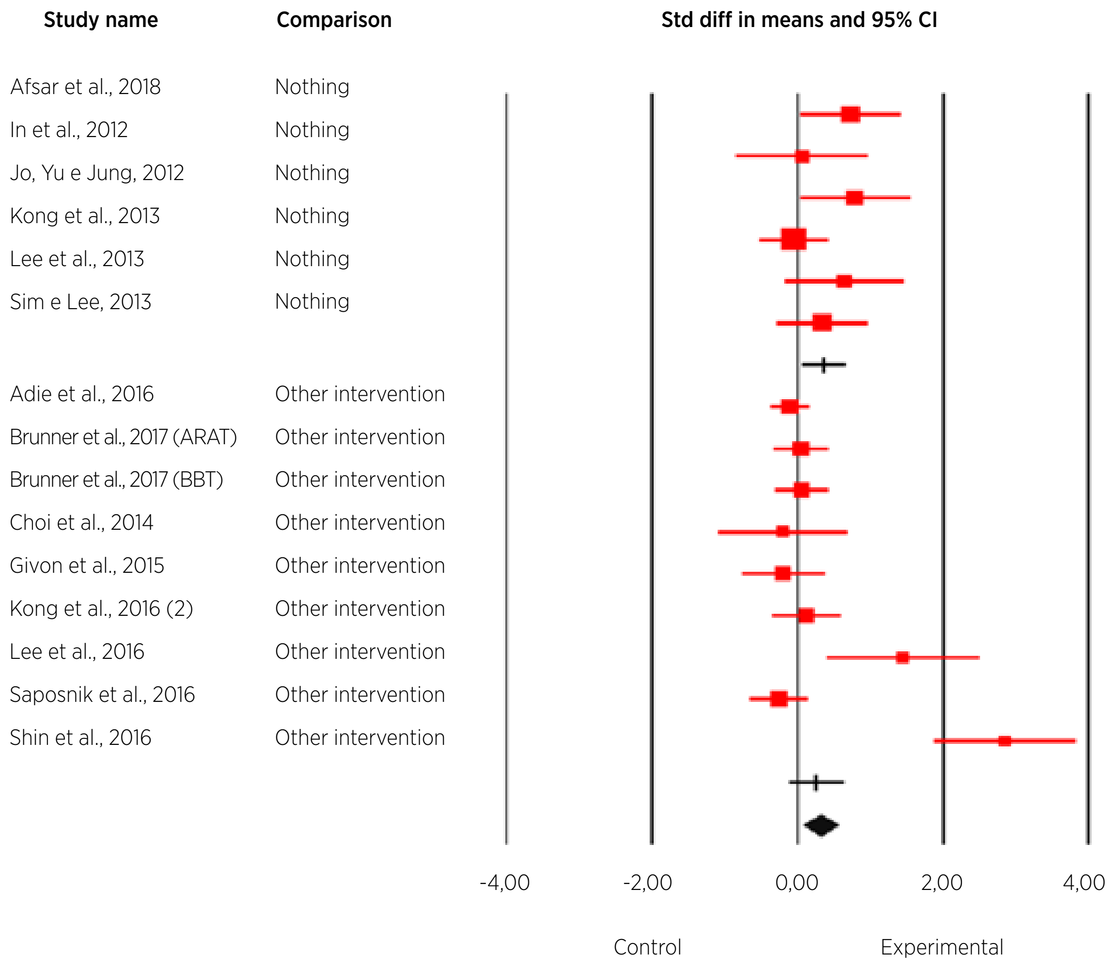

Figure 2. Forest plot for the VR effect to upper limb motor coordination in post-stroke individuals

DISCUSSION

This systematic review with meta-analysis aimed to investigate the effects of VR training on upper limb motor coordination in post-stroke individuals. In general, VR showed significantly improved upper limb motor coordination in post-stroke individuals. When compared to no intervention, it showed a moderate effect. Thus, it may be indicated to treat this population. In fact, when individuals receive no intervention on the affected upper limb, they tend to ignore it, no longer using it in daily activities, prioritizing the use of the non-paretic limb. This situation leads to the so-called "learned disuse" phenomenon, producing inadequate changes in individuals' neuroplasticity which are harmful to its evolution[38]. In this case, VR training that recruits and uses such limbs in specific activities—thus making it more active—avoids the neglect of the paretic limb and the progression of its involvement.

However, VR training fails to be superior to other types of intervention used in rehabilitating these patients' upper limb motor coordination. Although VR training is generally considered more attractive, the literature finds greater treatment adherence and possibly more significant results in children's rehabilitation39. Adults, even if more attracted to a more playful treatment, know the importance of rehabilitation for their disabilities and tend to have a similar adherence to any proposed treatment strategy40. Thus, since VR shows effects similar to other intervention types on upper limb motor coordination, it can be considered another option among the various resources to rehabilitate post-stroke individuals. However, we should mention that VR, though showing effects similar to other techniques, is a relatively expensive resource, inaccessible to all therapists and patients, which may restrict its choice.

A previous systematic review, published in 2007, aimed to evaluate the effects of VR training on upper limb motor recovery in post-stroke individuals, reporting that, although there was limited evidence, results were encouraging[41]. However, in addition to lacking a meta-analysis, the measured outcome was unspecific for motor coordination[41]. In total, three other systematic reviews with meta-analysis aimed to evaluate the effects of the intervention on this population's upper limb motor function[42-44]. Corroborating the results of our study, in general, all studies found a significant, moderate effect of VR training when compared to control[42-44]. However, no study performed a subgroup analysis considering types of comparison or was specific for upper limb motor coordination. Finally, another systematic review with meta-analysis evaluated the effects of VR on the upper limbs of post-stroke individuals, reporting separate data for body structure and function, in which motor coordination is inserted, with results similar to this study, i.e., a moderate effect[45]. Thus, although no previous review has specifically investigated the effects of VR on upper limb motor coordination in this population, we found that our data corroborate the findings of reviews evaluating general upper limb function, showing the moderate effect of the intervention. In fact, motor coordination is fundamental for upper limb function in post-stroke individuals, justifying the similar results found[46].

Among the strengths of this review, we can mention its systematic approach with meta- and subgroup analyses, and the inclusion of a substantial number of articles to evaluate a specific outcome yet uninvestigated in the literature. Among its limitations, we can consider the average moderate methodological quality of the included studies whose interpretation requires caution. However, we should mention that, due to the nature of the intervention, we could not blind participants and therapists regarding the groups participants were allocated[47]. Thus, an average score of 6.4—considering a maximum score of 8—reflects the reliability of the results in this review, which can be extrapolated to clinical practice. Moreover, we emphasize the variability of the analyzed training protocols, which show a wide range of daily training times, weekly frequency and duration, in addition to the diverse proposed activities/exercises and systems/games used. We also found great variability in the instruments for assessing balance, which made it impossible to use mean differences—which shows more solid numerical results—, thus requiring MDS. Finally, some studies failed to report all the necessary data for inclusion in the meta-analysis. Thus, randomized controlled trials should still be conducted with great methodological rigor, aiming at the most appropriate intervention protocol for the gain of upper limb motor coordination of post-stroke individuals.

CONCLUSION

This study showed that VR training is effective in improving upper limb motor coordination of post-stroke individuals, with a moderate effect when compared to no intervention. However, VR training is not superior to other types of intervention used in rehabilitating these patients' upper limb motor coordination.

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