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Virtual Reality-Based Mirror Therapy for Upper Extremity Function among Stroke Patients: A Meta-analysis and Systematic Review

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Abstract [**Objectives**] To investigate the evidence-based effect of virtual reality-based mirror therapy system (VR-MT) on upper extremity function among stroke patients. [**Methods**] A systematic electronic searching of the Medline, PubMed, Web of Science and CNKI was initially performed up to June 10, 2024. The risk of bias of the included studies was evaluated using RevMan 5.4 software based on the Cochrane Handbook for Systematic Reviews. The random-effects model or fixed-effects models was employed to estimate the standardized mean difference (*SMD*). The subgroup analyses were conducted exploring the VR-MT type (immersive or non-immersive) and comparing with MT or control group. [**Results**] In total 8 studies with a total of 273 stroke patients were included in this review. The pooled analysis of these trials showed a statistically significant enhancement in FMA-UE scores (6 studies, $SMD = 0.72$, [95% *CI* 0.37 to 1.06]; $P < 0.0001$, $I^2 = 31\%$) and Box and Block Test (BBT) (3 studies, $SMD = 0.49$, [95% *CI* 0.05 to 0.93]; $P = 0.03$, $I^2 = 0\%$), rather than Manual Function Test (MFT) scores (3 studies, $SMD = 0.38$, [95% *CI* -0.09 to 0.84]; $P = 0.11$, $I^2 = 0\%$) following the application of reality-based mirror therapy. Additionally, the subgroup analysis results indicated that immersive VR-MT can significantly improve FMA-UE (5 studies, $SMD = 0.73$, [95% *CI* 0.24 to 1.23]; $P = 0.004$, $I^2 = 43\%$). In contrast, the overall effect of non-immersive VR-MT was non-significant (2 studies, $SMD = 0.33$, [95% *CI* -0.69 to 1.34]; $P = 0.53$, $I^2 = 72\%$). [**Conclusions**] In this systematic review and meta-analysis, our findings indicate that immersive VR-MT has the potential to improve upper extremity function among stroke patients.

Key words Stroke, Mirror therapy, Virtual reality, Upper extremity function, Meta-analysis

1 Introduction

Stroke is the second leading cause of death in the world. China's population accounts for 20% of the world population, and stroke is also the main cause of death in China. About one-third of patients die or are disabled within three months or one year[1]. According to reports[2], 55% -75% of post-stroke patients have limited upper limb motor function, and the loss of upper limb motor function hinders patients from performing complex daily living activities and returning to work.

Mirror therapy (MT) is a treatment method mainly for improving upper limb motor function based on the theory of the mirror neuron system (MNS). Current evidence suggests that cortical areas involved in motor execution can be activated not only through proprioceptive movements but also by observing others performing actions, which is mainly related to the function of mirror neurons[3]. To address the limitations of traditional MT, virtual mirror assistive devices and virtual reality feedback devices have been considered for introduction into rehabilitation therapy. Virtual assistance can enable patients to focus more on the training itself, providing an immersive experience for therapeutic training. Additionally, the virtual reality-based mirror therapy system (VR-MT), which utilizes the concept of MT, is expected to be an effective and innovative treatment method compared to conventional MT[4]. Currently, there are relatively few systematic reviews that provide strong evidence-based evidence showing that VR-MT has greater advantages over traditional MT in improving upper limb motor function for stroke patients.

2 Methods

2.1 Literature search We conducted a rigorous systematic review adhering to the guidelines in *Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement*[5]. On June 10, 2024, an initial electronic search was executed across Medline, PubMed, Web of Science, and CNKI databases. The search query focused on virtual reality-based mirror therapy interventions, utilizing the following terms: ("mirror therapy" OR "mirror visual feedback" OR "mirror" OR "mirror training") AND ("virtual rehabilitation" OR "virtual reality" OR "VR" OR "head-mounted display"). For cerebral ischemia, the selected terms were: ("Stroke" OR "cerebral ischemic" OR "ischemic stroke" OR "brain infarction" OR "brain ischemia"). The search strategy for article types encompassed: ("clinical study" OR "RCT" OR "human" OR "patients"). These three groups of terms were subsequently combined with the Boolean operator "AND" and searched across all fields, without any language restrictions. Furthermore, we scrutinized the reference lists of included studies and pertinent reviews to ensure eligibility, while excluding irrelevant studies. In view of this, we excluded reviews, expert opinions, and case studies.

2.2 Inclusion and exclusion criteria (i) Inclusion criteria: study design: only randomized controlled trials or clinical controlled trials were considered. Patients: Participants had to be adults (aged 18 years or above) who were undergoing acute, subacute, or chronic stages of stroke recovery. Intervention: A comprehensive description of the virtual reality-based mirror therapy intervention was mandatory. Control: The control group could have received traditional mirror therapy, standard occupational therapy, or no physical interventions. Outcomes: The following assessment tools were required: Fugl-Meyer Motor Assessment for

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Upper Extremity (FMA-UE): This quantitative measure assesses upper limb motor recovery post-stroke and is sensitive to changes[6]. Box and Block Test (BBT): An efficient test to measure manual dexterity deficits in stroke patients. A higher score indicates better gross manual dexterity[7]. Manual Function Test (MFT): Assesses the practical and functional use of hands in daily activities, crucial for patients' quality of life and independence. It comprises four items each for the shoulder and hands, reflecting upper extremity function post-stroke[8]. (ii) Exclusion criteria: studies that did not fulfill the aforementioned inclusion criteria were excluded from the analysis.

2.3 Study selection, extraction and data collection The primary reviewer crafted a data extraction sheet, which was subsequently scrutinized by the secondary reviewer, adhering strictly to the guidelines outlined in the Cochrane Handbook for Systematic Reviews. Whenever the numerical values of the outcomes were not explicitly disclosed in the text or tables of the published paper, a diligent attempt was undertaken to reach out to the corresponding author via email, seeking clarification. In scenarios where a study presented multiple follow-up endpoints, we prioritized the endpoint that exhibited the most significant difference. Furthermore, if the median, standard error, and interquartile range were reported, these values underwent careful conversion to mean and standard deviation (SD) to ensure consistency and comparability across the studies.

2.4 Assessment risk of bias With the aid of the RevMan 5.4 software[9], we crafted a comprehensive risk of bias assessment table to evaluate the quality of the selected literature. This assessment encompassed several critical aspects, namely: (i) the accuracy of the random sequence generation process, (ii) the adequacy of allocation concealment measures, (iii) the implementation of blinding protocols for both assessors and participants, (iv) the effectiveness of blinding during outcome assessment, (v) the completeness and integrity of outcome data, (vii) the potential for selective reporting, and (viii) any other potential biases that may have influenced the studies.

2.5 Data analysis The analysis was conducted with the aid of the RevMan 5.4 software, a trusted tool from the Cochrane Collaboration's Nordic Cochrane Center in Copenhagen, Denmark. For continuous outcome variables, we adopted the standard mean differences (*SMD*) approach to ensure accurate representation. Additionally, we analyzed 95% confidence intervals (*CIs*) as summary statistics, aiming for a robust and comprehensive evaluation.

Given the inherent heterogeneity of outcomes across various studies, we opted for a fixed-effects model as the default approach, prioritizing consistency and reliability. However, whenever the outcome measures were deemed comparable, we pooled the datasets in a meticulous meta-analysis. To rigorously evaluate the heterogeneity between studies, we employed the I^2 statistic, a robust indicator of variation. The I^2 test served as a scrutinizing lens for statistical heterogeneity, while the I^2 statistic itself quantified the extent of inconsistency. Based on the I^2 results, we made a considered choice between the fixed-effects and random-effects models. In scenarios where the I^2 value surpassed 50%, signaling significant heterogeneity, we resorted to the random-effects model for parameter estimation. Conversely, in the absence of such heterogeneity, we adhered to the fixed-effects model.

Furthermore, we planned two subgroup analyses: one comparing the control group (VR-MT vs MT and VR-MT vs control) and another exploring the VR-MT type (immersive vs non-immersive). A two-tailed P-value of less than 0.05 was deemed statistically significant in these analyses.

3 Results and analysis

3.1 Studies retrieved Our initial search efforts yielded a comprehensive pool of 327 articles, among which 240 were identified as original contributions. Upon a thorough review of the abstracts, we narrowed down the selection to 42 citations for further scrutiny. After a rigorous examination of the full texts, we identified 8 relevant randomized controlled trials (RCTs) that met the stringent inclusion criteria for our meta-analysis. Notably, 34 papers were excluded, primarily due to their non-RCT nature. The flowchart in Figure 1 illustrates the study selection process in detail.

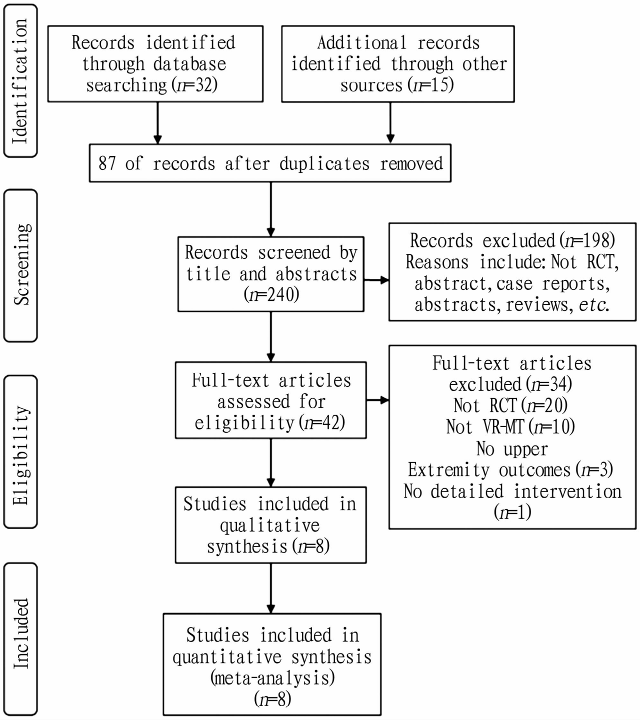


Fig. 1 Flow-chart illustrating the literature search strategy

3.2 Description of included studies Table 1 presents a comprehensive overview of the salient features of the eight studies included in our analysis. These studies, encompassing a collective sample of 273 stroke patients, span the years 2012 to 2024. Of these, five studies independently pioneered and employed an immersive VR-MT system, while the remaining three utilized a non-immersive VR-MT approach. Consistently across all eight studies, the experimental group underwent VR-MT therapy, augmented with traditional rehabilitation modalities such as occupational and physical therapy. Conversely, the control group received conventional motor training coupled with traditional rehabilitation methods in three studies. Further, seven studies employed the FMA-UE to assess upper extremity function, while three studies utilized the BBT and another three studies adopted the MFT for evaluation purposes.

Table 1 Characteristics of included studies

Study	Group	Gender (male/female)	Age//years	Stroke onset time	VR type	VR technology	Outcome extracted
Jo *et al.* [10]	VR-MT ($n=15$) MT ($n=15$) COT ($n=15$)	VR-MT (7/8) MT (8/7) COT (8/7)	VR-MT (51.73 ±13.63) MT (51 ±12.97) COT (47.13 ±13.91)	VR-MT (4.53 ±1.1 months) MT (4.80 ±1.42 months) COT (5.06 ±1.09 months)	Immersive	Pico G2 Vr 4K, insta 360° X3	FMA-UE, MFT, BBT
Sip *et al.* [11]	VR-MT ($n=10$) MT ($n=10$)	–	VR-MT (54.9 ±3.98) MT (59.2 ±4.34)	VR-MT (3.4 ±1.43 months) MT (3.3 ±0.67 months)	Immersive	Oculus Quest 2 VR glasses module, Virtual Mirror Hand 1.0	FMA-UE
Wang *et al.* [12]	VR-MT ($n=31$) COT ($n=29$)	VR-MT (22/9) COT (24/5)	VR-MT (53.45 ±13.09) COT (56.54 ±18.30)	VR-MT (2.68 ±2.79 months) COT (3.17 ±3.39 months)	Non-immersive	OpenPose	FMA-UE
Hsu *et al.* [13]	VR-MT ($n=17$) MT ($n=17$) COT ($n=18$)	VR-MT (8/10) MT (7/10) COT (5/12)	VR-MT (52.9 ±11.8) MT (56.7 ±11.5) COT (56.9 ±13.0)	VR-MT (30.7 ±21.1 months) MT (39.8 ±28.8 months) COT (38.1 ±26.6 months)	Immersive	Oculus Rift, Unity cross-platform game engine	FMA-UE, BBT
Mekbib *et al.* [14]	VR-MT ($n=12$) MT ($n=11$)	VR-MT (9/3) MT (8/3)	VR-MT (52.17 ±13.26) MT (61.00 ±7.69)	VR-MT (36.92 ±22.04 days) MT (39.36 ±18.08 days)	Immersive	HTC Vive HMD, Unity 3D game engine	FMA-UE
Lin *et al.* [15]	VR-MT ($n=9$) MT ($n=9$)	VR-MT (7/2) MT (6/3)	VR-MT (49.7 ±13.4) MT (58.8 ±9.6)	VR-MT (42.2 ±21.3 months) MT (48.2 ±32.4 months)	Immersive	Oculus Rift, Unity cross-platform game engine	FMA-UE
Choi *et al.* [16]	VR-MT ($n=12$) MT ($n=12$) COT ($n=12$)	VR-MT (7/5) MT (7/5) COT (9/3)	VR-MT (58.00 ±15.15) MT (59.58 ±11.87) COT (59.33 ±13.63)	VR-MT (28.91 ±15.80 months) MT (26.33 ±15.51 months) COT (29.00 ±19.21 months)	Non-immersive	Cube Wave. Game programs	MFT
In *et al.* [17]	VR-MT ($n=11$) MT ($n=8$)	VR-MT (7/4) MT (4/4)	VR-MT (63.45 ±11.78) MT (64.50 ±12.69)	VR-MT (14.00 ±4.88 months) MT (12.75 ±6.78 months)	Non-immersive	Wooden box and an LCD monitor	FMA-UE, MFT, BBT

NOTE VR-MT, virtual reality-based mirror therapy; MT, mirror therapy; COT, control; FMA-UE, Fugl-Meyer assessment upper extremity; BBT, box and block test; MFT, manual function test.

3.3 Risk of bias

The risk of bias in the efficacy analysis for each included RCT is clearly demonstrated in Fig. 2. In the rigorous evaluation of all studies, the randomization process served as a fundamental criterion. Among the various investigations, seven studies demonstrated a commitment to scientific rigor by employing randomization methods as well as allocation concealment strategies, both critical to ensuring unbiased outcomes. However, a noteworthy exception emerged in the form of a single study, which fell short of providing a clear description of the allocation concealment protocol. Despite this inconsistency, all studies exhibited a consistent yet unfortunate trend of posing a high risk of bias in the implementation of blinding protocols. This bias was evident in both the assessors, who were tasked with evaluating the study outcomes, and the participants themselves.

Notably, four studies took the additional step of ensuring the objectivity of their findings by having blinded assessors conduct the outcome measures. This measure significantly minimized the potential for bias and enhanced the credibility of the study results. Furthermore, all studies reported comprehensive findings, encompassing the entire spectrum of expected outcomes, thereby providing a thorough and comprehensive overview of the study's implications.

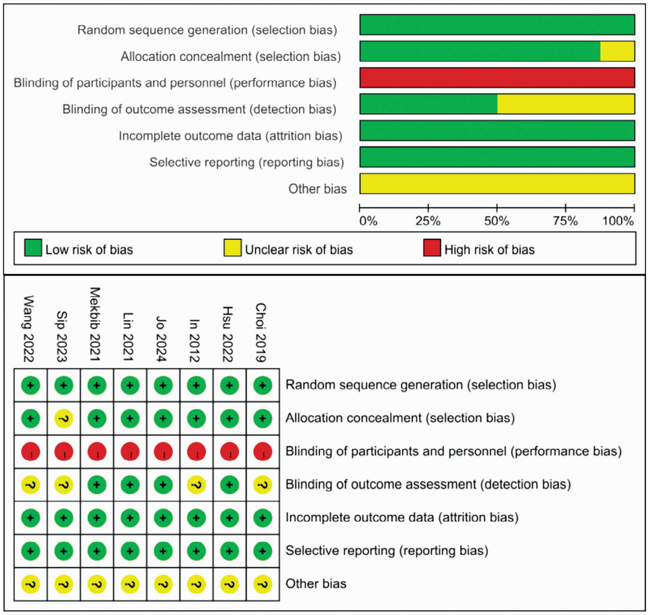
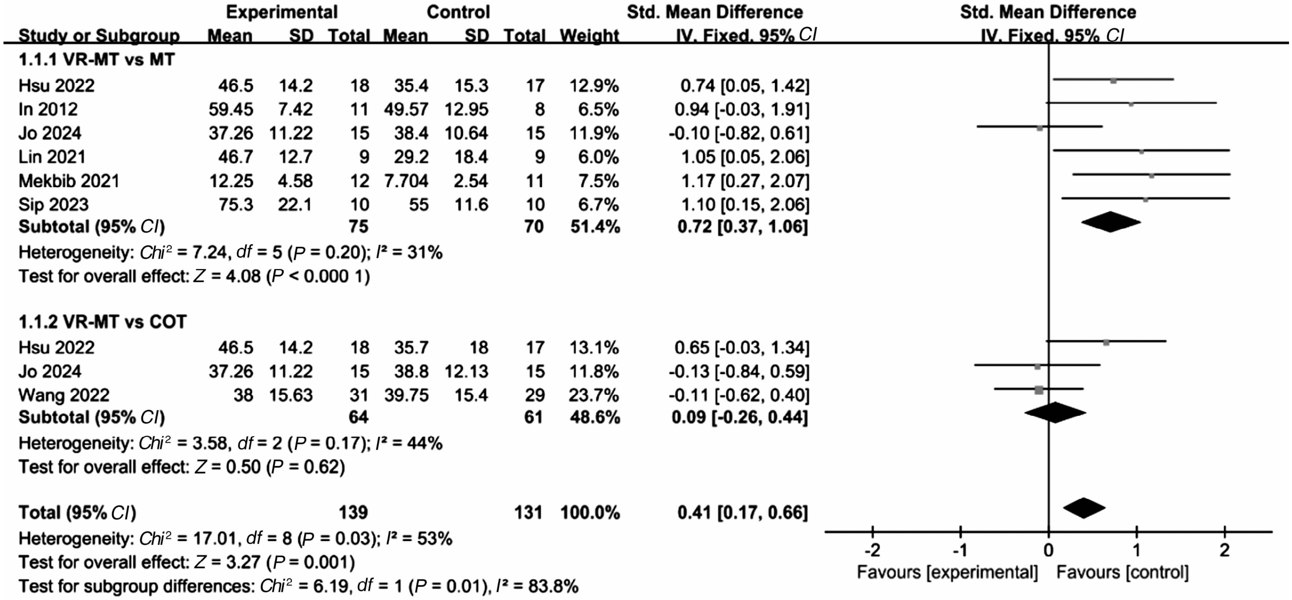


Fig. 2 Risk of bias in the included studies

3.4 Results from individual studies and synthesis of results

3.4.1 FMA-UE.

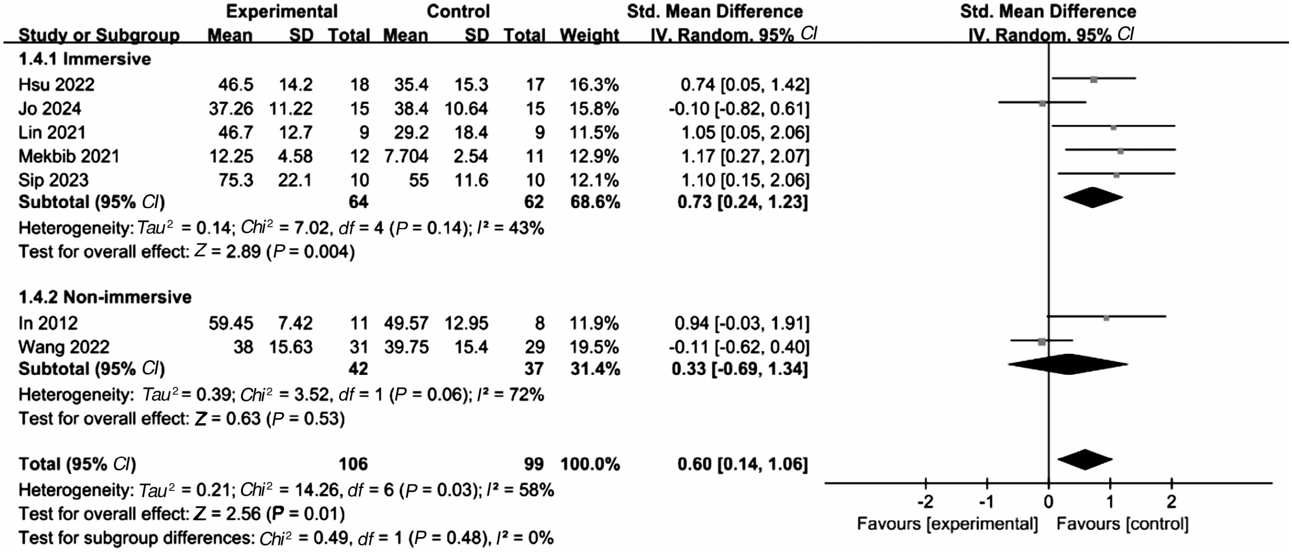
A meticulous and comprehensive meta-analysis was undertaken, adhering strictly to a fixed-effects model that ensures the utmost rigor and precision. By aggregating the data from six rigorously chosen studies, we observed a statistically significant enhancement in the Functional Motor Assessment-Upper Extremity (FMA-UE) scores (6 studies, $SMD = 0.72$, [95% CI 0.37 to 1.06]; $P < 0.0001$, $I^2 = 31\%$). This improvement suggests a favorable outcome for reality-based mirror therapy (VR-MT) in comparison to conventional Mirror Therapy (MT). However, it is noteworthy that, in three of these studies, the VR-MT did not yield statistically significant differences when compared to the control group (3 studies, *SMD* = 0.09, [95% *CI* −0.26 to 0.44]; *P* = 0.621, I^2 = 44%). Nonetheless, the overall findings provide valuable insights into the potential benefits of VR-MT in upper extremity rehabilitation (Fig. 3).



Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Fixed, 95% CI
1.1.1 VR-MT vs MT								
Hsu 2022	46.5	14.2	18	35.4	15.3	17	12.9%	0.74 [0.05, 1.42]
In 2012	59.45	7.42	11	49.57	12.95	8	6.5%	0.94 [-0.03, 1.91]
Jo 2024	37.26	11.22	15	38.4	10.64	15	11.9%	-0.10 [-0.82, 0.61]
Lin 2021	46.7	12.7	9	29.2	18.4	9	6.0%	1.05 [0.05, 2.06]
Mekbib 2021	12.25	4.58	12	7.704	2.54	11	7.5%	1.17 [0.27, 2.07]
Sip 2023	75.3	22.1	10	55	11.6	10	6.7%	1.10 [0.15, 2.06]
Subtotal (95% *CI*)			**75**			**70**	**51.4%**	**0.72 [0.37, 1.06]**
Heterogeneity: *Chi*² = 7.24, *df* = 5 (*P* = 0.20); *I*² = 31%								
Test for overall effect: *Z* = 4.08 (*P* < 0.000 1)								
1.1.2 VR-MT vs COT								
Hsu 2022	46.5	14.2	18	35.7	18	17	13.1%	0.65 [-0.03, 1.34]
Jo 2024	37.26	11.22	15	38.8	12.13	15	11.8%	-0.13 [-0.84, 0.59]
Wang 2022	38	15.63	31	39.75	15.4	29	23.7%	-0.11 [-0.62, 0.40]
Subtotal (95% *CI*)			**64**			**61**	**48.6%**	**0.09 [-0.26, 0.44]**
Heterogeneity: *Chi*² = 3.58, *df* = 2 (*P* = 0.17); *I*² = 44%								
Test for overall effect: *Z* = 0.50 (*P* = 0.62)								
Total (95% *CI*)			**139**			**131**	**100.0%**	**0.41 [0.17, 0.66]**
Heterogeneity: *Chi*² = 17.01, *df* = 8 (*P* = 0.03); *I*² = 53%								
Test for overall effect: *Z* = 3.27 (*P* = 0.001)								
Test for subgroup differences: *Chi*² = 6.19, *df* = 1 (*P* = 0.01), *I*² = 83.8%								

Fig. 3 The forest plot for the overall impact of reality-based mirror therapy on FMA-UE compared with mirror therapy

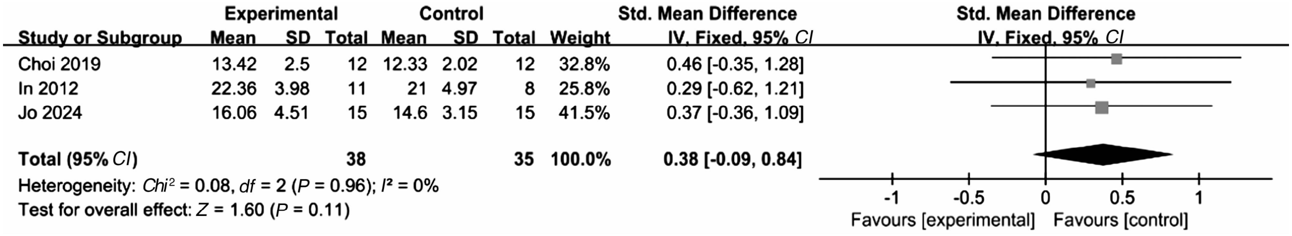
Considering the different type of VR-MT, subgroup analysis was conducted on the VR type (immersive vs non-immersive). The analysis results indicate that immersive VR-MT can significantly improve FMA-UE (5 studies, *SMD* = 0.73, [95% *CI* 0.24 to 1.23]; *P* = 0.004, I^2 = 43%). In contrast, the overall effect of non-immersive VR-MT is not significant (2 studies, *SMD* = 0.33, [95% *CI* −0.69 to 1.34]; *P* = 0.53, I^2 = 72%) (Fig. 4).



Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.4.1 Immersive								
Hsu 2022	46.5	14.2	18	35.4	15.3	17	16.3%	0.74 [0.05, 1.42]
Jo 2024	37.26	11.22	15	38.4	10.64	15	15.8%	-0.10 [-0.82, 0.61]
Lin 2021	46.7	12.7	9	29.2	18.4	9	11.5%	1.05 [0.05, 2.06]
Mekbib 2021	12.25	4.58	12	7.704	2.54	11	12.9%	1.17 [0.27, 2.07]
Sip 2023	75.3	22.1	10	55	11.6	10	12.1%	1.10 [0.15, 2.06]
Subtotal (95% *CI*)			**64**			**62**	**68.6%**	**0.73 [0.24, 1.23]**
Heterogeneity: *Tau*² = 0.14; *Chi*² = 7.02, *df* = 4 (*P* = 0.14); *I*² = 43%								
Test for overall effect: *Z* = 2.89 (*P* = 0.004)								
1.4.2 Non-immersive								
In 2012	59.45	7.42	11	49.57	12.95	8	11.9%	0.94 [-0.03, 1.91]
Wang 2022	38	15.63	31	39.75	15.4	29	19.5%	-0.11 [-0.62, 0.40]
Subtotal (95% *CI*)			**42**			**37**	**31.4%**	**0.33 [-0.69, 1.34]**
Heterogeneity: *Tau*² = 0.39; *Chi*² = 3.52, *df* = 1 (*P* = 0.06); *I*² = 72%								
Test for overall effect: **Z** = 0.63 (*P* = 0.53)								
Total (95% *CI*)			**106**			**99**	**100.0%**	**0.60 [0.14, 1.06]**
Heterogeneity: *Tau*² = 0.21; *Chi*² = 14.26, *df* = 6 (*P* = 0.03); *I*² = 58%								
Test for overall effect: **Z** = 2.56 (**P = 0.01**)								
Test for subgroup differences: *Chi*² = 0.49, *df* = 1 (*P* = 0.48), *I*² = 0%								

Fig. 4 The forest plot for the overall impact of different type of reality-based mirror therapy on FMA-UE

3.4.2 MFT. A thorough and comprehensive meta-analysis was undertaken, employing a rigorously structured fixed-effects model to ensure the utmost precision and reliability. This analysis entailed the aggregation of data from three meticulously chosen studies, all of which underwent rigorous scrutiny to ensure their suitability for inclusion. Upon the completion of this rigorous analysis, it was determined that there was no statistically significant difference observed in the Manual Function Test scores following the application of Virtual Reality-based Motor Training (VR-MT) (3 studies, *SMD* = 0.38, [95% *CI* −0.09 to 0.84]; *P* = 0.11, I^2 = 0%). This finding underscores the need for further research to explore the potential benefits and limitations of VR-MT in relation to manual function (Fig. 5).

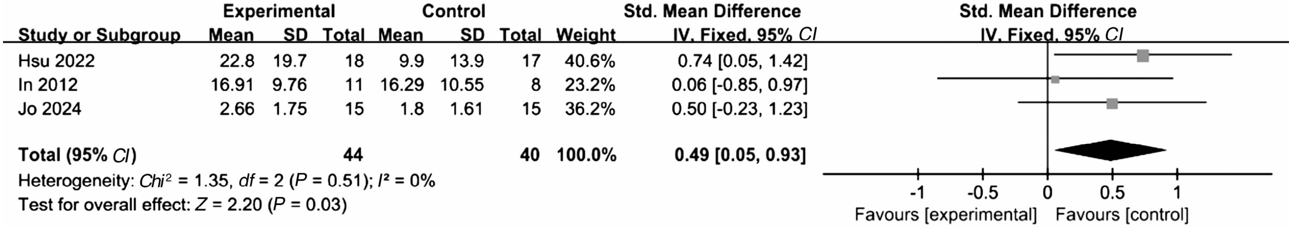


Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Fixed, 95% *CI*
Choi 2019	13.42	2.5	12	12.33	2.02	12	32.8%	0.46 [-0.35, 1.28]
In 2012	22.36	3.98	11	21	4.97	8	25.8%	0.29 [-0.62, 1.21]
Jo 2024	16.06	4.51	15	14.6	3.15	15	41.5%	0.37 [-0.36, 1.09]
Total (95% *CI*)			**38**			**35**	**100.0%**	**0.38 [-0.09, 0.84]**

Heterogeneity: $Chi^2 = 0.08$, $df = 2$ ($P = 0.96$); $I^2 = 0\%$
Test for overall effect: $Z = 1.60$ ($P = 0.11$)

Fig. 5 The forest plot for the overall impact of reality-based mirror therapy on MFT

3.4.3 BBT. A thorough and comprehensive meta-analysis was undertaken, employing a rigorously structured fixed-effects model to ensure the utmost precision and reliability. This approach entailed the integration of data from six rigorously screened and carefully selected studies, each contributing valuable insights into the field. Upon aggregating and analyzing this collective data, we observed a statistically significant enhancement in the performance of the Box and Block Test following the application of reality-based mirror therapy (3 studies, $SMD = 0.49$, [95% *CI* 0.05 to 0.93]; $P = 0.03$, $I^2 = 0\%$). This finding not only underscores the potential efficacy of VR-MT in improving upper extremity but also highlights the importance of conducting meta-analyses to synthesize and interpret the results of multiple studies, thereby providing a more comprehensive understanding of the subject matter (Fig. 6).



Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Fixed, 95% *CI*
Hsu 2022	22.8	19.7	18	9.9	13.9	17	40.6%	0.74 [0.05, 1.42]
In 2012	16.91	9.76	11	16.29	10.55	8	23.2%	0.06 [-0.85, 0.97]
Jo 2024	2.66	1.75	15	1.8	1.61	15	36.2%	0.50 [-0.23, 1.23]
Total (95% *CI*)			**44**			**40**	**100.0%**	**0.49 [0.05, 0.93]**

Heterogeneity: $Chi^2 = 1.35$, $df = 2$ ($P = 0.51$); $I^2 = 0\%$
Test for overall effect: $Z = 2.20$ ($P = 0.03$)

Fig. 6 The forest plot for the overall impact of reality-based mirror therapy on BBT

4 Discussion

A comprehensive systematic review and meticulous meta-analysis were undertaken to assess the effects of virtual reality-based mirror therapy on the upper extremity within the cerebral ischemic stroke. The primary findings of this rigorous meta-analysis indicate that virtual reality-based mirror therapy is remarkably effective in improving FMA-UE, Box and Block Test (BBT), while there was no statistically significant difference observed in the Manual Function Test (MFT). Additionally, the subgroup analysis demonstrated that immersive VR-MT can significantly improve FMA-UE rather than non-immersive VR-MT compared with traditional mirror therapy.

Currently, traditional mirror therapy, that is, planar mirror imaging, is widely used internationally, which limits its operation and effectiveness due to the treatment equipment. However, there are some limitations, such as the fragility of glass mirrors, their large size and inconvenience in moving, and their poor interestingness. Moreover, factors such as patients' duration of attention and active participation can affect the effectiveness of treatment. In 2020, Bullock *et al.* proposed the concept of VR-MVF (virtual reality-based mirror visual feedback) for research on functional neurological disorders[18]. In 2021, Won *et al.* evaluated the feasibility of using a virtual reality mirror visual feedback module for complex regional pain syndrome[19]. Combining the latest progress in virtual reality and mirror research, Professor Long's team[20] developed a virtual reality rehabilitation system (VRRS) that utilizes computer real-time mirror flipping for the entire upper limb (shoulder, arm, wrist, and hand). Using games as a carrier to simulate real-world scenarios, task-oriented training is conducted in VR. During the training, patients can actively control objects in the virtual scene through virtual limbs. The recognition system tracks the patient's limb movement trajectory and records movement information, which is then fed back to the patient in a visual form to guide them in constantly adjusting their posture and movements. They believe that VRRS improves the user's ability to control the body and their perception of body position, and can be applied to enhance the effect of upper limb rehabilitation for stroke patients.

The meta-analysis revealed that this therapy significantly enhanced FMA-UE and BBT scores, while no statistically significant difference was observed in MFT scores. Further, a subgroup analysis indicated that immersive VR-MT outperforms non-immersive VR-MT in improving FMA-UE scores, when compared to traditional mirror therapy, suggesting a potential advantage of immersive virtual reality therapy in rehabilitation. This finding aligns with previous studies that have documented the potential benefits of VR as an adjunct therapy to enhance upper extremity function[21]. Upon reviewing the individual studies, it was observed that three of them employed immersive VR-MT systems, with the majority reporting significant effect sizes[16]. Prior research has indicated that immersive virtual reality has a greater positive impact on the recovery of upper extremities in adult stroke patients[22]. The advantages of using immersive VR in VR-MT are numerous. Firstly, it allows for the creation of more convincing "brain illusions" by blending real and virtual objects due to the full immersion experience. Secondly, it enables stroke patients to observe mirror images in the most natural position. Thirdly, it eliminates distractions from the clinical environment, fostering greater concentration[23]. A crucial prerequisite for these benefits is the embodiment of the hand in immersive VR, which hinges on the senses of self-location, agency, and ownership[23].

5 Conclusions

A thorough systematic review and meticulous meta-analysis have been conducted to evaluate the impact of virtual reality-based mirror therapy on upper extremity function in cerebral ischemic stroke patients. The key findings reveal that this therapy significantly enhances FMA-UE and Box and Block Test (BBT) scores, while no statistically significant difference was observed in Manual Function Test (MFT) scores. Further, a subgroup analysis indicates that immersive VR-MT outperforms non-immersive VR-MT in improving FMA-UE scores, when compared to traditional mirror therapy, suggesting a potential advantage of immersive virtual reality therapy in upper extremity rehabilitation.

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(From page 34)

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