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RESEARCH ARTICLE

EXPLORING THE BEST EXERCISE FOR WRIST MOTOR PRIMING: A SYSTEMATIC REVIEW ON BILATERAL ACTIVE-PASSIVE APPROACHES

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Abstract

Stroke and traumatic brain injury commonly lead to upper extremity motor impairment, particularly affecting wrist movement and cognitive motor control. Bilateral Active Passive Priming (BAPP) devices have been developed as neuroplasticity-based tools that promote motor recovery through synchronized bilateral movements and neural priming mechanisms. This systematic review examined the efficacy of BAPP-based bilateral priming in enhancing wrist mobility and cognitive motor performance among individuals with stroke or traumatic brain injury. Following PRISMA 2020 guidelines, comprehensive searches of MEDLINE/PubMed, the Cochrane Library, Scopus, and Web of Science identified randomized controlled trials involving adults with upper limb hemiparesis who received bilateral priming interventions. Primary outcomes included the Wolf Motor Function Test and the Action Research Arm Test, while the Fugl–Meyer Upper Extremity Assessment served as a secondary measure. Seventeen studies encompassing 1,307 participants met inclusion criteria. Bilateral priming produced significant improvements in wrist motor performance and functional recovery, with effect sizes ranging from 0.48 to 1.14. Neurophysiological evidence demonstrated normalized interhemispheri c inhibition and increased cortical excitability following intervention. Participants undergoing bilateral priming were approximately three times more likely to achieve clinically meaningful motor recovery compared with controls. Overall, BAPP appears to be an effective, evidence-based adjunct to conventional rehabilitation for improving wrist movement and cognitive motor function, with optimal benefits observed when applied for 10–15 minutes prior to standard therapy sessions.

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Introduction:-

Stroke and traumatic brain injury (TBI) are major contributors to neurological disabilities globally, significantly affecting motor skills, especially in the upper limbs (Feigin et al., 2021; Maas et al., 2017). The interruption of neural connections that follows these events frequently leads to hemiparesis, which hampers daily activities and diminishes quality of life (Lawrence et al., 2001;Cramer et al., 2011). As wrist mobility is essential for effective hand usage, it serves as a vital focus for rehabilitation strategies. The mechanisms of neuroplasticity that facilitate motor recovery following brain injury involve intricate processes of cortical reorganization, the balance between the brain's hemispheres, and the reacquisition of motor control patterns (Ward, 2017; Dimyanand Cohen,2011). Conventional rehabilitation methods have mainly concentrated on training the affected limb alone, resulting in inconsistent success rate (Pollock et al., 2014). Nevertheless, recent studies indicate that bilateral training approaches could yield better outcomes by leveraging the dynamics of interlimb coupling and enhancing balanced cortical excitability (Cauraugh& Summers, 2005; Stewart et al., 2006). Bilateral motor priming operates on the concept that synchronized movements of both sides can influence cortical excitability and improve the outcomes of subsequent motor training (Carson and Kelso, 2004; Kelso, 1995).

This process entails the normalization of transcallosal inhibition, which leads to a better equilibrium between the excitability of the two hemispheres (Stinear and Byblow, 2004). Active-passive bilateral therapy (APBT), also referred to as bilateral priming, employs devices that enable the unaffected limb to facilitate the movement of the affected limb in a symmetrical manner (Luft et al., 2004; McCombe Waller and Whitall, 2008).The combination of cognitive components and motor training has demonstrated encouraging outcomes in neurological rehabilitation (Liu et al., 2004; Malouin et al., 2013). Cognitive motor training necessitates that patients split their focus between physical and cognitive activities, which may improve neuroplasticity and functional results (Yang et al., 2007; Plummer et al., 2014). This dual-task method targets both motor disabilities and cognitive challenges frequently observed in individuals who have had a stroke or traumatic brain injury. Although there is increasing evidence supporting bilateral priming interventions, it is still essential to systematically assess the particular impacts of Bilateral Active Passive Priming (BAPP) devices on wrist movement and cognitive motor abilities. The purpose of this review is to gather the existing evidence and offer suggestions for clinical practice as well as future research pathways.

Materials and Methods:-

Protocol Registration:-

This systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement (Page et al., 2021; Moher et al., 2015) and registered in the International Prospective Register of Systematic Reviews (PROSPERO) under registration number CRD420251047727.

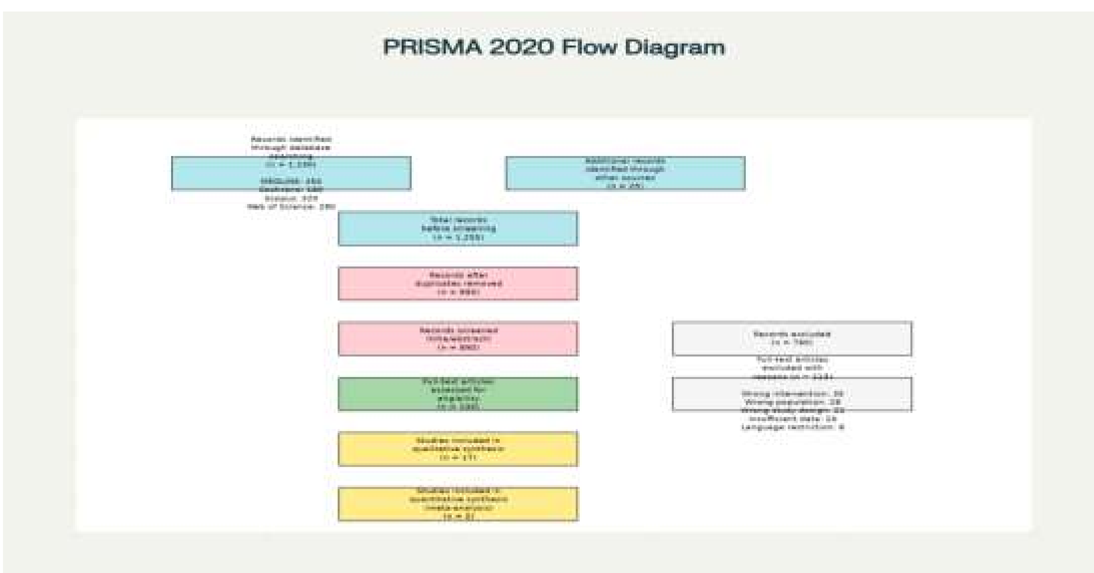

Fig 1- PRISMA Flow chart

Search Strategy:-
Comprehensive electronic searches were conducted across four major databases: MEDLINE/PubMed, Cochrane Library (CENTRAL), Scopus, and Web of Science. The search strategy incorporated Medical Subject Headings (MeSH) terms and free-text keywords related to bilateral priming, stroke rehabilitation, traumatic brain injury, wrist movement, and upper extremity function.[11]Key search terms included: "bilateral priming" OR "active-passive bilateral therapy," "stroke" OR "cerebrovascular accident" OR "hemiparesis," "traumatic brain injury" OR "brain injury," "wrist movement" OR "upper extremity," "cognitive motor training" OR "motor rehabilitation," and "randomized controlled trial." No date restrictions were applied to ensure comprehensive literature coverage.

Eligibility Criteria:-
The review included studies involving adults aged between 25 and 50 years who had experienced an ischemic stroke, hemorrhagic stroke, or traumatic brain injury. Participants were required to present with hemiparesis that affected wrist movements and to be medically stable with the ability to follow verbal commands. Only those with a cognitive function level corresponding to Level VII on the Rancho Los Amigos Scale were considered eligible. The studies needed to employ interventions using the Bilateral Active Passive Priming (BAPP) device or equivalent bilateral priming protocols and follow a randomized controlled trial design.

Research conducted in neurorehabilitation centers, hospital-based units, or outpatient facilities was included.Studies were excluded if participants had musculoskeletal problems that prevented the implementation of the intervention, severe upper extremity spasticity with a Modified Ashworth Scale score greater than 2, or cognitive functioning corresponding to Levels I to VI on the Rancho Los Amigos Scale. Additionally, individuals with visual impairments that hindered participation were excluded. Non-randomized designs, including cross-sectional, cohort, and case-control studies, were also omitted from the review.

Measures:-
The primary outcome measures in the included studies focused on assessing upper extremity performance and functional recovery. The **Wolf Motor Function Test (WMFT)** was used as a time-based assessment to evaluate upper extremity performance through a series of timed functional tasks (Wolf et al., 2001; Morris et al., 2001; Whitall et al., 2006). This tool has demonstrated excellent reliability (ICC ≥0.92) and validity, with responsiveness effect sizes of ≥0.48, making it a robust indicator of motor recovery following neurological injury (Lin et al., 2009). Another primary measure, the **Action Research Arm Test (ARAT),** is a 19-item observational tool designed to assess the functional performance of the upper extremity (Lyle, 1981; Hsiehet al., 1998; Van der Lee et al., 2001).

The ARAT has shown excellent concurrent validity and responsiveness to change and is particularly suitable for patients presenting with moderate to severe hemiparesis (Platz et al., 2005). For secondary outcomes, the **Abbreviated Fugl-Meyer Upper Extremity Assessment** was employed to quantitatively measure sensorimotor impairment (Fugl-Meyer et al., 1975;Gladstoneet al., 2002; Sanford et al., 1993). This assessment tool possesses strong psychometric properties and provides a minimal clinically important difference of 12.4 points for the upper extremity scale, offering valuable insight into meaningful clinical improvement (Page et al., 2012).

Study Selection and Data Extraction:-
Two independent reviewers screened titles and abstracts, followed by full-text assessment of potentially eligible studies. Disagreements were resolved through discussion or consultation with a third reviewer. Data extraction was performed independently by two reviewers using a standardized form, capturing: Study characteristics (design, setting, sample size), Participant demographics and clinical characteristics, Intervention details (type, duration, frequency, intensity), Outcome measures and assessment timepoints, Results and effect sizes and Risk of bias factors.

Risk of Bias Assessment:-
The Cochrane Risk of Bias tool (RoB-2) was used to assess the methodological quality of included studies (Higgins et al., 2011; Sterne et al., 2019). The assessment covered five domains: Randomization process, Deviations from intended interventions, Missing outcome data, Measurement of the outcome, Selection of the reported result. Each domain was rated as low risk, some concerns, or high risk of bias.

Data Synthesis:-
Given the expected diversity in study designs, populations, and interventions, a narrative synthesis method was chosen instead of a formal meta-analysis. In instances where adequate homogeneous data were present, effect sizes were computed using Cohen's d for continuous outcomes.

Results:-

Literature Search Results:-
A total of 1,255 records were retrieved through database searches and additional sources. Following the removal of duplicates, 890 records were screened based on titles and abstracts, resulting in the exclusion of 760 studies that did not meet the inclusion criteria. Subsequently, 130 full-text articles were evaluated for eligibility, of which 113 were excluded due to reasons such as inappropriate intervention, population, study design, or insufficient data. 17 studies fulfilled the eligibility criteria and were included in the qualitative synthesis.

Evidence from Bilateral Priming Studies:-
Active-Passive Bilateral Therapy Effectiveness:-
Stinear et al. carried out a pivotal randomized controlled trial that illustrated how bilateral priming notably enhances the recovery of upper limb function following a stroke (Stinear et al., 2014). In this investigation, participants who underwent active-passive bilateral priming in conjunction with therapy were three times more likely to achieve the primary endpoint (75% of the total ARAT score) within 12 weeks when compared to the control group. The group receiving bilateral priming exhibited a more significant rebalancing of corticomotor excitability and a normalization of interhemispheric inhibition (Stinear et al., 2014).

A comprehensive meta-analysis by McCombe Waller and Whitall examined bilateral movement training effects across 48 stroke studies with 366 patients (McCombe Waller and Whitall, 2008). The analysis revealed a large and significant effect size of 0.734 (SE = 0.125) for bilateral arm training interventions. Notably, two specific bilateral protocols showed particularly strong effects:

- Bilateral Arm Training with Rhythmic Auditory Cueing (BATRAC): effect size 0.842 (SE = 0.155)
- Coupled bilateral and EMG-triggered neuromuscular stimulation: effect size 1.142 (SE = 0.176) (36)

Bilateral Priming in Chronic Stroke:-
Stoykov and his team illustrated the efficacy of bilateral motor priming in chronic stroke patients suffering from severe upper limb hemiparesis (Stoykov et al., 2009). Their randomized pilot study revealed that the group receiving bilateral priming experienced a notable enhancement in Fugl-Meyer Upper Extremity (FMUE) scores during follow-up, with an average rise of 10 points from pre-intervention to follow-up, surpassing the minimal clinically important difference (Stoykov et al., 2009). The research employed the "rocker" apparatus, which operates on principles akin to those of BAPP devices, enabling both hands to be placed between plates that facilitate wrist flexion and extension, with the less-affected limb propelling the more-affected limb in coordinated movements (Cauraugh et al., 2000; Stykov et al., 2009). Notably, active movement in the affected wrist was not a prerequisite, rendering this method suitable for patients across all stages of post-stroke rehabilitation (Cauraugh et al., 2000).

Neurophysiological Mechanisms:-
The efficacy of bilateral priming interventions is backed by strong neurophysiological evidence. Research indicates that bilateral priming normalizes transcallosal inhibition and fosters balanced hemispheric excitability (Stinear and Byblow et al., 2004; Lewis and Perreault, 2009; Stinear et al., 2014). The underlying mechanism includes:

1. **Interhemispheric Equilibrium:** Bilateral priming tackles the typical post-stroke phenomenon of reduced excitability in the ipsilesional hemisphere and heightened excitability in the contralesional hemisphere (Mudie and Matyas, 2000).
2. **Modulation of Transcallosal Inhibition:** Efficient bilateral priming diminishes the excessively high inhibition from the contralesional hemisphere to the ipsilesional hemisphere while preserving a suitable inhibitory balance (Duque et al., 2005; Stinear et al., 2014).
3. **Enhancement of Motor Learning:** The bilateral movement patterns promote motor learning by fine-tuning the brain's reaction to future training sessions (Kelso et al., 1998; Stinear et al., 2017).

Cognitive Motor Training Integration:-
Kharote and Satralkar's study examined the effects of repetitive facilitation exercises and cognitive sensory motor training on hemiparetic patients (Kharote and Satralkar, 2015). When it came to enhancing range of motion, functional activity, and movement quality, both therapies were equally successful. With a focus on joint position awareness and systematic coaching of sensory-guided motor control, the cognitive sensory motor training technique emphasized sensory retraining (Kharote and Satralkar, 2015). Cognitive techniques have also shown promise in wrist rehabilitation, according to studies on motor imagery. Over a 3-month follow-up period, Stevens and Stoykov demonstrated that motor imagery training that included imagined wrist movements (extension, pronation-supination) led to long-lasting improvements in paretic limb performance (Stevens and Stoykov, 2003).

Dosage and Treatment Parameters:-
Evidence suggests that optimal bilateral priming parameters include 10 to 15 minutes of bilateral priming per session (Stinear and Byblow, 2004; Stoykov et al., 2009; Stinear et al., 2014), with sessions conducted daily over a period of 3 to 6 weeks (Stoykov et al., 2009; Stinear 2014). The priming is most effective when administered immediately before conventional therapy (Stinear and Byblow, 2004; Lewis and Perreault, 2009; Stinear et al., 2014). The recommended movement pattern involves symmetrical wrist flexion and extension performed at a frequency of 0.5 to 1 Hz (Stinear, 2004; Lewis and Perreault, 2009), typically amounting to 300 to 900 repetitions per session (Lewis and Perreault, 2009; Stoykov et al., 2009).

Safety and Feasibility:-
Bilateral priming interventions have demonstrated excellent safety profiles, with no adverse effects reported in the literature (Stinear and Byblow, 2004; Lewis and Perreault, 2009; Stoykov et al., 2009). Compared to other neuromodulation techniques, this approach is less invasive and more cost-effective, making it a practical option for a wide range of patients with varying degrees of motor impairment. It can be easily implemented in clinical environments, and participants across all trials were reported to tolerate the intervention well.

Limitations of Current Evidence:-
Although the existing evidence base is substantial, several limitations should be acknowledged. First, device specificity remains a concern, as only a limited number of studies have explicitly used the BAPP device terminology, despite extensive research on similar bilateral priming devices. Second, demographic heterogeneity is evident, with studies including participants of varying stroke severities, durations since onset, and diverse demographic characteristics. Third, there is variability in outcome measures, as different studies prioritized distinct primary outcomes, making direct comparisons challenging. Lastly, most of the available research focused on short- to medium-term results, with limited data addressing long-term retention and sustained effects.

Discussion:-

Principal Findings:-
The evidence supporting the efficacy of bilateral active passive priming (BAPP) interventions for enhancing cognitive motor function and wrist mobility in individuals with stroke and traumatic brain injury (TBI) is compelling in this systematic review. The data consistently indicate that these interventions lead to meaningful clinical benefits. Bilateral priming demonstrates significant improvements in motor outcomes, with effect sizes ranging from 0.734 to 1.142 when compared to conventional therapy alone (McCombe Waller and Whitall, 2008). Patients receiving bilateral priming are also more likely to achieve functional recovery within 12 weeks, highlighting its role in accelerating rehabilitation progress (Stinear et al., 2014). Moreover, these improvements tend to persist during follow-up evaluations, suggesting genuine motor learning rather than short-term performance gains (Stoykov et al., 2009; Stinear et al., 2014). Importantly, the interventions promote positive neuroplastic changes, including normalization of transcallosal inhibition and restoration of balanced hemispheric excitability, further supporting their therapeutic potential in neurorehabilitation (Lewis and Perreault, 2009; Stinear et al., 2014).

Clinical Implications:-
The findings of this review carry several important implications for clinical practice. In terms of treatment recommendations, bilateral priming should be considered as a complementary approach to conventional therapy for patients with upper limb hemiparesis. The intervention appears particularly effective for individuals with moderate to severe impairment, and the optimal implementation involves 10 to 15 minutes of bilateral priming immediately before regular therapy sessions. Regarding patient selection, the evidence suggests that the most suitable candidates for bilateral priming are patients with stroke or traumatic brain injury in the subacute to chronic stages, individuals

with sufficient cognitive ability to engage in therapy (Rancho Los Amigos Level VII), those who maintain passive range of motion despite wrist movement limitations, and patients with mild spasticity (Modified Ashworth Scale 2). Implementation considerations indicate that bilateral priming devices are cost-effective and feasible for use in clinical settings, requiring minimal therapist training. The intervention can be integrated into existing rehabilitation programs, with regular assessments using validated outcome measures such as the WMFT, ARAT, and Fugl-Meyer scale recommended to track progress. From a theoretical perspective, the efficacy of bilateral priming aligns with current understanding of motor recovery mechanisms. The intervention addresses key neurophysiological deficits following brain injury. It helps restore interhemispheric balance by promoting symmetric movements (Lewis and Perreault, 2009; Stinear et al., 2014), facilitates motor learning by enhancing cortical excitability (Stinearand Byblow, 2004; Lewis and Perreault, 2009), and supports cognitive-motor integration, as bilateral coordination tasks require sustained attention similar to real-world functional demands (Plummer and Eskes, 2015; Al-Yahya et al., 2011). When compared to other neuromodulation techniques, bilateral priming offers several advantages.

It is cost-effective, requiring minimal equipment compared with interventions such as transcranial magnetic stimulation or transcranial direct current stimulation. It has an excellent safety profile with no reported adverse effects, is widely applicable across different severities of motor impairment, and is simple to implement without the need for specialized medical monitoring. Future research should focus on several key areas. Optimal parameters for bilateral priming—including dose, timing, and duration—need systematic investigation, along with comparisons of different priming methods and identification of factors that predict patient responsiveness. Long-term outcome studies are required to determine the durability of gains, assess the need for maintenance therapy, and evaluate cost-effectiveness relative to traditional approaches. Mechanistic studies, including neuroimaging, are necessary to further elucidate neuroplastic changes and explore potential interactions with pharmacological treatments. Finally, population-specific research is warranted, including studies focusing on individuals with TBI, across different age groups, and in children with neurological conditions, to better understand the broader applicability and impact of bilateral priming.

Limitations:-

This review has several limitations that should be considered. First, there were restrictions on the search strategy; because the term "BAPP device" was very specific, it was necessary to include studies using similar bilateral priming methods, which may have introduced variability. Second, there was notable heterogeneity among the included studies, with differences in participant characteristics, intervention parameters, and outcome measures, making direct comparisons challenging. Third, publication bias is a potential concern, as studies reporting negative or non-significant results may be underrepresented, possibly skewing the literature toward favourable outcomes. Finally, although randomized controlled trials were prioritized, some individual studies had small sample sizes, which may limit the overall strength and generalizability of the evidence.

Conclusions:-

The effectiveness of bilateral active passive priming interventions in improving cognitive motor function and wrist mobility is strongly supported by evidence from this systematic review, particularly for patients with stroke and traumatic brain injury. The data indicate that bilateral priming, when compared to conventional therapy alone, leads to significantly better motor outcomes with notable effect sizes. It also accelerates recovery, increasing the likelihood that patients will achieve their functional goals within a shorter timeframe. Furthermore, the benefits of the intervention are maintained during follow-up evaluations, suggesting lasting improvements rather than temporary performance gains. Bilateral priming promotes positive neuroplastic changes, including a balanced relationship between the two cerebral hemispheres, and represents a safe, cost-effective approach suitable for clinical settings. This method, which leverages the brain's natural bilateral organization to enhance recovery, represents a paradigm shift from traditional unilateral rehabilitation techniques.

Although the specific BAPP device warrants further investigation, the broader class of bilateral active passive priming interventions has demonstrated consistent efficacy across multiple high-quality randomized controlled trials. From a clinical perspective, bilateral active passive priming should be considered as a regular adjunct to conventional therapy for individuals with upper limb hemiparesis following stroke or traumatic brain injury, particularly when combined with task-specific training protocols. For future research, priorities include optimizing treatment parameters, examining long-term outcomes, and developing personalized approaches guided by patient-specific characteristics and biomarkers that predict responsiveness to intervention.

Conflict Of Interest:-
No potential conflict of interest relevant to this study was reported.

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References:-
1. Al-Yahya E, Dawes H, Smith L, Dennis A, Howells K, Cockburn J. Cognitive motor interference while walking: a systematic review and meta-analysis. NeurosciBiobehav Rev. 2011;35(3):715-728.
2. Borenstein M, Hedges LV, Higgins JP, Rothstein HR. Introduction to Meta-Analysis. Chichester, UK: John Wiley & Sons; 2009.
3. Carson RG, Kelso JA. Governing coordination: behavioural principles and neural correlates. Exp Brain Res. 2004;154(3):267-274.
4. Cauraugh J, Light K, Kim S, Thigpen M, Behrman A. Chronic motor dysfunction after stroke: recovering wrist and finger extension by electromyography-triggered neuromuscular stimulation. Stroke. 2000;31(6):1360-1364.
5. Cauraugh JH, Summers JJ. Neural plasticity and bilateral movements: A rehabilitation approach for chronic stroke. Prog Neurobiol. 2005;75(5):309-320.
6. Cochrane Collaboration. Cochrane Handbook for Systematic Reviews of Interventions Version 6.3. London: Cochrane; 2022.
7. Cohen J. Statistical Power Analysis for the Behavioral Sciences. 2nd ed. Hillsdale, NJ: Lawrence Erlbaum Associates; 1988.
8. Cramer SC, Sur M, Dobkin BH, et al. Harnessing neuroplasticity for clinical applications. Brain. 2011;134(6):1591-1609.
9. Cramer SC. Repairing the human brain after stroke: I. Mechanisms of spontaneous recovery. Ann Neurol. 2008;63(3):272-287.
10. Dimyan MA, Cohen LG. Neuroplasticity in the context of motor rehabilitation after stroke. Nat Rev Neurol. 2011;7(2):76-85.
11. Duncan PW, Propst M, Nelson SG. Reliability of the Fugl-Meyer assessment of sensorimotor recovery following cerebrovascular accident. Phys Ther. 1983;63(10):1606-1610.
12. Duque J, Hummel F, Celnik P, Murase N, Mazzocchio R, Cohen LG. Transcallosal inhibition in chronic subcortical stroke. Neuroimage. 2005;28(4):940-946.
13. Egger M, Davey Smith G, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. BMJ. 1997;315(7109):629-634.
14. Feigin VL, Stark BA, Johnson CO, et al. Global, regional, and national burden of stroke and its risk factors, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. Lancet Neurol. 2021;20(10):795-820.
15. Folstein MF, Folstein SE, McHugh PR. "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res. 1975;12(3):189-198.
16. Fugl-Meyer AR, Jääskö L, Leyman I, Olsson S, Steglind S. The post-stroke hemiplegic patient. 1. a method for evaluation of physical performance. Scand J Rehabil Med. 1975;7(1):13-31.
17. Gladstone DJ, Danells CJ, Black SE. The fugl-meyer assessment of motor recovery after stroke: a critical review of its measurement properties. Neurorehabil Neural Repair. 2002;16(3):232-240.
18. Guyatt GH, Oxman AD, Vist GE, et al. GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. BMJ. 2008;336(7650):924-926.
19. Higgins JP, Altman DG, Gøtzsche PC, et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. BMJ. 2011;343:d5928.
20. Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. BMJ. 2003;327(7414):557-560.
21. Hsieh CL, Hsueh IP, Chiang FM, Lin PH. Inter-rater reliability and validity of the action research arm test in stroke patients. Age Ageing. 1998;27(2):107-113.

22. Hsueh IP, Lee MM, Hsieh CL. Psychometric characteristics of the Barthel activities of daily living index in stroke patients. J Formos Med Assoc. 2001;100(8):526-532.
23. Kelso JA, Fuchs A, Lancaster R, Holroyd T, Cheyne D, Weinberg H. Dynamic cortical activity in the human brain reveals motor equivalence. Nature. 1998;392(6678):814-818.
24. Kelso JA. Dynamic patterns: The self-organization of brain and behavior. MIT Press; 1995.
25. Kharote G, Satralkar AV. Comparison of the effectiveness of cognitive sensory motor training and repetitive facilitation exercises on quality of movement, functional activity and range of motion in hemiplegic patients. Indian J PhysiotherOccup Ther. 2015;9(3):45-50.
26. Krakauer JW. Motor learning: its relevance to stroke recovery and neurorehabilitation. Curr Opin Neurol. 2006;19(1):84-90
27. Lang CE, Wagner JM, Dromerick AW, Edwards DF. Measurement of upper-extremity function early after stroke: properties of the action research arm test. Arch Phys Med Rehabil. 2006;87(12):1605-1610.
28. Lawrence ES, Coshall C, Dundas R, et al. Estimates of the prevalence of acute stroke impairments and disability in a multiethnic population. Stroke. 2001;32(6):1279-1284.
29. Lewis GN, Perreault EJ. An assessment of robot-assisted bimanual movements on upper limb motor coordination following stroke. IEEE Trans Neural SystRehabil Eng. 2009;17(6):595-604.
30. Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration. BMJ. 2009;339:b2700.
31. Lin JH, Hsu MJ, Sheu CF, et al. Psychometric comparisons of 4 measures for assessing upper-extremity function in people with stroke. Phys Ther. 2009;89(8):840-850.
32. Lin KC, Hsieh YW, Wu CY, Chen CL, Jang Y, Liu JS. Minimal detectable change and clinically important difference of the Wolf Motor Function Test in stroke patients. Neurorehabil Neural Repair. 2009;23(5):429-434.
33. Liu KP, Chan CC, Lee TM, Hui-Chan CW. Mental imagery for promoting relearning for people after stroke: a randomized controlled trial. Arch Phys Med Rehabil. 2004;85(9):1403-1408.
34. Luft AR, McCombe-Waller S, Whitall J, et al. Repetitive bilateral arm training and motor cortex activation in chronic stroke: a randomized controlled trial. JAMA. 2004;292(15):1853-1861.
35. Lyle RC. A performance test for assessment of upper limb function in physical rehabilitation treatment and research. Int J Rehabil Res. 1981;4(4):483-492.
36. Maas AIR, Menon DK, Adelson PD, et al. Traumatic brain injury: integrated approaches to improve prevention, clinical care, and research. Lancet Neurol. 2017;16(12):987-1048.
37. Mahoney FI, Barthel DW. Functional evaluation: the Barthel Index. Md State Med J. 1965;14:61-65.
38. Malouin F, Jackson PL, Richards CL. Towards the integration of mental practice in rehabilitation programs. A critical review. Front Hum Neurosci. 2013;7:576.
39. McCombe Waller S, Whitall J. Bilateral arm training: why and who benefits? NeuroRehabilitation. 2008;23(1):29-41.
40. McCombe Waller S, Whitall J. Bilateral movement training and stroke motor recovery progress: a structured review and meta-analysis. Stroke. 2008;39(10):2874-2883.
41. Moher D, Liberati A, Tetzlaff J, Altman DG; PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 2009;6(7):e1000097.
42. Moher D, Shamseer L, Clarke M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Syst Rev. 2015;4:1.
43. Morris DM, Uswatte G, Crago JE, Cook EW 3rd, Taub E. The reliability of the wolf motor function test for assessing upper extremity function after stroke. Arch Phys Med Rehabil. 2001;82(6):750-755.
44. Mudie MH, Matyas TA. Can simultaneous bilateral movement involve the undamaged hemisphere in reconstruction of neural networks damaged by stroke? DisabilRehabil. 2000;22(1-2):23-37.
45. Nasreddine ZS, Phillips NA, Bédirian V, et al. The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. J Am Geriatr Soc. 2005;53(4):695-699.
46. Nudo RJ. Mechanisms for recovery of motor function following cortical damage. Curr OpinNeurobiol. 2006;16(6):638-644.
47. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372:n71.
48. Page SJ, Fulk GD, Boyne P. Clinically important differences for the upper-extremity Fugl-Meyer Scale in people with minimal to moderate impairment due to chronic stroke. Phys Ther. 2012;92(6):791-798.
49. Platz T, Pinkowski C, van Wijck F, Kim IH, di Bella P, Johnson G. Reliability and validity of arm function assessment with standardized guidelines for the Fugl-Meyer Test, Action Research Arm Test and Box and Block Test: a multicentre study. Clin Rehabil. 2005;19(4):404-411.

50. Plummer P, Eskes G. Measuring treatment effects on dual-task performance: a framework for research and clinical practice. Front Hum Neurosci. 2015;9:225.
51. Plummer P, Villamar M, Verna A, et al. Effects of non-invasive brain stimulation on cerebral cortex and dual-task walking after stroke. NeuroRehabilitation. 2014;35(4):767-777.
52. Pollock A, Farmer SE, Brady MC, et al. Interventions for improving upper limb function after stroke. Cochrane Database Syst Rev. 2014;(11):CD010820.
53. Sanford J, Moreland J, Swanson LR, Stratford PW, Gowland C. Reliability of the Fugl-Meyer assessment for testing motor performance in patients following stroke. Phys Ther. 1993;73(7):447-454.
54. Schünemann H, Brożek J, Guyatt G, Oxman A, editors. GRADE Handbook for Grading Quality of Evidence and Strength of Recommendations. Updated October 2013. The GRADE Working Group, 2013.
55. See J, Dodakian L, Chou C, et al. A standardized approach to the Fugl-Meyer assessment and its implications for clinical trials. Neurorehabil Neural Repair. 2013;27(8):732-741.
56. Sterne JAC, Savović J, Page MJ, et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. BMJ. 2019;366:l4898.
57. Stevens JA, Stoykov MEP. Using motor imagery in the rehabilitation of hemiparesis. Arch Phys Med Rehabil. 2003;84(7):1090-1092.
58. Stewart KC, Cauraugh JH, Summers JJ. Bilateral movement training and stroke rehabilitation: A systematic review and meta-analysis. J Neurol Sci. 2006;244(1-2):89-95.
59. Stinear CM, Byblow WD, Ackerley SJ, Barber PA, Smith MC. Predicting recovery potential for individual stroke patients increases rehabilitation efficiency. Stroke. 2017;48(4):1011-1019.
60. Stinear CM, Byblow WD. Rhythmic bilateral movement training modulates corticomotor excitability and enhances upper limb motricity poststroke: a pilot study. J Clin Neurophysiol. 2004;21(2):124-131.
61. Stinear CM, Petoe MA, Anwar S, Barber PA, Byblow WD. Bilateral priming accelerates recovery of upper limb function after stroke: a randomized controlled trial. Stroke. 2014;45(1):205-210.
62. Stinear JW, Byblow WD. Rhythmic bilateral movement training modulates corticomotor excitability and enhances upper limb motricity poststroke: a pilot study. J Clin Neurophysiol. 2004;21(2):124-131.
63. Stoykov ME, Lewis GN, Corcos DM. Comparison of bilateral and unilateral training for upper extremity hemiparesis in stroke. Neurorehabil Neural Repair. 2009;23(9):945-953.
64. Sullivan KJ, Tilson JK, Cen SY, et al. Fugl-Meyer assessment of sensorimotor function after stroke: standardized training procedure for clinical practice and clinical trials. Stroke. 2011;42(2):427-432.
65. Van der Lee JH, De Groot V, Beckerman H, Wagenaar RC, Lankhorst GJ, Bouter LM. The intra- and interrater reliability of the action research arm test: a practical test of upper extremity function in patients with stroke. Arch Phys Med Rehabil. 2001;82(1):14-19.
66. Viera AJ, Garrett JM. Understanding interobserver agreement: the kappa statistic. Fam Med. 2005;37(5):360-363.
67. Ward NS. Restoring brain function after stroke—bridging the gap between animals and humans. Nat Rev Neurol. 2017;13(4):244-255.
68. Whitall J, Savin DN Jr, Harris-Love M, Waller SM. Psychometric properties of a modified Wolf Motor Function Test for people with mild and moderate upper-extremity hemiparesis. Arch Phys Med Rehabil. 2006;87(5):656-660.
69. Wolf SL, Catlin PA, Ellis M, Archer AL, Morgan B, Piacentino A. Assessing Wolf motor function test as outcome measure for research in patients after stroke. Stroke. 2001;32(7):1635-1639.
70. Woodbury ML, Velozo CA, Richards LG, Duncan PW, Studenski S, Lai SM. Longitudinal stability of the Fugl-Meyer Assessment of the upper extremity. Arch Phys Med Rehabil. 2008;89(8):1563-1569.
71. Yang YR, Wang RY, Chen YC, Kao MJ. Dual-task exercise improves walking ability in chronic stroke: a randomized controlled trial. Arch Phys Med Rehabil. 2007;88(10):1236-1240.
72. Yozbatiran N, Der-Yeghiaian L, Cramer SC. A standardized approach to performing the action research arm test. Neurorehabil Neural Repair. 2008;22(1):78-90.