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Review of improvements in upper limb function with balance training and adjunct intervention in stroke survivors

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ABSTRACT

Balance is one of the main factors influencing the ability to walk. Various rehabilitation strategies have been developed to help stroke survivors regain functional ability. However, limited evidence is available on the effects of balance training on improving upper limb function. The goal of this review was to summarize the most recent research on the benefits of balance training and adjunct intervention for upper limb function in stroke survivors. Using the search phrases “stroke” AND “balance training” AND “hand function", the PubMed and Scopus databases were used to find relevant articles. Only those published in English were chosen, while the study included randomized controlled trials held between 2012 and 2021 involving stroke survivors aged 18 and above who underwent balance training. Dissertations, case studies, and review articles were excluded. Overall, 28 of 237 articles were eligible after screening based on the eligibility criteria. Ten articles were selected for the review. The intervention and control groups had 156 and 154 participants, respectively. Core muscle exercises; adjunct interventions such as virtual reality, action observation, and resistance training; and comparisons with combination therapy were among the main types of balance training. The Fugl-Meyer assessment upper extremity and Wolf motor function test were the primary outcome measures used to evaluate upper limb function. Of the ten trials chosen, six utilized combination therapy and demonstrated noticeable improvements in upper limb function.

Keywords: stroke; upper limb function; hand function; balance training; physiotherapy; rehabilitation

1. INTRODUCTION

Stroke is a disease currently ranked as the second leading cause of death worldwide (Feigin et al., 2021). Physical disability due to stroke greatly affects the capacity of many stroke survivors to participate in the community, diminishing their quality of life (Sulistyanto et al., 2022). Common impairments after stroke include upper and lower limb hemiparesis, so mobility is affected. Most stroke survivors suffer from impaired hand function (Faria-Fortini et al., 2011). The inability to use the hands to perform activities of daily living (ADL) is a significant drawback to taking care of oneself independently (Lieshout et al., 2020).

Balance training is an evidence-based intervention to improve mobility after stroke (Komiya et al., 2021), since balance is one of the main factors influencing the ability to walk (Lee et al., 2016). In addition to hand function impairments, over 80% of subacute stroke survivors were found to experience balance disability (Khan and Chevidikunnan, 2021). Various rehabilitation strategies have been developed to help stroke survivors regain functional ability. However, limited evidence is available on the effects of balance training on upper limb function.

A review of the effects of balance training on improved hand function after a stroke needs to be explored to guide rehabilitation teams in clinical decision-making and practice. This review aims to summarize recent scientific evidence concerning how balance training might improve hand function among stroke survivors. The review outcomes should enhance clinicians' understanding and practice, enabling them to help patients achieve better functional ability after stroke.

2. METHODOLOGY

2.1 Study design

The study was designed as a literature review involving a systematic search of articles, encompassing a comprehensive examination of the existing relevant literature that fulfilled the eligibility criteria.

2.2 Search methodology

Two researchers performed a literature search via PubMed and Scopus using the following search terms: 'stroke' AND 'balance training' AND 'hand function'. The following MeSH terms were used to perform a further search using PubMed: (("Stroke"[Mesh] AND "Postural Balance"[Mesh]) OR "Core Stability"[Mesh]) AND "Upper Extremity"[Mesh]. To ensure that all the research chosen had undergone standardized publication procedures, these search databases were selected as the sources of information. Additional manual searches were undertaken based on the references found in the chosen publications. A third researcher was consulted when necessary to resolve any disagreements.

2.3 Study selection

All selected articles were published in English. Randomized controlled trials held between 2012 and 2021 that involved conducting balance training with stroke survivors aged 18 years and above. Review articles, case reports, and dissertations were excluded.

2.4 Data extraction and recording

The following data were extracted and recorded: (i) details of the article (title, author, year of publication, study design, and sample size); (ii) demographic and clinical characteristics of study participants (mean age, onset of stroke); and (iii) study outcomes (research variables, interventions, outcome measures of hand function assessments such as the Fugl-Meyer assessment upper extremity (FMA-UE) and Wolf motor function test (WMFT), as well as their corresponding results). Ethical approval was not required as the review was based on existing publications.

3. RESULTS

The electronic search yielded 237 results. Of the 28 eligible articles, ten were selected for review. Figure 1 illustrates the PRISMA flowchart of the selection process. Table 1 summarizes the information gathered and the significant findings in each selected article. The intervention and control groups contained 156 and 154 participants, respectively. The latter received conventional balance training, with two studies omitting balance training and only employing upper limb exercise (Lee et al., 2020; Yang et al., 2021). All the intervention groups combined balance training with various therapeutic approaches. The mean age of the participants across the studies was 61.4 years old.

3.1 Types of intervention

The control group experienced standard balance training or upper limb training alone. All ten studies delivered adjunct therapies in the experimental group. The major types of balance training included therapeutic core muscle exercises and a combination of interventions such as action observation (AO), virtual reality (VR), and resistance training, while comparisons were made with combination therapy (conventional and adjunct).

In two studies, core strengthening and stability exercise, in addition to trunk control training, were given to persons with subacute and chronic stroke (El-Nashar et al., 2019; Lee et al., 2020). Lee et al. (2020) tested the impact of trunk control exercises on various domains of balance ability in stroke patients using unstable surfaces, including a Swiss ball and a balancing pad. Harmsen et al. (2015) delivered balance training in the form of upper arm reaching tasks and a mirror therapy-based action observation strategy among chronic stroke patients. To prevent the activation of the mirror neuron system, which is known to enhance motor learning, the control group watched a presentation of still landscape images acting as the control stimulus.

Five selected articles used VR with balance training. This combination was delivered by Jeon et al. (2019), who compared the effects of VR on the upper limb function, balance, and ADL of acute stroke survivors using stable and unstable surfaces. Another study involving VR in balance training for chronic stroke survivors was undertaken by Henrique et al. (2019) using an exergame approach. Boxing training in virtual or real settings as an adjunct to the neurodevelopmental (NDT) approach was explored by Ersoy and Iyigun (2020) to improve upper limb function and balance in stroke patients. Visual feedback was also used as an adjunct to trunk restraint or trunk support interventions intended to improve upper limb function in a study conducted by Yang et al. (2021). Additionally, Lee et al. (2018) introduced game-based VR canoe-paddling training to improve postural balance and upper limb function in subacute stroke survivors.

Gambassi et al. (2019) conducted dynamic resistance training using elastic bands and ankle and wrist weights on chronic ischemic stroke patients. In the article by Jiang et al. (2021) the researchers used a combination of a new self-assisted inhibition technique for the affected upper limb and balance training to improve hand function.

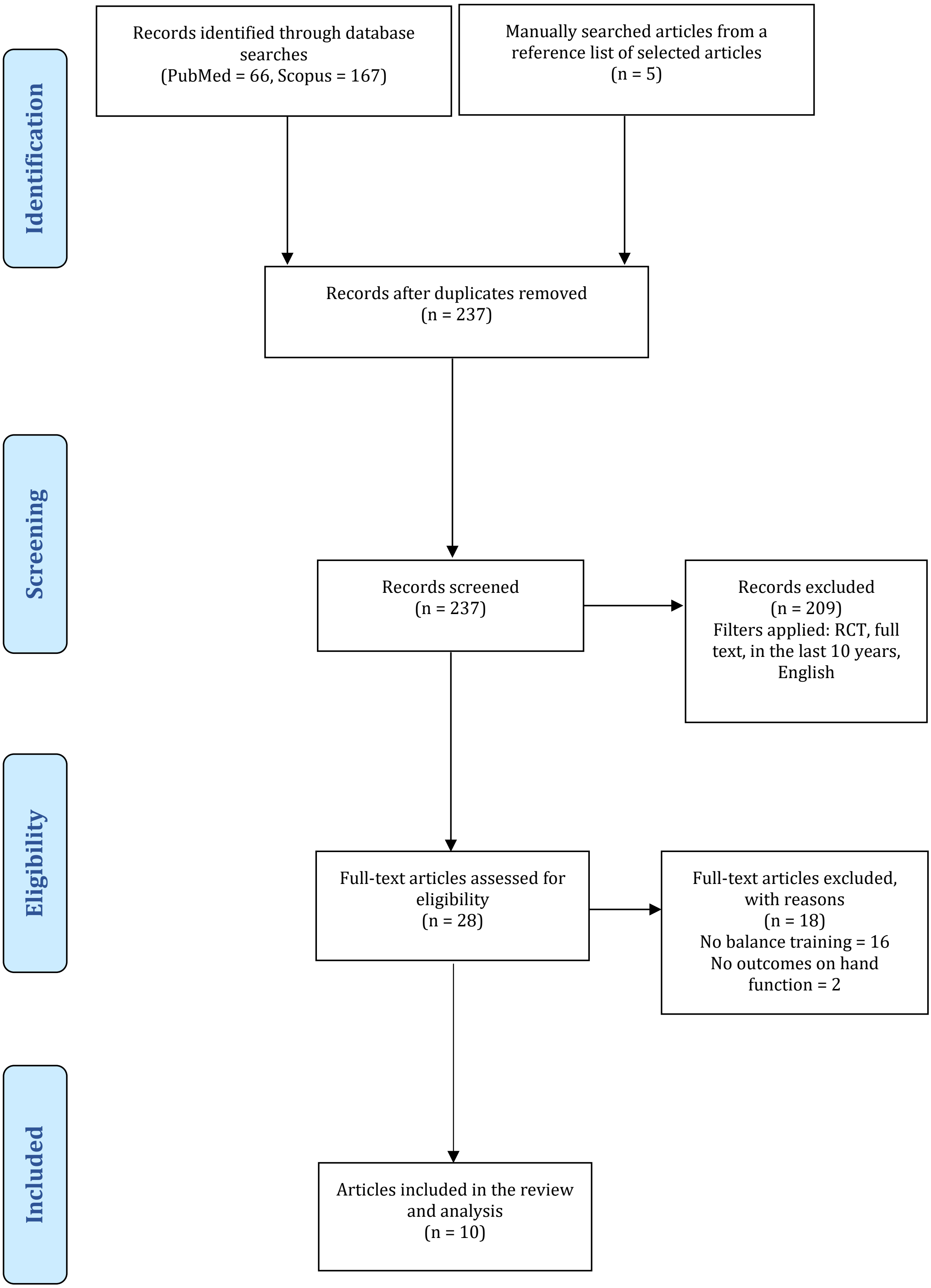

Figure 1. Flowchart of article selection

Table 1. Demographics, characteristics, details of interventions, outcome measures, and results of selected studies

Author (year of publication)	Total sample (N), number per group, number per affected side (right/left)	Mean age (years), mean onset of stroke	Main variables	Type of intervention	Outcome measures for hand function	Results
Jiang et al. (2021)	60 EG 1: 20 EG 2: 20 CG: 20 EG 1: 10/10 EG 2: 9/9 CG: 10/9	56.5 > 6 months	▪ Rate of contraction of affected elbow flexors ▪ Upper limb function	EG 1: Progressive balance training combined with inhibition of upper limb flexors by placing affected hand behind back. EG 2: Progressive balance training combined with inhibition of upper limb flexors by maintaining the elbow joint in an extended position with the assistance of the unaffected hand. CG: Place arms naturally by the 2 sides of the trunk with progressive balance training. *Frequency:* 30 min/session, 1 session/day, 5 days/week, total of 4 weeks	FMA-UE	The combination of the new inhibition method (shoulder elevation group) and the standing balance training reduced the abnormal activity of affected elbow flexors during walking. It increased walking speed and improved the affected upper limb motor function (p<0.001).
Yang et al. (2021)	28 EG: 14 CG: 14 EG: 6/8 CG: 6/8	64.3 30 months	▪ Upper limb function ▪ Trunk stability ▪ Balance function	EG: Upper limb training based on visual feedback with trunk support. CG: Upper limb training based on visual feedback and trunk restraint. *Frequency:* 30 min/day, 3 times/week, total of 4 weeks	ROM, MMT, FMA-UE	Trunk support-based upper limb training effectively improved trunk stability (p<0.01), balance (p<0.01), and upper limb function (p<0.05).
Ersoy and Iyigun (2020)	40 EG: 20 CG: 20 EG: 7/13 CG: 14/6	59.2 3 years	▪ Upper limb function ▪ Balance function ▪ Cognitive function	EG : Real boxing training programs in addition to NDT. CG: Virtual boxing training in addition to NDT. *Frequency:* 30 min/day, 3 sessions/week, for 8 weeks, total of 24 sessions	WMFT, MDT, VBA	Boxing treatment, real (p=0.000) or virtual (p=0.004), could significantly affect balance and bilateral upper limb movement time.
Lee et al. (2020)	38 EG: 19 CG: 19 EG: 12/6 CG: 10/7	61.3 7 weeks	▪ Sensorimotor function ▪ Balance function ▪ Walking function	EG: Trunk exercises training on an unstable surface in hook-lying and sitting. CG: ROM exercises of the upper limb. *Frequency:* 30 min/session, two non-consecutive days/week, total of six weeks	Grip strength using hand dynamometer	Trunk exercises on unstable surfaces significantly improved the ability to raise the unaffected arm rapidly in sitting without foot support, indicating improved trunk control (p=0.034). Grip strength of the unaffected limb did not differ significantly between the two groups (p=0.357).

Table 1. Demographics, characteristics, details of interventions, outcome measures, and results of selected studies (Continued)

Author (year of publication)	Total sample (N), number per group, number per affected side (right/left)	Mean age (years), mean onset of stroke	Main variables	Type of intervention	Outcome measures for hand function	Results
Gambassi et al. (2019)	22 EG: 11 CG: 11 EG: 5/6 CG: 1/10	63.5 5 years	▪ Upper limb muscle strength ▪ Hemodynamic parameters ▪ Cardiac autonomic modulation ▪ Oxidative stress markers	EG: Dynamic resistance training based on functional training with TheraBand. CG: Physical movements that mimic basic and instrumental ADL, postural changes, and gait exercises on parallel bars. *Frequency:* Two times/week over 8 weeks with a 48-h rest interval provided between each exercise session	IHGPL, IHGNPL	Significant reduction in upper limb muscle strength IHGPL (p=0.017) and IHGNPL (p=0.016) was observed in CG. No changes were seen in in EG.
El-Nashar et al. (2019)	30 EG: 15 CG: 15 Affected side: not specified	58.8 3 years	▪ Upper limb function ▪ Balance function	EG: Balance training with core stability exercises. CG: Conventional physical therapy program with stretching and strengthening exercise for shoulder, trunk control exercises. *Frequency:* 30-60 min/session, total 18 sessions for 6 weeks	WMFT	Core muscle training had a significant effect on improving trunk balance in chronic stroke patients but no additional effect on improving upper limb function when compared to the conventional physical therapy program. There were no statistically significant differences between groups in WMFT and time of upper extremity task performance.
Henrique et al. (2019)	31 EG: 15 CG: 16 Affected side: not specified	76.2 16 months	▪ Upper limb function ▪ Balance function	EG: Exergame rehabilitation for upper limb motor function and balance rehabilitation. CG: Conventional physiotherapy – ROM exercises. *Frequency:* 30 min/session, 2 sessions/week, for 12 weeks, total 24 sessions	FMA-UE, BBS	There were significant improvements in FMA-UE and BBS scores in both EG and CG ($p<0.001$) from pre-intervention to post-intervention. When comparing evaluation results from pre-intervention to post-intervention, the FMA-UE variables measured on the shoulder, elbow, and forearm separately ($p<0.001$) showed a significant reduction in the CG.

Table 1. Demographics, characteristics, details of interventions, outcome measures, and results of selected studies (Continued)

Author (year of publication)	Total sample (N), number per group, number per affected side (right/left)	Mean age (years), mean onset of stroke	Main variables	Type of intervention	Outcome measures for hand function	Results
Jeon et al. (2019)	14 EG: 7 CG: 7 EG: 4/3 CG: 4/3	53.9 9 days	▪ Upper limb function ▪ Balance function ▪ Performance of ADL	EG: Combined virtual reality and balance training on an unstable surface. CG: Balance training on a stable surface. *Frequency:* 60 min/day, 5 sessions/week, total 4 weeks	MFT	Both groups displayed significant improvement in MFT ($p<0.05$). No significant differences in the improvement of MFT after intervention between EG and CG.
Lee et al. (2018)	30 EG: 15 CG: 15 EG: 6/9 CG: 5/10	61.6 3 months	▪ Upper limb function ▪ Balance function	EG: Game-based VR canoe paddling training and conventional rehabilitation – balance and lower limb strengthening, ADL training. CG: Conventional rehabilitation. *Frequency:* 30 min/day, 3 times/week, total 5 weeks	MFT	Both groups demonstrated significant improvements in balance and upper extremity function, with EG showing significantly greater improvements than CG in both variables ($p<0.05$).
Harmsen et al. (2015)	37 EG: 18 CG: 19 EG: 8/10 CG: 9/10	58.5 42 months	▪ Upper limb function ▪ Upper limb kinematics	EG: Motor task training based on upper arm reaching movement as fluently and fast as possible toward the target endpoint in adjunct with AOT. CG: Upper arm reaching movement with observation of a slideshow with static photographs of landscapes. *Frequency:* 1 session	FMA-UE, Accelerometer	Movement time decreased significantly in both groups : 18.3% in the AOT group. ($p<0.001$) and 9.1% in the CG group ($p=0.036$). There was a significant difference in movement time decrease between groups (mean difference of 0.14 s).

Note. EG: experimental group, CG: control group, FMA: Fugl Meyer assessment, FMA-UE: Fugl Meyer assessment-upper extremity, ROM: range of motion, MMT: manual muscle testing. NDT: neurodevelopmental therapy, WMFT: Wolf motor function test, MDT: manual dexterity test, VBA: video boxing analysis, IHGPL: isometric hand grip of paretic limbs, IHGNPL: isometric hand grip of paretic non-paretic limbs, ADL: activities of daily living, BBS: Berg balance scale, MFT: manual function test, VR: virtual reality, and AOT: action observation therapy

3.2 Types of outcome measures for assessing hand function

The primary outcome measures for assessing hand function were the FMA-UE and the WMFT. Other assessment tools included the manual function test (MFT), range of motion (ROM) test, manual muscle testing (MMT), a hand dynamometer, and an accelerometer.

The FMA-UE was extensively used in four studies to measure motor function and describe the upper-extremity motor recovery of stroke survivors (Harmsen et al., 2015; Henrique et al., 2019; Jiang et al., 2021; Yang et al., 2021). The five domains forming the FMA scale are motor function in the upper and lower limbs, sensation, balance, joint range of motion and joint pain (Fugl-Meyer et al., 1975). Only the motor function domain of the upper limb was considered and evaluated in the chosen articles. Using a three-point ordinal scale, upper limb motor function is rated from 0 to 2 for *no function*, *partial function*, and *perfect function*. The maximum possible score on the FMA is 100.

The perfect score for the FMA-UE is 66, while the upper extremities are classified into shoulder, elbow, forearm, wrist, and fingers. The remaining 34 points are comprised of the lower limb components. The reliability and validity of FMA-UE have proven to be good, with a total of 10 tasks and 33 sub-tasks on the scale (Pandian et al., 2015; See et al., 2013). The assessment scale measures the volitional movement synergies of the shoulder, elbow, and wrist joints, as well as the stability of the wrist joint. Upper limb coordination and speed are also measured.

The 17-item modified version of the WMFT was used in two studies to measure the functional ability of the upper limb affected by stroke (El-Nashar et al., 2019; Ersoy and Iyigun, 2020). The original WMFT had 21 items in the outcome measure (Wolf et al., 1989). Now more commonly used in practice (Taub et al., 1993), the modified WMFT consists of components such as strength measurement in items 7 and 14, with the remaining 15 items consisting of timed functional tasks lasting a maximum of 120 per task, involving simple to complex movements. The least-affected side of the upper limb is measured first on a six-point ordinal scale from 0 to 5, whereas the most-affected side is measured last. These sub-scores examine movement quality while the individual is performing functional tasks; the maximum total score is 75. This is also known as the functional ability score. The WMFT has sufficient criterion validity with the FMA-UE and overall good reliability for the total functional score (Morris et al., 2001; Whitall et al., 2006; Wolf et al., 2001).

In two of the research articles, the MFT was used as the primary outcome measurement tool for evaluating upper limb function, which includes gross and fine motor abilities (Jeon et al., 2019; Lee et al., 2018). This useful assessment tool has an inter-tester and intra-tester reliability of r = 0.95 (Miyamoto et al., 2009). The tool has a maximum score of 32 points, with a higher score indicating better upper limb function. The eight items in the test are subdivided into upper extremity motion (four items), grasping and pinching (two items), and manipulative activities (two items).

Other scales used to measure upper limb function objectively were the ROM test of shoulder flexion and MMT of the triceps muscle (Yang et al., 2021). A camera was used to record the active ROM of the affected shoulder joint flexion, while a goniometer was used to measure the ROM. The same assessor performed ROM and MMT pre- and post-measurements, averaging three times for each motion to ensure accuracy. The MMT was evaluated using a standardised test sequence, instructions, and scores based on a six-point scale for each muscle.

An objective hand grip strength measurement was conducted using the JAMAR® hand dynamometer (Gambassi et al., 2019; Lee et al., 2020). The affected upper limb movement times were also used as a primary outcome measure and obtained using an accelerometer — TEMEC Vita port 3 digital recording system (Harmsen et al., 2015).

3.3 Assessing improvement in hand function

Of the ten selected studies, six showed significant hand function improvements when using combination therapy (Ersoy and Iyigun, 2020; Henrique et al., 2019; Jeon et al., 2019; Jiang et al., 2021; Lee et al., 2018; Yang et al., 2021). These studies varied in training duration, intensity, and frequency, hence the difficulties in standardizing the interventions.

3.3.1 Assessing improvement within groups

The research by Jeon et al. (2019) revealed significant improvements in upper limb function in the experimental and control groups of acute stroke survivors for a total of 20 sessions over four weeks, both groups had 30 min of traditional rehabilitation therapy daily, five times per week (20 sessions). The experimental group received an additional 30 min of balance training through virtual reality on an unstable surface, whereas the control group performed balance training for 30 min on a stable surface. There was no significant difference between the WMFT scores when both groups were compared.

The results from the exergame study also demonstrated significantly improved upper limb function in both groups, suggesting that both treatment methods were effective (Henrique et al., 2019). The intervention period for chronic stroke patients was 12 weeks, with sessions conducted twice a week for 30 min each (24 sessions). The researchers compared the exergame and conventional therapy methods, such as performing active range of motion exercises to improve balance and upper limb function.

The NDT approach was administered for a total of 24 sessions (over eight weeks, three sessions/week and 30 min/day) in research conducted to investigate the effects of an adjunct intervention on upper limb, balance, and cognitive function in stroke patients (Ersoy and Iyigun, 2020). An additional 30 min of virtual or real boxing training was given, bringing the total treatment time for each session to an hour. The results showed that neither method was superior to the other. Both groups demonstrated statistically significant improvements in hand function post-intervention.

3.3.2 Assessing improvement between groups

Only one study revealed significant intergroup improvements in upper limb function (Jiang et al., 2021). A total of 20 sessions of balance training — lasting for 30 min per training session, with one session per day over five days per week for four weeks — was implemented to discover how a new inhibition technique as an adjunct affected upper limb motor function after stroke. The between-group comparison indicated significantly improved FMA-UE scores in the experimental shoulder elevation group. In contrast, no significant difference was found between the comparison and control groups.

The between-group differences in unaffected side upper limb strength were insignificant in a study using balance training in addition to conventional rehabilitation with stroke patients (Lee et al., 2020). The treatment duration comprised 30 min of training on two non-consecutive days per week for a total of six weeks (12 sessions). However, unaffected arm-raising speeds measured using a gyroscope sensor were found to be significantly faster in the experimental group, suggesting that faster arm-raising speeds after training were not due to improved motor function in the unaffected upper limb.

Another study also indicated little improvement in the between-group WFMT scores (El-Nashar et al., 2019). The experimental group had an additional 30 min of core stability training. The session consisted of 30 min of intervention, three times per week for six weeks (18 sessions). The results showed that, compared to conventional physiotherapy programs, core muscle training did not further improve hand function. Nevertheless, it had a substantial impact on improving trunk balance in chronic stroke patients.

Dynamic resistance training as an interventional treatment was administered two times per week over the course of eight weeks (16 sessions), with a 48-h rest period between each exercise session (Gambassi et al., 2019). The isometric hand grip paretic limb and isometric hand grip non-paretic limb remained unchanged in the experimental group, but they significantly reduced in the control group. The latter group were given physical movements imitating ADL, postural changes, and gait exercises on parallel bars.

3.3.3 Improvement within and between groups

In one study treating upper limbs with trunk support or trunk restraints, two groups performed training for 30 min a day, three times a week, for four weeks (12 sessions) (Yang et al., 2021). The authors concluded that the use of trunk support that did not hinder upper limb movements was significantly more effective than the trunk restraint in the experimental group; this was evident from the FMA-UE scores. However, both groups showed significant improvements in ROM, MMT, and FMA-UE scores.

Separate research displayed significant distinctions in upper limb function both within and between groups, with a 10.96% greater improvement observed in the experimental group, compared to the control group. This emphasized the essential role the core muscles play in ensuring trunk stability by connecting the lower limbs to the upper limbs (Lee et al., 2018). In addition to a conventional rehabilitation program comprising balance and lower limb strength training alongside ADL training, an experimental group received game-based VR canoe paddling. The results were significantly improved postural balance and upper limb function of the subacute stroke survivors in both groups. The intervention period lasted five weeks, with 30-min sessions delivered three times a week (15 sessions).

A combination of AO, mirror therapy, and upper limb reaching tasks showed substantially improved arm movement times within both groups (Harmsen et al., 2015). The decrease in movement time was significantly greater in the experimental AO group, compared to the control group. The primary purpose of the study was not to assess improvements in hand function but to determine the effectiveness of AO on learning motor tasks of the arm. The treatment duration details were not included in the article.

4. DISCUSSION

This review revealed that various types of balance training, when used as an adjunct to other therapeutic interventions, can considerably improve stroke-affected upper limb function. Based on identifying the clinical relationship between the trunk and the limbs, several balance training methods were selected and delivered in each research study to enhance upper limb function (Fisher, 1987; Rood, 1956). To optimally perform upper limb motor tasks, like reaching, grasping, and manipulating objects, the shoulder girdle must be dynamically stable on a secure trunk (Rosenblum and Josman, 2003).

Individuals who have suffered a stroke may present asymmetrical trunk activation, which causes a decline in trunk stability and balance (Haruyama et al., 2017). Research is lacking on the impact of core strengthening on the function of the upper limb (El-Nashar et al., 2019). Core stability exercise therapy simultaneously engages the abdominal and multifidi muscles to stabilize the head and body before and during limb movements (Yu and Park, 2013).

Implicit learning and engagement also influence the strategies used in combination therapies. McCombe Waller and Prettyman (2012) found that when hemiparetic upper limb training was performed in a standing position, without specific postural control instructions, postural control improved. Without drawing attention to dual tasking through explicit cues, activation of the trunk and lower limb muscles may influence upper limb motor activity (Kaur et al., 2014). Moreover, dual tasking is often challenging and can produce anxiety, which impedes the efficiency of upper limb motor control in stroke survivors (Hejazi-Shirmard et al., 2020). Punching or boxing are excellent examples of complex movements involving the upper limb, lower limb, and trunk (Lenetsky et al., 2013).

The FMA-UE was the most frequently used primary outcome measure when assessing upper limb motor performance, followed by the WMFT. The outcome measure selection trend in these articles suggests the higher reliability and validity attributes of the FMA-UE, compared to the WMFT. Previous studies have shown that the FMA has greater responsiveness and validity value than the WMFT (Hsieh et al., 2009).

Improved hand function within all groups was found to be meaningfully significant. The studies covered the severity range in the patient population, from acute to chronic stroke. A similar paper also demonstrated significant intragroup differences when using the primary upper limb outcome measure, with no intergroup difference recorded (Park et al., 2017). The results of the experimental group did not differ significantly from those from the control group, proving the efficacy of both treatments. Interestingly, this highlights that in stroke survivors, active participation and use of the hemiparetic limb are essential in improving upper limb function, regardless of the treatment method received. This concept of active and repetitive use of the affected hand aligned with a systematic review by Diaz-Arribas et al. (2020), which showed that intensive therapy with or without robotic aids can effectively improve upper limb motor control and dexterity.

In the paper showing significant between-group improvements in upper limb function, the percentage increase in the mean FMA-UE scores for the interventional group was 21%, with only a 6% increase in the control group (Jiang et al., 2021). The study focused on addressing the associated reactions of the upper limb elbow flexors while performing frequent dynamic upper limb activities in daily life. Spasticity of the hemiparetic upper limb largely influences motor function (De Oliveira Cacho et al., 2017). Therefore, the management and regulation of upper limb spasticity — specifically the elbow flexors, which are influenced by postural balance — are essential strategies for addressing upper limb issues post-stroke (Wang et al., 2020). Interventions in the other publications included in this review did not utilize inhibition techniques for the spastic upper limb. This issue was highlighted in a study by El-Nashar et al. (2019) in which the recruited participants had moderate spasticity of the biceps, and appropriate training focused on the correct impairments may have been overlooked.

Some studies concluded that no significant improvements in upper limb function occurred between groups, with these findings both supported and contradicted by other comparable studies. It was highlighted that the research limitations were due to the short treatment durations of six or eight weeks, and the authors recommended that future studies should utilize longer durations (El-Nashar et al., 2019; Gambassi et al., 2019). Other researchers who conducted core stability programs shared this view, stating that a short duration was insufficient to produce significant outcomes (Jamison et al., 2012; Lust et al., 2009). Meanwhile, both Miyake et al. (2013) and Woodbury et al. (2009) have suggested that enhancing trunk stability through core exercises not only improves overall performance but also facilitates the use of distal mobility, particularly in the upper extremities.

In the research study by Gambassi et al. (2019), even though the upper limb muscle strength before and after the intervention did not change, the hand grip strength of the bilateral arm in the control group reduced considerably, indicating the importance of upper limb resistance exercises for the muscle strength of stroke survivors. The cause of the significant decline in isometric hand grip strength in the control group and whether dynamic movements play a role in this both remain unconfirmed. The findings obtained by Lee et al. (2020) also revealed no changes in upper limb strength after training, but the faster arm-raising speeds suggested the involvement of better trunk control. These outcomes were reinforced by an earlier study indicating that difficulty with postural control after stroke was linked to less effective upper limb movement (Dickstein et al., 2004).

Throughout the review, three studies revealed significantly improved upper limb function in the within and between-group comparisons (Harmsen et al., 2015; Lee et al., 2018; Yang et al., 2021). Although Harmsen et al. (2015) did not seek to measure any meaningful long-term change in upper limb function, they discovered that combining evidenced-based interventions was effective in the motor relearning process. As reported by Yang et al. (2021), the difference between the improved FMA scores of the trunk support and trunk restraint groups was 2.64 points, with more significant improvements noted in the trunk support group. This most likely occurred due to the increased frequency with which the tricep muscle was used during reaching movements with less restriction on trunk movement, which led to better upper limb muscle strength and function (Brauer et al., 2013; Yang et al., 2021). These findings of significantly different FMA scores contrasted with the insignificant differences reported by Wee et al. (2014), who summarized that evidence was lacking about trunk control training to reduce upper limb impairments in chronic stroke patients. In addition, to further improve upper limb reaching activities, core muscle exercises in combination with traditional exercises were found to be effective in stroke survivors with a hemiplegic upper limb (Kumaresan and Mahiba, 2016). Among subacute stroke patients, the upper limb MFT scores were significantly higher — by 13.38% — in the experimental group, compared to the control group (Lee et al., 2018). The simultaneous activation of the trunk muscles, upper limbs, and lower limbs during intricate movements (such as canoe paddling) substantially enhanced upper limb function post-stroke, as discovered by Yang et al. (2021), who also reported that trunk restraint was less beneficial in improving upper limb function in stroke patients.

Concerning the stroke type experienced by the patients, the majority exhibited left-side brain involvement. However, the two studies by Henrique et al. (2019) and El-Nashar et al. (2019) did not specify the affected side, while Harmsen et al. (2015) categorized the affected side as dominant or non-dominant. Notably, none of the reviewed studies indicated that the affected side after a stroke had any significant influence on improved upper limb function.

One notable strength of the current study is the clarification of the clinical connection between the trunk and upper limbs, which provides a theoretical foundation for understanding the importance of balance training and core stability in improving upper limb function following a stroke. Additionally, the review includes studies from across the entire spectrum of stroke recovery, from the acute to chronic stages. This longitudinal perspective greatly enhances the study's applicability, providing valuable insights applicable to various phases of stroke rehabilitation. This broad timeframe not only improves the generalizability of the findings but also contributes to a more comprehensive understanding of the intricate factors involved in addressing upper limb function throughout the stroke recovery process.

4.1 Study limitations

This review has certain limitations that need to be addressed. First, the number of articles selected for this review is relatively low, compared to most published scoping review papers. However, when using the search engines to find relevant articles, specific search terms and keywords were utilized. The second drawback of this study is that only two databases — PubMed and Scopus — were used to search for papers. This may have contributed to the small number of articles retrieved for the review. Nonetheless, both are major databases used in the medical field. Other databases, such as Google Scholar, might produce many papers, so a long list of exclusion criteria would be required to reduce them to an acceptable number for screening. Thus, the methodology used for the search might be compromized. Thirdly, only randomized controlled trials were included in the review, thus limiting the number of papers that could be utilized to fulfil the study objective. Other study designs, such as cohort studies and case-control studies, might add value to this type of review. Randomized controlled trials are well established as the best type of research for determining whether an intervention is effective (Akobeng, 2005). In summary, it is suggested that future scoping reviews include more databases and study designs during the search, which would further improve the quality of the review. In addition, a longer time range would be beneficial as the current study only selected articles published between 2012 and 2021.

5. CONCLUSION

Upper limb function in stroke survivors can be improved with balance training combined with an additional intervention. More methodologically rigorous trials are needed to assess the extent to which various interventions are beneficial supplements to balance training for improving upper limb outcomes after stroke.

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REFERENCES

Akobeng, A. K. (2005). Understanding randomised controlled trials. *Archives of Disease in Childhood*, 90(8), 840–844.

Brauer, S. G., Hayward, K. S., Carson, R. G., Cresswell, A. G., and Barker, R. N. (2013). The efficacy of SMART Arm training early after stroke for stroke survivors with severe upper limb disability: A protocol for a randomised controlled trial. *BMC Neurology*, 13, 71.

De Oliveira Cacho, R., Cacho, E. W. A., Loureiro, A. B., de Medeiros Cirne, G. N., Pereira, S. A., de Abreu Freitas, R. P., Lima, N. M. F. V., and Borges, G. (2017). The spasticity in the motor and functional disability in adults with post-stroke hemiparetic. *Fisioterapia em Movimento*, 30(4), 745–752.

Diaz-Arribas, M. J., Martin-Casas, P., Cano-de-la-Cuerda, R., and Plaza-Manzano, G. (2020). Effectiveness of the Bobath concept in the treatment of stroke: A systematic review. *Disability and Rehabilitation*, 42(12), 1636–1649.

Dickstein, R., Shefi, S., Marcovitz, E., and Villa, Y. (2004). Anticipatory postural adjustment in selected trunk muscles in post stroke hemiparetic patients. *Archives of Physical Medicine and Rehabilitation*, 85(2), 261–267.

El-Nashar, H., ElWishy, A., Helmy, H., and El-Rwainy, R. (2019). Do core stability exercises improve upper limb function in chronic stroke patients? *The Egyptian Journal of Neurology, Psychiatry and Neurosurgery*, 55, 38.

Ersoy, C., and Iyigun, G. (2020). Boxing training in patients with stroke causes improvement of upper extremity, balance, and cognitive functions but should it be applied as virtual or real? *Topics in Stroke Rehabilitation*, 28(2), 112–126.

Faria-Fortini, I., Michaelsen, S. M., Cassiano, J. G., and Teixeira-Salmela, L. F. (2011). Upper extremity function in stroke subjects: Relationships between the international classification of functioning, disability, and health domains. *Journal of Hand Therapy*, 24(3), 257–264.

Feigin, V. L., Stark, B. A., Johnson, C. O., Roth, G. A., Bisignano, C., Abady, G. G., Abbasifard, M., Abbasi-Kangevari, M., Abd-Allah, F., Abedi, V., Abualhasan, A., Abu-Rmeileh, N. M., Abushouk, A. I., Adebayo, O. M., Agarwal, G., Agasthi, P., Ahinkorah, B. O., Ahmad, S., Ahmadi, S., . . . Murray, C. J. L. (2021). Global, regional, and national burden of stroke and its risk factors, 1990–2019: A systematic analysis for the Global Burden of Disease Study 2019. *The Lancet Neurology*, 20(10), 795–820.

Fisher, B. (1987). Effect of trunk control and alignment on limb function. *The Journal of Head Trauma Rehabilitation*, 2(2), 72–79.

Fugl-Meyer, A. R., Jääskö, L., Leyman, I., Olsson, S., and Steglind, S. (1975). The post-stroke hemiplegic patient. 1. a method for evaluation of physical performance. *Scandinavian Journal of Rehabilitation Medicine*, 7(1), 13–31.

Gambassi, B. B., Coelho-Junior, H. J., Santos, C. P. D., de Oliveira Gonçalves, I., Mostarda, C. T., Marzetti, E., Sotão, S. S., Uchida, M. C., De Angelis, K., and Rodrigues, B. (2019). Dynamic resistance training improves cardiac autonomic modulation and oxidative stress parameters in chronic stroke survivors: A randomized controlled trial. *Oxidative Medicine and Cellular Longevity*, 2019, 5382843.

Harmsen, W. J., Bussmann, J. B. J., Selles, R. W., Hurkmans, H. L. P., and Ribbers, G. M. (2015). A mirror therapy-based action observation protocol to improve motor learning after stroke. *Neurorehabilitation and Neural Repair*, 29(6), 509–516.

Haruyama, K., Kawakami, M., and Otsuka, T. (2017). Effect of core stability training on trunk function, standing balance, and mobility in stroke patients. *Neurorehabilitation and Neural Repair*, 31(3), 240–249.

Hejazi-Shirmard, M., Lajevardi, L., Rassafiani, M., and Taghizadeh, G. (2020). The effects of anxiety and dual-task on upper limb motor control of chronic stroke survivors. *Scientific Reports*, 10(1), 15085.

Henrique, P. P. B., Colussi, E. L., and De Marchi, A. C. B. (2019). Effects of exergame on patients' balance and upper limb motor function after stroke: A randomized controlled trial. *Journal of Stroke and Cerebrovascular Diseases*, 28(8), 2351–2357.

Hsieh, Y.-W., Wu, C.-Y., Lin, K.-C., Chang, Y.-F., Chen, C.-L., and Liu, J.-S. (2009). Responsiveness and validity of three outcome measures of motor function after stroke rehabilitation. *Stroke*, 40(4), 1386–1391.

Jamison, S. T., McNeilan, R. J., Young, G. S., Givens, D. L., Best, T. M., and Chaudhari, A. M. W. (2012). Randomized controlled trial of the effects of a trunk stabilization program on trunk control and knee loading. *Medicine and Science in Sports and Exercise*, 44(10), 1924–1934.

Jeon, M.-J., Moon, J.-H., and Cho, H.-Y. (2019). Effects of virtual reality combined with balance training on upper limb function, balance, and activities of daily living in persons with acute stroke: A preliminary study. *Physical Therapy Rehabilitation Science*, 8(4), 187–193.

Jiang, W., Wang, S., Wu, Q., and Li, X. (2021). Effects of self-assisted shoulder elevation of the affected side combined with balance training on associated reactions of upper limb and walking function in chronic stroke patients: A randomized controlled trial. *Medical Science Monitor*, 27, e928549.

Kaur, N., Bhanot, K., Brody, L. T., Bridges, J., Berry, D. C., and Ode, J. J. (2014). Effects of lower extremity and trunk muscles recruitment on serratus anterior muscle activation in healthy male adults. *International Journal of Sports Physical Therapy*, 9(7), 924–937.

Khan, F., and Chevidikunnan, M. F. (2021). Prevalence of balance impairment and factors associated with balance among patients with stroke. A cross sectional retrospective case control study. *Healthcare*, 9(3), 320.

Komiya, M., Maeda, N., Narahara, T., Suzuki, Y., Fukui, K., Tsutsumi, S., Yoshimi, M., Ishibashi, N., Shirakawa, T., and Urabe, Y. (2021). Effect of 6-week balance exercise by real-time postural feedback system on walking ability for patients with chronic stroke: A pilot single-blind randomized controlled trial. *Brain Sciences*, 11(11), 1493.

Kumaresan, A., and Mahiba, J. A. (2016). Effect of core muscle exercise in improving reaching activities in participants with hemiplegia. *International Journal of Pharma and Bio Sciences*, 7, 1096–1104.

Lee, K. B., Lim, S. H., Kim, Y. D., Yang, B. I., Kim, K. H., Lee, K. S., Kim, E. J., and Hwang, B. Y. (2016). The contributions of balance to gait capacity and motor function in chronic stroke. *Journal of Physical Therapy Science*, 28(6), 1686–1690.

Lee, M. M., Lee, K. J., and Song, C. H. (2018). Game-based virtual reality canoe paddling training to improve postural balance and upper extremity function: A preliminary randomized controlled study of 30 patients with subacute stroke. *Medical Science Monitor*, 24, 2590-2598.

Lee, P.-Y., Huang, J.-C., Tseng, H.-Y., Yang, Y.-C., and Lin, S.-I. (2020). Effects of trunk exercise on unstable surfaces in persons with stroke: A randomized controlled trial. *International Journal of Environmental Research and Public Health*, 17(23), 9135.

Lenetsky, S., Harris, N. K., and Brughelli, M. (2013). Assessment and contributors of punching forces in combat sports athletes: Implications for strength and conditioning. *Strength and Conditioning Journal*, 35(2), 1–7.

Lieshout, E. C. C. V., van de Port, I. G., Dijkhuizen, R. M., and Visser-Meily, J. M. A. (2020). Does upper limb strength play a prominent role in health-related quality of life in stroke patients discharged from inpatient rehabilitation? *Topics in Stroke Rehabilitation*, 27(7), 525–533.

Lust, K. R., Sandrey, M. A., Bulger, S. M., and Wilder, N. (2009). The effects of 6-week training programs on throwing accuracy, proprioception, and core endurance in baseball. *Journal of Sport Rehabilitation*, 18(3), 407–426.

McCombe Waller, S., and Prettyman, M. G. (2012). Arm training in standing also improves postural control in participants with chronic stroke. *Gait and Posture*, 36(3), 419–424.

Miyake, Y., Kobayashi, R., Kelepecz, D., and Nakajima, M. (2013). Core exercises elevate trunk stability to facilitate skilled motor behavior of the upper extremities. *Journal of Bodywork and Movement Therapies*, 17(2), 259–265.

Miyamoto, S., Kondo, T., Suzukamo, Y., Michimata, A., and Izumi, S-I. (2009). Reliability and validity of the manual function test in patients with stroke. *American Journal of Physical Medicine and Rehabilitation*, 88(3), 247–255.

Morris, D. M., Uswatte, G., Crago, J. E., Cook, E. W., III, and Taub, E. (2001). The reliability of the wolf motor function test for assessing upper extremity function after stroke. *Archives of Physical Medicine and Rehabilitation*, 82(6), 750–755.

Pandian, S., Arya, K. N., and Kumar, D. (2015). Effect of motor training involving the less-affected side (MTLA) in post-stroke subjects: A pilot randomized controlled trial. *Topics in Stroke Rehabilitation*, 22(5), 357–367.

Park, J., Gong, J., and Yim, J. (2017). Effects of a sitting boxing program on upper limb function, balance, gait, and quality of life in stroke patients. *NeuroRehabilitation*, 40(1), 77–86.

Rood, M. (1956). Neurophysiological mechanisms utilized in the treatment of neuromuscular dysfunction. *American Journal of Occupational Therapy*, 10, 220–225.

Rosenblum, S., and Josman, N. (2003). The relationship between postural control and fine manual dexterity. *Physical & Occupational Therapy in Pediatrics*, 23(4), 47–60.

See, J., Dodakian, L., Chou, C., Chan, V., McKenzie, A., Reinkensmeyer, D. J., and Cramer, S. C. (2013). A standardized approach to the Fugl-Meyer assessment and its implications for clinical trials. *Neurorehabilitation and Neural Repair*, 27(8), 732–741.

Sulistyanto, B. A., Irnawati, I., and Sulistiyawati, S. (2022). Disability and quality of life in stroke patients in a rural area. *KnE Life Sciences*, 7(2), 699–705.

Taub, E., Miller, N. E., Novack, T. A., Cook, E. W., 3rd, Fleming, W. C., Nepomuceno, C. S., Connell, J. S., and Crago, J. E. (1993). Technique to improve chronic motor deficit after stroke. *Archives of Physical Medicine and Rehabilitation*, 74(4), 347–354.

Wang, S., Chen, X., Zhuang, R., Yang, Z., Jiang, W., and Wang, T. (2020). Flexors activity of affected upper extremity in stroke patients during different standing conditions and their relationships with clinical scales: A cross-sectional study. *Neurological Research*, 42(3), 244–252.

Wee, S. K., Hughes, A.-M., Warner, M., and Burridge, J. H. (2014). Trunk restraint to promote upper extremity recovery in stroke patients: A systematic review and meta-analysis. *Neurorehabilitation and Neural Repair*, 28(7), 660–677.

Whitall, J., Savin, D. N., Jr., Harris-Love, M., and Waller, S. M. (2006). Psychometric properties of a modified Wolf motor function test for people with mild and moderate upper-extremity hemiparesis. *Archives of Physical Medicine and Rehabilitation*, 87(5), 656–660.

Wolf, S. L., Catlin, P. A., Ellis, M., Archer, A. L., Morgan, B., and Piacentino, A. (2001). Assessing Wolf motor function test as outcome measure for research in patients after stroke. *Stroke*, 32(7), 1635–1639.

Wolf, S. L., Lecraw, D. E., Barton, L. A., and Jann, B. B. (1989). Forced use of hemiplegic upper extremities to reverse the effect of learned nonuse among chronic stroke and head-injured patients. *Experimental Neurology*, 104(2), 125–132.

Woodbury, M. L., Howland, D. R., McGuirk, T. E., Davis, S. B., Senesac, C. R., Kautz, S., and Richards, L. G. (2009). Effects of trunk restraint combined with intensive task practice on poststroke upper extremity reach and function: A pilot study. *Neurorehabilitation and Neural Repair*, 23(1), 78–91.

Yang, S.-H., Chung, E.-J., Lee, J., Lee, S.-H., and Lee, B.-H. (2021). The effect of trunk stability training based on visual feedback on trunk stability, balance, and upper limb function in stroke patients: A randomized control trial. *Healthcare*, 9(5), 532.

Yu, S.-H., and Park, S.-D. (2013). The effects of core stability strength exercise on muscle activity and trunk impairment scale in stroke patients. *Journal of Exercise Rehabilitation*, 9(3), 362–367.