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Title: Action observation training for improving walking ability and balance of stroke patients: a systematic review and meta-analysis

Running title: Action observation training for walking ability and balance

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ABSTRACT

Objective: To determine the effect of action observation training on the walking ability and balance of stroke patients.

Methods: PubMed, Cochrane Central Register of Controlled Trials, PEDro, and ScienceDirect databases were searched from database inception to March 2024. Randomized controlled trials (RCTs) published in English were included. Two independent reviewers assessed the methodological quality of the trials using the Joanna Briggs Institute (JBI) critical appraisal tool for RCTs and performed data extraction using the JBI data extraction form for observational/experimental studies. Review Manager 5.4 was used for quantitative analyses.

Results: Fourteen RCTs with a total of 367 participants were included in this review. The average quality score of the studies was 8.4 out of 13. The pooled results showed a significant improvement in walking ability measured by the 10-Meter Walk Test (mean difference (MD)=0.15; $p=0.0001$), Timed Up and Go Test (MD=-2.58; $p<0.00001$), and Dynamic Gait Index (MD=2.93; $p=0.007$), and spatiotemporal gait parameters, including stride length (MD=9.67; $p<0.0001$), step length (MD=4.41; $p=0.004$), cadence (MD=7.06; $p=0.0003$), and gait velocity (MD=9.31; $p<0.00001$). A significant improvement was found in balance measured by the Limit of Stability (MD=40.50; $p<0.00001$), yet the Activities-specific Balance Confidence Scale showed no significant improvement (MD=10.26; $p=0.10$).

Conclusions: Action observation training led to improvements in the walking ability of stroke patients. There is some evidence to suggest the effectiveness of action observation training for improving the balance ability of stroke patients, however, the number of studies is still very limited.

Keywords: action observation, balance, gait, stroke, walking

INTRODUCTION

Residual paralysis following a stroke, along with other impairments, can seriously impair stroke patients' walking ability and balance (Eng and Tang, 2007). Gait impairment is often a major contributor to long-term disability after a stroke (Franceschini et al., 2009; Mauritz, 2002), which can significantly impact patients' quality of life, independence, and productivity (Obembe et al., 2014). Accordingly, stroke patients spend most of their physical rehabilitation time practicing walking compared to other functional activities (Hendricks et al., 2002). Balance impairment often persists into the chronic stage of stroke (Duncan et al., 2005) and is related to increased occurrence of adverse events such as post-stroke falls, resulting in the loss of independence, reduced physical activity, and social isolation (Schmid et al., 2015).

Various exercise interventions have been found to be effective in improving gait and balance post-stroke, such as task-specific walking-oriented training (Mehrholz et al., 2017; Polese et al., 2013; Pollock et al., 2014), progressive resistance training, and over-ground walking (Veerbeek et al., 2014). However, these interventions may fail to improve motor recovery of a highly paretic lower extremity (Dobkin, 2008) and hemiplegic patients with impaired mobility may have limited ability to take part in these training programs (Park and Kang, 2013). To overcome such barriers, action observation training can be an effective alternative. Several authors have suggested the use of action observation training as it can be easily administered to patients and it is considered a safe approach to promote motor recovery without having to depend on residual motor function (Ertelt and Binkofski, 2012; Patel, 2017; Takeuchi and Izumi, 2013).

Action observation training is a novel approach in the field of stroke rehabilitation that emerged following the discovery of the mirror neuron system (MNS) in humans that is capable of matching action observation with action execution (Ertelt and Binkofski, 2012). It is a method in which motor actions or movements are observed, imitated, and practiced repetitively,

focusing on the benefits of combining the observation of actions or tasks with the repetitive practice of the observed actions or tasks (Buccino, 2014; Ertelt and Binkofski, 2012). It is believed that action observation can play a role in the imitation and relearning of motor skills (Garrison et al., 2010a). During action observation, mirror neurons discharge not only when individuals perform a motor action but also when they observe the same motor action performed by others (Buccino, 2014; Cattaneo and Rizzolatti, 2009).

Studies using neuroimaging techniques have provided neurophysiological evidence for the use of action observation training in stroke patients (Brunner et al., 2014; Buccino et al., 2001; Ertelt et al., 2007; Garrison et al., 2013). Specifically, a functional magnetic resonance imaging study (Ertelt et al., 2007) reported that the action observation group experienced a significant rise in brain activations, compared to the control group, in the bilateral ventral premotor complex, bilateral superior temporal gyrus, the supplementary motor area, and the contralateral supramarginal gyrus. In theory, the MNS in humans is located in the ventral premotor complex and inferior parietal areas (Ertelt et al., 2007).

The actual rehabilitative effect of action observation training in the stroke population was first reported in 2007 (Ertelt et al., 2007). Since then, numerous studies have evaluated the effect of action observation training on stroke patients, primarily for improving their upper limb function (Cowles et al., 2013; Franceschini et al., 2012; Sale et al., 2014; Sugg et al., 2015), walking ability, and balance (Kim and Kim, 2012; Kim and Lee, 2018, 2013). In 2018, a Cochrane review (Borges et al., 2018) reported that when compared to any control group, action observation training was beneficial in improving upper limb function and dependence on activities of daily living.

The capacity of the MNS to take part in motor learning through action observation has only recently been applied to gait rehabilitation and balance post-stroke. A previous systematic review and meta-analysis (Peng et al., 2019) reported that action observation training resulted

in moderate to large effect sizes in improving motor function of the arm and hand, walking ability, gait velocity, and performance in doing daily activity in patients who have suffered a stroke; however, it did not investigate the effect of the training on balance ability and it seems that it had not included all relevant studies concerning the effect of action observation training on walking ability. Therefore, this current systematic review aimed to provide updated information regarding the effect of action observation training for improving the walking ability and balance of stroke patients and perform a meta-analysis to provide the effect size of the intervention.

METHODS

A systematic review was undertaken following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009). The protocol was registered in PROSPERO with registration number: CRD42021140961.

Inclusion and exclusion criteria

The inclusion criteria of this systematic review were: 1) study participants were adult stroke patients; 2) the experimental intervention contained action observation training sessions, where action observation training was considered as observing another individual performing motor actions through videos and executing/performing the observed actions afterward; 3) the comparison interventions included sham action observation training, conventional physiotherapy or occupational therapy, usual/standard care, no therapy, and other known therapies or interventions; 4) used outcome measures that assessed walking ability and/or balance; and 4) randomized controlled trials published in English, including pilot trials and randomized cross-over trials. For studies with a cross-over design, only the first study period was considered for inclusion to avoid any possible carry-over effects.

The exclusion criteria were as follows: 1) patients with mixed etiology, for example, traumatic brain injury, cerebral palsy, and Parkinson's disease as this review only focused on

walking ability and balance caused by a stroke; 2) studies that were not randomized controlled trials; and 3) studies published in languages other than English.

Information sources and search strategy

Four databases (PubMed, Cochrane Central Register of Controlled Trials (CENTRAL), PEDro, and ScienceDirect) were searched from the database inception to March 2024. For this review, three key search concepts were established based on the type of intervention, type of patient/population, and type of outcome. The keywords of these search concepts were identified along with their synonyms and truncations (indicated with the asterisk (*) sign). The search concepts and synonyms included: (1) action observation, (2) stroke (e.g. stroke OR cerebrovascular disease OR cerebrovascular disease OR CVA), and (3) walking and balance (e.g. walk* OR gait OR balanc*). The keywords were combined using the Boolean operators ‘AND’ and ‘OR’ to obtain relevant published articles. The operator ‘OR’ identifies either of the specified keywords, thereby broadening the search, while the operator ‘AND’ identifies citations containing all of the specified keywords, thereby narrowing the search (e.g. action observation AND (stroke OR cerebrovascular accident OR cerebrovascular disease or CVA) AND (walk* OR gait OR balanc*)). The precision of the search was enhanced by applying filters or limits at the final stage of the literature search; in this review, the article type was limited to randomized controlled trials published in English. The detailed search strategy can be found in Supplemental Appendix A. The reference list of relevant articles was manually searched to find additional studies.

Following the literature search, all identified citations were imported into Mendeley Reference Manager and duplicates were removed. The abstracts of the articles were reviewed against the eligibility criteria of this review by two reviewers (SAPT and PEM); articles were rejected if their title and abstract provided sufficient information that they were not relevant.

Assessment of methodological quality

Potentially relevant studies were retrieved in full and were critically appraised for methodological quality by two independent reviewers (SAPT and PEM) using the standardized Joanna Briggs Institute checklist for randomized controlled trials, which consists of 13 questions (Tufanaru et al., 2017). Each question was scored as zero if it was not met or was unclear, and as one if the question was met. There is no single approach that is considered the best method for deciding whether the study's quality is sufficient (Porritt et al., 2014). Therefore, the total score of the critical appraisal and risks of bias are given in this review. No disagreements occurred among review authors during the critical appraisal process.

Data extraction and management

Data from included studies were extracted by two reviewers (SAPT and PEM) using the standardized Joanna Briggs Institute data extraction form for experimental/observational studies, which included information about study bibliographic data, design, population, intervention, comparison, and outcome. The mean and standard deviation (SD) for the post-test measurements were extracted independently by the two reviewers.

Data analysis

Review Manager 5.4 was used in this study to conduct the meta-analysis. Heterogeneity between studies was evaluated using Chi^2 and I^2 percentages, where heterogeneity was considered substantial if the p-value was less than 0.05. In the presence of heterogeneity between studies, a random-effect model was used for the pooled analysis; if not, then a fixed-effect model was applied. The pooled data for each outcome were reported as mean differences (MDs) or standardized mean differences (SMDs) with a 95% confidence interval (CI). Treatment effects for outcomes were determined using post-test MDs or SMDs and standard deviations (SDs). When quantitative pooling was not performed, results were qualitatively synthesized (narrative synthesis).

RESULTS

Study selection

Figure 1 shows the number of records identified, included, excluded, and the reasons for exclusion. A total of 112 articles were identified, with 90 remaining after duplicates were removed. A total of 27 articles appeared to be relevant to this review and were retrieved in full and taken forward to critical appraisal. Following this, 14 studies were considered relevant and included in the review. The list of excluded studies following critical appraisal and the reasons for exclusion is provided in supplemental Appendix B.

Methodological quality of included studies

The critical appraisal scores of the 14 studies ranged from 5 to 11 (Table 1), with an average score of 8.4 out of 13. No study was excluded based on the critical appraisal score. The studies included in this review had some methodological shortcomings; none of the studies was adequately powered (small sample sizes) as none performed a priori sample size calculation, thereby limiting the external validity of their findings. Moreover, although all studies reported randomization, only eight studies reported concealed group allocation (Bang et al., 2013; Kim and Kim, 2012; Kim and Lee, 2013; Moon and Bae, 2022, 2019; Park et al., 2017; Park et al., 2014; Shamsi et al., 2022). None of the included studies completed the intention-to-treat analysis. None of the studies blinded those who administered the treatments and only six studies reported blinding of assessors (Bang et al., 2013; Moon and Bae, 2022, 2019; Park et al., 2017; Park et al., 2014; Shamsi et al., 2022), with only two studies reporting the blinding of participants (Bang et al., 2013; Shamsi et al., 2022). The lack of blinding may have increased the risk of bias in these studies. However, it is acknowledged that the nature of physiotherapy trials, in general, does not support the blinding of participants and therapists (Olivo et al., 2008).

Study characteristics

The details of study characteristics are provided in Table 2.

Country and study design

All studies were undertaken in the Republic of Korea, except for one study (Shamsi et al., 2022), which was conducted in Iran. Twelve studies were two-armed trials (Bang et al., 2013; Kim and Kim, 2012; Kim and Lee, 2018, 2015; Moon and Bae, 2022, 2019; Oh et al., 2019; Park and Hwangbo, 2015; Park et al., 2017; H.-R. Park et al., 2014; Shamsi et al., 2022; Song and Lee, 2016), while two were three-armed (Kim and Lee, 2013; Lee et al., 2017).

Population

The 14 studies included a total of 367 participants, with 24 dropouts in the trials overall. Individual sample sizes of these trials ranged from 11 (Kim and Lee, 2015) to 40 (Park and Hwangbo, 2015). The population across the 14 studies consisted of participants between the ages of 50 to 65 years. Six studies included participants after their first-ever stroke (Bang et al., 2013; Kim and Lee, 2013; Moon and Bae, 2022, 2019; Park et al., 2017; Shamsi et al., 2022). The mean time post-stroke (stroke onset time) varied across studies, the earliest being at four months (Kim and Kim, 2012) and the latest at 50 months (Moon and Bae, 2019). All studies involved patients with no sign of cognitive impairment or a Mini-Mental State Exam score of ≥ 21 .

Intervention

All 14 studies provided action observation training through the use of videos, where patients watched or observed videos of different walking actions or tasks and were then required to imitate or execute the observed actions or tasks through physical training. The specific contents of the videos varied across all studies, but the contents were primarily related to walking actions or activities.

The action observation training protocol was different in their video duration, overall training duration per day, and frequency of training per week. The duration of video used included: two minutes and 30 seconds in two studies (Kim and Lee, 2018, 2015), 10 minutes in four studies (Bang et al., 2013; Kim and Kim, 2012; Park and Hwangbo, 2015; Park et al., 2014), 12 minutes in one study (Shamsi et al., 2022), 15 minutes in one study (Lee et al., 2017), 20 minutes in two studies (Kim and Lee, 2013; Song and Lee, 2016), and 30 minutes in one study (Park et al., 2017). Ten studies provided 30 minutes of action observation training per day (Kim and Lee, 2018, 2015, 2013; Lee et al., 2017; Moon and Bae, 2022, 2019; Oh et al., 2019; Park and Hwangbo, 2015; Park et al., 2017; Park et al., 2014). The frequency of action observation training provided included; three times per week for three weeks in one study (Kim and Lee, 2018), five times per week for four weeks in four studies (Bang et al., 2013; Kim and Lee, 2013; Moon and Bae, 2022; Oh et al., 2019), three times per week for four weeks in six studies (Kim and Lee, 2015; Moon and Bae, 2019; Park et al., 2017; Park et al., 2014; Shamsi et al., 2022; Song and Lee, 2016), five times per week for eight weeks in one study (Park and Hwangbo, 2015), and three times per week for six weeks in one study (Lee et al., 2017). None of the studies included any long-term follow-up.

Comparison interventions

Ten studies compared the intervention to some form of sham therapy through watching videos containing nature or landscape videos or pictures that are irrelevant to gait training (Bang et al., 2013; Kim and Lee, 2018, 2015; Moon and Bae, 2022, 2019; Park and Hwangbo, 2015; Park et al., 2017; Park et al., 2014; Shamsi et al., 2022; Song and Lee, 2016). One study used a video containing stretching programs (Kim and Kim, 2012). One study compared functional action observation training (watching functional daily walking activity videos) with general action observation training (watching videos of walking while looking at the front, left and right, up and down, etc.) (Oh et al., 2019). Two studies (Kim and Lee, 2013; Lee et al., 2017)

were three-armed trials; one study (Kim and Lee, 2013) compared action observation training (treatment arm) with motor imagery (alternative active treatment arm) and physical training only (control arm), and the other study (Lee et al., 2017) compared action observation training with activity (treatment arm) with mirror therapy with activity (alternative active treatment arm) and action observation training only (control arm). In all 14 studies, the control or comparison interventions were provided with the same duration and frequency as the experimental intervention. The treatment and control groups in nine studies received additional physiotherapy or neurodevelopmental training (Kim and Kim, 2012; Kim and Lee, 2013; Lee et al., 2017; Moon and Bae, 2022, 2019; Park and Hwangbo, 2015; Park et al., 2017; Park et al., 2014; Shamsi et al., 2022).

Outcomes

The included trials used a wide range of outcome measures to measure walking ability and balance. Table 3 shows all post-test data for all outcome measures.

Fourteen studies evaluated walking ability. Spatiotemporal gait parameters were evaluated in six studies using the GAITRite system (Kim and Kim, 2012; Kim and Lee, 2013; Oh et al., 2019; Park et al., 2017), Zebris platform (Moon and Bae, 2022), and Kistler force plate (Shamsi et al., 2022) including gait velocity, stride length, step length, and cadence. Other outcome measures used included 10-Meter Walk Test (10MWT) (Bang et al., 2013; Moon and Bae, 2019; Park and Hwangbo, 2015; Park et al., 2017; Park et al., 2014; Song and Lee, 2016), Timed Up and Go Test (TUGT) (Bang et al., 2013; Kim and Lee, 2018, 2015, 2013; Moon and Bae, 2019; Park and Hwangbo, 2015), Dynamic Gait Index (DGI) (Kim and Lee, 2018, 2015; Moon and Bae, 2019; Park et al., 2014; Song and Lee, 2016), Community Walk Test (CWT) (Park et al., 2017), Figure-of-8 Walk Test (F8WT) time and steps (Park et al., 2014), Walking Ability Questionnaire (WAQ) (Kim and Lee, 2013), Functional Ambulation Category (FAC)

(Kim and Lee, 2013), Modified Emory Functional Ambulation Profile (mEFAP) (Lee et al., 2017), and Functional Gait Assessment (FGA) (Oh et al., 2019).

Six studies reported the effects of action observation training on balance ability. Static balance was measured using Weight Distribution Index (WDI) (Kim and Lee, 2018), Overall Balance Index (OBI), Anteroposterior Balance Index (ABI), Mediolateral Balance Index (MBI) using the Biodex Balance System (Lee et al., 2017), 5 Times Sit-to-Stand Test (5TSTS) (Moon and Bae, 2022), and the Zebris platform to measure the length and velocity of COP displacement and weight load distribution (Moon and Bae, 2022). Dynamic balance was measured using the Activities-specific Balance Confidence Scale (ABC scale) (Moon and Bae, 2022; Park et al., 2017), Limit of Stability (LOS) (Kim and Lee, 2018; Park and Hwangbo, 2015), Functional Reaching Test (FRT) (Kim and Lee, 2013), and fall risk (FR) using the Biodex Balance System (Lee et al., 2017).

Effect of Action Observation Training

Walking Ability

The meta-analysis results revealed that action observation training significantly improved spatiotemporal gait parameters; the pooled effect was statistically significant in favor of action observation training in stride length (MD = 9.67; CI = 5.04, 14.30; $p < 0.0001$) (Figure 2), step length (MD = 4.41; CI = 1.45, 7.38; $p = 0.004$) (Figure 3), and cadence (MD = 7.06; CI = 3.26, 10.85; $p = 0.0003$) (Figure 4). No heterogeneity was found among the studies included in these analyses.

With regards to gait velocity, data from one study (Moon and Bae, 2022) was extremely different from the other studies, which caused heterogeneity among the studies in the gait velocity analysis. When this study (Moon and Bae, 2022) was included in the analysis, the result obtained for gait velocity was not significant (MD = 6.44; CI = -0.62, 13.49; $p = 0.07$)

(Figure 5a), yet when excluded, the results changed to become statistically significant in favor of action observation training (MD = 9.31; CI = 5.37, 13.25; $p < 0.00001$) (Figure 5b).

Based on the pooled effect, statistically significant improvements were also found in the 10MWT (MD = 0.15; CI = 0.07, 0.22; $p = 0.0001$) (Figure 6), TUGT (MD = -2.58; CI = -3.72, -1.45; $p < 0.00001$) (Figure 7), and DGI (MD = 2.93; CI = 0.80, 5.07; $p = 0.007$) (Figure 8) in favor of action observation training. There was no heterogeneity among the studies included in these analyses. Two studies (Park and Hwangbo, 2015; Song and Lee, 2016) were not included in the 10MWT analysis as the data were reported in the unit of seconds, instead of meters per second (m/s).

Action observation training resulted in significant differences in time and steps of the F8WT (Park et al., 2014), CWT (Park et al., 2017), and FGA (Oh et al., 2019) between the intervention group and control group. However, no significant differences were found between the intervention and control group in the WAQ (Kim and Lee, 2013), the FAC (Kim and Lee, 2013), and the mEFAP (Lee et al., 2017).

Balance Ability

According to the pooled effect of two studies, statistically significant improvements were found in the LOS (MD = 40.50; CI = 23.28, 57.71; $p < 0.00001$) (Figure 9). The pooled result of two studies for the ABC scale was not significant (MD = 10.26; CI = -1.88, 22.40; $p = 0.10$) (Figure 10), although the result of the individual studies showed a significant difference between the intervention and control group. Significant differences were found between the intervention and control group in the 5TSTS (Moon and Bae, 2022), and length of COP displacement, speed of COP displacement, and weight load distribution (Moon and Bae, 2022). However, no significant differences were found between the intervention and control groups in the FRT (Kim and Lee, 2013), WDI (Kim and Lee, 2018), and OBI, ABI, MBI, and FR (Lee et al., 2017).

Action Observation Training versus Alternative Treatments

When action observation training was compared to alternative active treatments (mirror therapy (Lee et al., 2017) and motor imagery (Kim and Lee, 2013)), no significant improvements were found between the groups in spatiotemporal gait parameters (gait velocity, stride length, step length, cadence), walking ability (TUGT, WAQ, FAC, mEFAP), and balance (FRT, OBI, ABI, MBI, FR).

DISCUSSION

This systematic review and meta-analysis found that action observation training resulted in improvements in the walking ability or gait performance of stroke patients when compared to sham or conventional interventions, shown by significant improvements in gait velocity, stride length, step length, cadence, 10MWT, TUGT, and DGI. However, action observation training showed no superiority when compared to mirror therapy and motor imagery training. With regards to balance ability, this review found some evidence to indicate that action observation training improved the balance ability of stroke patients, yet the number of studies is still very limited.

In the present review, we performed a meta-analysis of walking ability according to specific outcome measures. The meta-analysis of walking ability by Peng et al. (2019) provided the pooled results of gait velocity and walking ability in general, yet it is unclear what outcome measures of walking ability were included. Two additional studies (Moon and Bae, 2022; Shamsi et al., 2022) were included in our analysis of gait velocity and we included six additional studies (Kim and Lee, 2015; Lee et al., 2017; Moon and Bae, 2022, 2019; Shamsi et al., 2022; Song and Lee, 2016) that were not included in the review by Peng et al. (2019). Another difference is that we used MDs to determine the effect size of the intervention, whereas they used Hedge's *g* index.

Compared with the control group, action observation improved the walking ability of stroke patients. It is believed that action observation can play a role in the imitation and relearning of motor skills through the activation of the MNS (Garrison et al., 2010b). The MNS is likely to react with more sensitivity to visual stimulation that is induced from the observation of precise movement actions or tasks together with their execution (Pomeroy et al., 2011), in particular, meaningful actions that one is familiar with and can easily understand (Brass et al., 2007) and everyday life acts (Calvo-Merino et al., 2005; Celnik et al., 2006), including walking actions or activities. The findings of a qualitative study found that stroke patients who underwent a program of observation preferred tasks that were personal to them and not the generic type of daily tasks (Ewan et al., 2010). It is postulated that observing walking actions performed by healthy people may assist the encoding of motor memory for a normal walking/gait pattern (Celnik et al., 2006) and may reactivate stored motor patterns associated with normal walking, which may then result in improved recovery of damaged motor control (Pelosin et al., 2010).

This review found some evidence to indicate that action observation training improved both the static and dynamic balance of stroke patients. It is proposed that locomotor adaptation can be driven by observing the actions of other people, for example, walking in a difficult environment; it was found that locomotor adaptation significantly correlated with the postural sway observed (Patel et al., 2015). However, further research is needed to confirm the effect of action observation on balance as the number of studies is still very limited.

When compared to motor imagery training, action observation training showed no superiority. This may be explained by Jeannerod's theory (Jeannerod, 2006) that action observation and motor imagery are two methods of motor stimulation that are functionally equivalent to each other. Neuroimaging evidence has depicted that the brain areas involved during action observation partially overlap with areas involved during motor imagery. In

addition, action observation and motor imagery have been shown to activate brain regions that largely cover the areas involved in motor execution (Hardwick et al., 2018).

Likewise, action observation training showed no superiority when compared to mirror therapy. Mirror therapy has demonstrated positive effects in stroke patients; however, there is no agreement about the neural mechanism of mirror therapy (Shih et al., 2017). There are limited neuroimaging studies involving action observation training and mirror therapy in stroke patients, and no studies have directly investigated the similarities or differences in neural mechanisms between action observation training and mirror therapy (Shih et al., 2017).

The findings of this review are similar to the results of other studies concerning action observation training in other populations. Action observation has been found to elicit improvements in gait and bradykinesia in patients with Parkinson's disease (Jaywant et al., 2016; Pelosin et al., 2013, 2010) and improvements in the functional status of children with cerebral palsy (Buccino et al., 2012). It has also led to improvements in gait in patients who have undergone surgical joint replacement (Bellelli et al., 2010; S. D. Park et al., 2014; Villafañe et al., 2016). Therefore, if action observation works, it is expected to have an effect in most other neurological conditions and perhaps in other situations.

All studies included in the present review included patients without any cognitive impairments or with a Mini-Mental State Exam score of 21 or more. The reason for this is that the training requires patients to have a high level of concentration while observing the videos, and this was emphasized in several studies included in this review. This suggests that action observation training may be unsuitable for patients who have moderate to severe cognitive impairments, or those who find it difficult to concentrate.

This systematic review has several limitations. Firstly, although a comprehensive and systematic search was conducted, it is not without its shortcomings. Hand-searching for journals was not carried out, so some relevant studies may have been missed. Secondly, grey

literature was not searched, which may lead to publication bias towards a selection of positive results. Lastly, only studies published in English were considered, so a degree of language bias may be present as relevant studies in this topic area that are published in other languages were omitted.

All studies included in this review provided action observation training to patients in the sub-acute or chronic stage of stroke through the use of videos, yet there was a lack of consistency in the specific video contents, video duration, duration of overall training per day, and frequency of training per week of action observation training across the included studies. Future research could explore alternative methods of delivering action observation training, such as live observation and the use of technological advancements (for example, virtual reality, and augmented reality), and address specific questions about the optimal parameters of the training and the optimal stage of stroke to initiate the training, which could optimize the intervention and guide future research in refining the protocol for action observation training. Trials with long-term follow-up assessments are also needed to evaluate the maintenance of the training effects and the potential for action observation training to promote long-lasting changes in motor function and functional outcomes.

CONCLUSIONS

Based on the findings of this review, action observation training has led to improvements in the walking ability of stroke patients. There is some evidence to suggest the effectiveness of action observation training for improving the balance ability of stroke patients, however, the number of studies is still very limited. Well-designed trials with larger sample sizes are still needed to provide stronger evidence for the effect of action observation training on walking ability and balance post-stroke.

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APPENDIX A. SUPPLEMENTARY MATERIAL

Supplementary data of this article can be found online at XXX.

APPENDIX B. SUPPLEMENTARY MATERIAL

Supplementary data of this article can be found online at XXX.

REFERENCES

- Bang, D.H., Shin, W.S., Kim, S.Y., Choi, J.D., 2013. The effects of action observational training on walking ability in chronic stroke patients: a double-blind randomized controlled trial. *Clin Rehabil* 27, 1118–1125. <https://doi.org/10.1177/0269215513501528>
- Bellelli, G., Buccino, G., Bernardini, B., Padovani, A., Trabucchi, M., 2010. Action Observation Treatment Improves Recovery of Postsurgical Orthopedic Patients: Evidence for a Top-Down Effect? *Arch Phys Med Rehabil* 91, 1489–1494. <https://doi.org/10.1016/j.apmr.2010.07.013>
- Borges, L.R., Fernandes, A.B., Melo, L.P., Guerra, R.O., Campos, T.F., 2018. Action observation for upper limb rehabilitation after stroke. *Cochrane Database Syst Rev* 2018, CD011887. <https://doi.org/10.1002/14651858.CD011887.pub2>

- Brass, M., Schmitt, R.M., Spengler, S., Gergely, G., 2007. Investigating Action Understanding: Inferential Processes versus Action Simulation. *Curr Biol* 17, 2117–2121. <https://doi.org/10.1016/j.cub.2007.11.057>
- Brunner, I.C., Skouen, J.S., Ersland, L., Grüner, R., 2014. Plasticity and Response to Action Observation. *Neurorehabil Neural Repair* 28, 874–884. <https://doi.org/10.1177/1545968314527350>
- Buccino, G., 2014. Action observation treatment: A novel tool in neurorehabilitation. *Philos Trans R Soc Lond B Biol Sci* 369, 20130185. <https://doi.org/10.1098/rstb.2013.0185>
- Buccino, G., Arisi, D., Gough, P., Aprile, D., Ferri, C., Serotti, L., Tiberti, A., Fazzi, E., 2012. Improving upper limb motor functions through action observation treatment: a pilot study in children with cerebral palsy. *Dev Med Child Neurol* 54, 822–828. <https://doi.org/10.1111/j.1469-8749.2012.04334.x>
- Buccino, G., Binkofski, F., Fink, G.R., Fadiga, L., Fogassi, L., Gallese, V., Seitz, R.J., Zilles, K., Rizzolatti, G., Freund, H.J., 2001. Action observation activates premotor and parietal areas in a somatotopic manner: an fMRI study. *Eur J Neurosci* 13, 400–4.
- Calvo-Merino, B., Glaser, D.E., Grèzes, J., Passingham, R.E., Haggard, P., 2005. Action Observation and Acquired Motor Skills: An fMRI Study with Expert Dancers. *Cereb Cortex* 15, 1243–1249. <https://doi.org/10.1093/cercor/bhi007>
- Cattaneo, L., Rizzolatti, G., 2009. The mirror neuron system. *Arch Neurol* 66, 557–60. <https://doi.org/10.1001/archneurol.2009.41>
- Celnik, P., Stefan, K., Hummel, F., Duque, J., Classen, J., Cohen, L.G., 2006. Encoding a motor memory in the older adult by action observation. *Neuroimage* 29, 677–684. <https://doi.org/10.1016/j.neuroimage.2005.07.039>
- Cowles, T., Clark, A., Mares, K., Peryer, G., Stuck, R., Pomeroy, V., 2013. Observation-to-imitate plus practice could add little to physical therapy benefits within 31 days of stroke:

- Translational randomized controlled trial. *Neurorehabil Neural Repair* 27, 173–182.
<https://doi.org/10.1177/1545968312452470>
- Dobkin, B.H., 2008. Training and exercise to drive poststroke recovery. *Nat Clin Pract Neurol* 4, 76–85. <https://doi.org/10.1038/ncpneuro0709>
- Eng, J.J., Tang, P.-F., 2007. Gait training strategies to optimize walking ability in people with stroke: a synthesis of the evidence. *Expert Rev Neurother* 7, 1417–1436.
<https://doi.org/10.1586/14737175.7.10.1417>
- Ertelt, D., Binkofski, F., 2012. Action observation as a tool for neurorehabilitation to moderate motor deficits and aphasia following stroke. *Neural Regen Res* 7, 2063–74.
<https://doi.org/10.3969/j.issn.1673-5374.2012.26.008>
- Ertelt, D., Small, S., Solodkin, A., Dettmers, C., McNamara, A., Binkofski, F., Buccino, G., 2007. Action observation has a positive impact on rehabilitation of motor deficits after stroke. *Neuroimage* 36, T164–T173. <https://doi.org/10.1016/j.neuroimage.2007.03.043>
- Ewan, L.M., Kinmond, K., Holmes, P.S., 2010. An observation-based intervention for stroke rehabilitation: experiences of eight individuals affected by stroke. *Disabil Rehabil* 32, 2097–2106. <https://doi.org/10.3109/09638288.2010.481345>
- Franceschini, M., Carda, S., Agosti, M., Antenucci, R., Malgrati, D., Cisari, C., Gruppo Italiano Studio Allevio Carico Ictus, 2009. Walking after stroke: what does treadmill training with body weight support add to overground gait training in patients early after stroke?: a single-blind, randomized, controlled trial. *Stroke* 40, 3079–85.
<https://doi.org/10.1161/STROKEAHA.109.555540>
- Franceschini, M., Ceravolo, M.G., Agosti, M., Cavallini, P., Bonassi, S., Dall’Armi, V., Massucci, M., Schifini, F., Sale, P., 2012. Clinical relevance of action observation in upper-limb stroke rehabilitation: A possible role in recovery of functional dexterity. A

- randomized clinical trial. *Neurorehabil Neural Repair* 26, 456–462.
<https://doi.org/10.1177/1545968311427406>
- Garrison, K.A., Aziz-Zadeh, L., Wong, S.W., Liew, S.L., Winstein, C.J., 2013. Modulating the motor system by action observation after stroke. *Stroke* 44, 2247–2253.
<https://doi.org/10.1161/STROKEAHA.113.001105>
- Garrison, K.A., Winstein, C.J., Aziz-Zadeh, L., 2010a. The mirror neuron system: A neural substrate for methods in stroke rehabilitation. *Neurorehabil Neural Repair* 24, 404–412.
<https://doi.org/10.1177/1545968309354536>
- Garrison, K.A., Winstein, C.J., Aziz-Zadeh, L., 2010b. The Mirror Neuron System: A Neural Substrate for Methods in Stroke Rehabilitation. *Neurorehabil Neural Repair* 24, 404–12.
<https://doi.org/10.1177/1545968309354536>
- Hardwick, R.M., Caspers, S., Eickhoff, S.B., Swinnen, S.P., 2018. Neural correlates of action: Comparing meta-analyses of imagery, observation, and execution. *Neurosci Biobehav Rev* 94, 31–44. <https://doi.org/10.1016/j.neubiorev.2018.08.003>
- Hendricks, H.T., van Limbeek, J., Geurts, A.C., Zwarts, M.J., 2002. Motor recovery after stroke: A systematic review of the literature. *Arch Phys Med Rehabil* 83, 1629–1637.
<https://doi.org/10.1053/apmr.2002.35473>
- Jaywant, A., Ellis, T.D., Roy, S., Lin, C.-C., Nearing, S., Cronin-Golomb, A., 2016. Randomized Controlled Trial of a Home-Based Action Observation Intervention to Improve Walking in Parkinson Disease. *Arch Phys Med Rehabil* 97, 665–673.
<https://doi.org/10.1016/j.apmr.2015.12.029>
- Jeannerod, M., 2006. *Motor Cognition*. Oxford University Press.
- Kim, J., Kim, K., 2012. Clinical Feasibility of Action Observation Based on Mirror Neuron System on Walking Performance in Post Stroke Patients. *J Phys Ther Sci* 24, 597–599.
<https://doi.org/10.1589/jpts.24.597>

- Kim, J.-C., Lee, H.-M., 2018. The Effect of Action Observation Training on Balance and Sit to Walk in Chronic Stroke: A Crossover Randomized Controlled Trial. *J Mot Behav* 50, 373–380. <https://doi.org/10.1080/00222895.2017.1363697>
- Kim, J.-C., Lee, H.-M., 2015. The Effect of Action Observation Training on Sit to Walk with Chronic Stroke Patients. *The Journal of Korean Physical Therapy* 27, 413–418. <https://doi.org/10.18857/JKPT.2015.27.6.413>
- Kim, J.-H., Lee, B.-H., 2013. Action observation training for functional activities after stroke: A pilot randomized controlled trial. *NeuroRehabilitation* 33, 565–574. <https://doi.org/10.3233/NRE-130991>
- Lee, H.J., Kim, Y.M., Lee, D.K., 2017. The effects of action observation training and mirror therapy on gait and balance in stroke patients. *J Phys Ther Sci* 29, 523–526. <https://doi.org/10.1589/jpts.29.523>
- Mauritz, K., 2002. Gait training in hemiplegia. *Eur J Neurol* 9, 23–29. <https://doi.org/10.1046/j.1468-1331.2002.0090s1023.x>
- Mehrholz, J., Thomas, S., Elsner, B., 2017. Treadmill training and body weight support for walking after stroke. *Cochrane Database of Systematic Reviews* 2017. <https://doi.org/10.1002/14651858.CD002840.pub4>
- Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., Altman, D., Antes, G., Atkins, D., Barbour, V., Barrowman, N., Berlin, J.A., Clark, J., Clarke, M., Cook, D., D’Amico, R., Deeks, J.J., Devereaux, P.J., Dickersin, K., Egger, M., Ernst, E., Gøtzsche, P.C., Grimshaw, J., Guyatt, G., Higgins, J., Ioannidis, J.P.A., Kleijnen, J., Lang, T., Magrini, N., McNamee, D., Moja, L., Mulrow, C., Napoli, M., Oxman, A., Pham, B., Rennie, D., Sampson, M., Schulz, K.F., Shekelle, P.G., Tovey, D., Tugwell, P., 2009. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Med* 6, e1000097. <https://doi.org/10.1371/journal.pmed.1000097>

- Moon, Y., Bae, Y., 2022. The effect of backward walking observational training on gait parameters and balance in chronic stroke: randomized controlled study. *Eur J Phys Rehabil Med* 58, 9–15. <https://doi.org/10.23736/S1973-9087.21.06869-6>
- Moon, Y., Bae, Y., 2019. Backward walking observational training improves gait ability in patients with chronic stroke: randomised controlled pilot study. *Int J Rehabil Res* 42, 217–222.
- Obembe, A.O., Olaogun, M.O., Adedoyin, R., 2014. Gait and balance performance of stroke survivors in South-Western Nigeria--a cross-sectional study. *Pan Afr Med J* 17 Suppl 1, 6. <https://doi.org/10.11694/pamj.suppl.2014.17.1.3001>
- Oh, S.J., Lee, J.H., Kim, D.H., 2019. The effects of functional action-observation training on gait function in patients with post-stroke hemiparesis: A randomized controlled trial. *Technol Health Care* 27, 159–165. <https://doi.org/10.3233/THC-181388>
- Olivo, S.A., Macedo, L.G., Gadotti, I.C., Fuentes, J., Stanton, T., Magee, D.J., 2008. Scales to Assess the Quality of Randomized Controlled Trials: A Systematic Review. *Phys Ther* 88, 156–175. <https://doi.org/10.2522/ptj.20070147>
- Park, C.-S., Kang, K.-Y., 2013. The Effects of Additional Action Observational Training for Functional Electrical Stimulation Treatment on Weight Bearing, Stability and Gait Velocity of Hemiplegic Patients. *J Phys Ther Sci* 25, 1173–1175. <https://doi.org/10.1589/jpts.25.1173>
- Park, E.C., Hwangbo, G., 2015. The effects of action observation gait training on the static balance and walking ability of stroke patients. *J Phys Ther Sci* 27, 341–344. <https://doi.org/10.1589/jpts.27.341>
- Park, H.J., Oh, D.W., Choi, J.D., Kim, J.M., Kim, S.Y., Cha, Y.J., Jeon, S.J., 2017. Action observation training of community ambulation for improving walking ability of patients

- with post-stroke hemiparesis: a randomized controlled pilot trial. *Clin Rehabil* 31, 1078–1086. <https://doi.org/10.1177/0269215516671982>
- Park, H.-R., Kim, J.-M., Lee, M.-K., Oh, D.-W., 2014. Clinical feasibility of action observation training for walking function of patients with post-stroke hemiparesis: a randomized controlled trial. *Clin Rehabil* 28, 794–803. <https://doi.org/10.1177/0269215514523145>
- Park, S.D., Song, H.S., Kim, J.Y., 2014. The effect of action observation training on knee joint function and gait ability in total knee replacement patients. *J Exerc Rehabil* 10, 168–171. <https://doi.org/10.12965/jer.140112>
- Patel, M., 2017. Action observation in the modification of postural sway and gait: Theory and use in rehabilitation. *Gait Posture* 58, 115–120. <https://doi.org/10.1016/j.gaitpost.2017.07.113>
- Patel, M., Roberts, R.E., Riyaz, M.U., Ahmed, M., Buckwell, D., Bunday, K., Ahmad, H., Kaski, D., Arshad, Q., Bronstein, A.M., 2015. Locomotor adaptation is modulated by observing the actions of others. *J Neurophysiol* 114, 1538–1544. <https://doi.org/10.1152/jn.00446.2015>
- Pelosin, E., Avanzino, L., Bove, M., Stramesi, P., Nieuwboer, A., Abbruzzese, G., 2010. Action Observation Improves Freezing of Gait in Patients With Parkinson's Disease. *Neurorehabil Neural Repair* 24, 746–752. <https://doi.org/10.1177/1545968310368685>
- Pelosin, E., Bove, M., Ruggeri, P., Avanzino, L., Abbruzzese, G., 2013. Reduction of Bradykinesia of Finger Movements by a Single Session of Action Observation in Parkinson Disease. *Neurorehabil Neural Repair* 27, 552–560. <https://doi.org/10.1177/1545968312471905>
- Peng, T.-H., Zhu, J.-D., Chen, C.-C., Tai, R.-Y., Lee, C.-Y., Hsieh, Y.-W., 2019. Action observation therapy for improving arm function, walking ability, and daily activity

- performance after stroke: a systematic review and meta-analysis. *Clin Rehabil* 33, 1277–1285. <https://doi.org/10.1177/0269215519839108>
- Polese, J.C., Ada, L., Dean, C.M., Nascimento, L.R., Teixeira-Salmela, L.F., 2013. Treadmill training is effective for ambulatory adults with stroke: a systematic review. *J Physiother* 59, 73–80. [https://doi.org/10.1016/S1836-9553\(13\)70159-0](https://doi.org/10.1016/S1836-9553(13)70159-0)
- Pollock, A., Gray, C., Culham, E., Durward, B.R., Langhorne, P., 2014. Interventions for improving sit-to-stand ability following stroke. *Cochrane Database Syst Rev* 2014, CD007232. <https://doi.org/10.1002/14651858.CD007232.pub4>
- Pomeroy, V., Aglioti, S.M., Mark, V.W., McFarland, D., Stinear, C., Wolf, S.L., Corbetta, M., Fitzpatrick, S.M., 2011. Neurological Principles and Rehabilitation of Action Disorders. *Neurorehabil Neural Repair* 25, 33S–43S. <https://doi.org/10.1177/1545968311410942>
- Porritt, K., Gomersall, J., Lockwood, C., 2014. JBI's Systematic Reviews. *Am J of Nurs* 114, 47–52. <https://doi.org/10.1097/01.NAJ.0000450430.97383.64>
- Sale, P., Ceravolo, M.G., Franceschini, M., 2014. Action observation therapy in the subacute phase promotes dexterity recovery in right-hemisphere stroke patients. *Biomed Res Int* 2014, 457538. <https://doi.org/10.1155/2014/457538>
- Schmid, A.A., Arnold, S.E., Jones, V.A., Jane Ritter, M., Sapp, S.A., Van Puymbroeck, M., 2015. Fear of Falling in People With Chronic Stroke. *The American Journal of Occupational Therapy* 69, 6903350020p1-6903350020p5. <https://doi.org/10.5014/ajot.2015.016253>
- Shamsi, F., Nami, M., Aligholi, H., Borhani-Haghighi, A., Zahediannasb, R., Hekmatnia, M., Karimi, M.T., 2022. The effects of action observation training as an add-on rehabilitation strategy on the walking ability of patients with chronic stroke. *J Bodyw Mov Ther* 29, 33–39. <https://doi.org/https://doi.org/10.1016/j.jbmt.2021.09.029>

- Shih, T., Wu, C., Lin, K., Cheng, C., Hsieh, Y., Chen, Chia-ling, Lai, C., Chen, Chih-chi, 2017. Effects of action observation therapy and mirror therapy after stroke on rehabilitation outcomes and neural mechanisms by MEG: study protocol for a randomized controlled trial. *Trials* 18, 459. <https://doi.org/10.1186/s13063-017-2205-z>
- Song, Y., Lee, H., 2016. The Effect of Treadmill Training Applied Simultaneously with Action Observation on Walking Ability in Chronic Stroke Patients. *The Journal of Korean Physical Therapy* 28, 176–182. <https://doi.org/10.18857/JKPT.2016.28.3.176>
- Sugg, K., Müller, S., Winstein, C., Hathorn, D., Dempsey, A., 2015. Does Action Observation Training With Immediate Physical Practice Improve Hemiparetic Upper-Limb Function in Chronic Stroke? *Neurorehabil Neural Repair* 29, 807–17. <https://doi.org/10.1177/1545968314565512>
- Takeuchi, N., Izumi, S.-I., 2013. Rehabilitation with Poststroke Motor Recovery: A Review with a Focus on Neural Plasticity. *Stroke Res Treat* 2013, 1–13. <https://doi.org/10.1155/2013/128641>
- Tufanaru, C., Munn, Z., Aromataris, E., Campbell, J., Hopp, L., 2017. Chapter 3: Systematic reviews of effectiveness. In: Aromataris E, Munn Z, editors. *Joanna Briggs Inst Rev Man [WWW Document]*. The Joanna Briggs Institute. URL <https://reviewersmanual.joannabriggs.org/>
- Veerbeek, J.M., van Wegen, E., van Peppen, R., van der Wees, P.J., Hendriks, E., Rietberg, M., Kwakkel, G., 2014. What Is the Evidence for Physical Therapy Poststroke? A Systematic Review and Meta-Analysis. *PLoS One* 9, e87987. <https://doi.org/10.1371/journal.pone.0087987>
- Villafañe, J.H., Pirali, C., Isgrò, M., Vanti, C., Buraschi, R., Negrini, S., 2016. Effects of Action Observation Therapy in Patients Recovering From Total Hip Arthroplasty Arthroplasty:

A Prospective Clinical Trial. J Chiropr Med 15, 229–234.

<https://doi.org/10.1016/j.jcm.2016.08.011>

Table 1. Critical appraisal results of included studies.

Question	Study													
	Bang et al. (2013)	Park et al. (2014)	Kim and Lee (2018)	Park et al. (2017)	Kim and Kim (2012)	Kim and Lee (2013)	Park and Hwangbo (2015)	Lee et al. (2017)	Song and Lee (2016)	Kim and Lee (2015)	Moon and Bae (2019)	Moon and Bae (2022)	Shamsi et al. (2022)	Oh et al. (2019)
Q1	Y	Y	Y	Y	Y	Y	U	U	U	U	Y	Y	N	U
Q2	Y	Y	U	Y	Y	Y	U	U	U	U	Y	Y	Y	U
Q3	Y	Y	Y	Y	Y	Y	U	Y	Y	Y	Y	N	Y	Y
Q4	Y	N	U	N	U	N	U	U	U	U	N	N	Y	U
Q5	N	N	U	N	N	N	U	U	U	U	Y	N	Y	U
Q6	Y	Y	U	Y	U	U	U	U	U	U	Y	Y	Y	U
Q7	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Q8	Y	Y	Y	Y	U	Y	N	U	U	Y	Y	Y	Y	Y
Q9	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Q10	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Q11	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Q12	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Q13	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Score	11/13	10/13	8/13	10/13	8/13	9/13	5/13	6/13	6/13	7/13	11/13	9/13	11/13	7/13

JBI critical appraisal checklist for randomized controlled trials: Q1 = Was true randomization used for assignment of participants to treatment groups?; Q2 = Was allocation to treatment groups concealed?; Q3 = Were treatment groups similar at baseline?; Q4 = Were participants blind to treatment assignment?; Q5 = Were those delivering treatment blind to treatment assignment?; Q6 = Were outcome assessors blind to treatment assignment?; Q7 = Were treatment groups treated identically other than the intervention of interest?; Q8 = Was follow-up complete, and if not, were strategies to address incomplete follow-up utilized?; Q9 = Were participants analyzed in the groups to which they were randomized?; Q10 = Were outcomes measured in the same way for treatment groups?; Q11 = Were outcomes measured in a reliable way?; Q12 = Was appropriate statistical analysis used?; Q13 = Was the trial design appropriate, and any deviations from the standard RCT design (individual randomization, parallel groups) accounted for in the conduct and analysis of the trial?; Y = Yes; N = No; U = Unclear

Table 2. Study characteristics.

Authors, Year, Origin of Study	Design, Sample size (drop-outs)	Intervention Group	Control/Comparison Group	Frequency	Outcome Measure	Key Findings
Bang et al. (2013); Republic of Korea	2-armed RCT 30 (0)	AOT: watching a video of treadmill walking actions for 10 minutes + 30 minutes of treadmill training	Sham AOT: watching nature videos unrelated to gait training for 10 minutes + 30 minutes of treadmill training	5 times per week for 4 weeks	- 10MWT - TUGT	- There were significant improvements in TUGT (p=0.018) and 10MWT (p=0.001) in the intervention group compared to the control group. - Small to huge effect sizes of 1.27 and 0.57 were found for TUGT and 10MWT, respectively.
		Total: 40 minutes				
Kim and Lee (2018); Republic of Korea	2-armed cross-over RCT 24 (3)	AOT: watching a video of walking actions for 2 minutes and 30 seconds + 12 minutes and 30 seconds of physical training	Sham AOT: watching static landscape photos for 2 minutes and 30 seconds + 12 minutes and 30 seconds of physical training	2 times a day, 3 times per week for 3 weeks	- TUGT - DGI - WDI - LOS	- The intervention and control groups have shown statistically significant within-group differences in TUGT, DGI, WDI, and LOS over time. - No significant difference was observed in terms of TUGT, DGI, and WDI, but only in LOS (p=0.01 at week-3) between groups.
		Total per session: 15 minutes Total per day: 2 x 15 minutes = 30 minutes				
Park et al. (2014); Republic of Korea	2-armed RCT 24 (3)	AOT: watching video clips of functional walking tasks for 10 minutes + physical training of the observed tasks for 20 minutes	Sham AOT: watching video clips of landscape images irrelevant to gait training for 10 minutes + perform the same walking tasks as participants in intervention group	3 times per week for 4 weeks	- 10MWT - F8WT - DGI	- Changes in values for 10MWT, time and steps in the F8WT and DGI showed significant changes between the intervention and control group (p<0.05).
		Total: 30 minutes				

Additional treatment: usual physiotherapy						
Park et al. (2017); Republic of Korea	2-armed RCT 26 (1)	AOT: watching video clips of four-staged ambulation training for 30 minutes + physical training of observed actions	Sham AOT: watching landscape video clips + physical training like intervention group for 30 minutes	3 times per week for 4 weeks	- GAITRite: Spatiotemporal gait parameters - 10MWT - CWT - ABC Scale	- Changes in values for 10MWT, CWT, ABC Scale and gait velocity (GAITRite) showed a significant improvement in the intervention group compared with the control group (p<0.05).
Total: 30 minutes						
Additional treatment: 30 minutes NDT training						
Kim and Lee (2015); Republic of Korea	2-armed RCT 12 (1)	AOT: watching video of STS and timed up and go movement for 2 minutes and 30 seconds + physical training of observed actions for 2 minutes and 30 seconds	Sham AOT: watching static scenery pictures related to mountains, beaches, and rural areas for 2 minutes and 30 seconds + the same physical training like intervention group for 2 minutes and 30 seconds	3 times per week for 4 weeks	- TUGT - DGI	- The TUGT significantly decreased in the intervention group (p<0.05) but there was no significant difference between the intervention and control groups (p=0.465). - There was no significant difference in DGI between the intervention and control group (p=0.537).
Total: 30 minutes						
Park and Hwangbo (2015); Republic of Korea	2-armed RCT 40 (0)	AOT: watching video on flatland gait, slope gait, and stair gait for 10 minutes + gait training for 20 minutes	Sham AOT: watched a video of nature for 10 minutes + gait training for 20 minutes	5 times per week for 8 weeks	- TUGT - 10MWT - LOS	- There were significant differences in the TUGT, 10MWT, and LOS between the intervention and control group after the experiment (p<0.05)
Total: 30 minutes						
Additional treatment: 30 minutes general physiotherapy						

Song and Lee(2016); Republic of Korea	2-armed RCT 16 (0)	Treadmill training + AOT: watching a video of walking motions while training on a treadmill for 20 minutes	Treadmill training + sham AOT: watching a video unrelated to walking (landscape) while training on a treadmill for 20 minutes	3 times per week for 4 weeks	- 10MWT - DGI	- There were significant differences in 10 MWT (p=0.012) and DGI (p=0.002) between the intervention and control groups.
Total: 20 minutes						
Kim and Kim (2012); Republic of Korea	2-armed RCT 30 (0)	AOT: watching video clips of walking actions (total of 10 minutes) + physical training of observed actions (10 minutes)	Watching video and performing a progressive relaxation program (stretching) (10 minutes)	Not specified	- GAITRite: Spatiotemporal gait parameters	- There were significant differences in gait velocity (GAITRite) between the intervention and control group (p<0.05).
Total: 20 minutes						
Additional treatment: 30 minutes PT training						
Lee et al. (2017); Republic of Korea	3-armed RCT 35 (0)	AOT with activity: watching a video for 15 minutes + physical training of the same observed motions for 15 minutes	MT with activity: mirror therapy for 15 minutes + physical training of the same motions without a mirror for 15 minutes	AOT only: watching a video only for 30 minutes	3 times per week for 6 weeks - OBI - ABI - MBI - FR - mEFAP	- AOT with activity group experienced significant improvement in OBI (p<0.05) and ABI (p<0.05) after training compared to MT with activity group and AOT only group. However, there was no significant difference between the groups (p>0.05). - All groups experienced improvements in the MBI, although not significant, but no significant difference was found between the groups (p>0.05). - FR and mEFAP did not significantly differ but decreased in the AOT with activity group and MT with activity group, did not
Total: 30 minutes						
Additional treatment: 30 minutes physiotherapy twice per week						

							significantly differ but increased in the AOT only group, and no significant difference was found between the groups ($p>0.05$).
Kim and Lee (2013); Republic of Korea	3-armed RCT 30 (3)	AOT: watching video of walking tasks for 20 minutes + 10 minutes physical training	MIT: listening to a motor imagery program for 20 minutes + 10 minutes physical training	PT: 30 minutes NDT training only	5 times per week for 4 weeks	- GAITRite: Spatiotemporal gait parameters - TUGT - WAQ - FAC - FRT	- There were significant improvements in TUGT and gait velocity (GAITRite) in the AOT group compared to the PT group ($p<0.05$). - No significant differences in any of the outcome measures were observed between the AOT group and the MIT group. - No significant difference in FRT between the groups.
Total: 30 minutes Additional treatment: 30 minutes NDT training							
Moon and Bae (2019); Republic of Korea	2-armed RCT 17 (3)	AOT: watched a backward walking video for 10 minutes + 20 minutes of the observed backward walking training	Sham AOT: watched a landscape picture video for 10 minutes + 20 minutes backward walking training		3 times per week for 4 weeks	- DGI - 10MWT - TUGT	- The intervention group showed more significant improvements in DGI ($p=0.04$), 10MWT ($p=0.04$), and TUGT ($p=0.03$) than the control group.
Total: 30 minutes Additional treatment: 30 minutes conventional therapy							
Moon and Bae (2022); Republic of Korea	2-armed RCT 29 (5)	AOT: watched a video walking backwards in a straight line, in a curve, on unstable ground, and in a zigzag in a noisy room for 10 minutes + 20 minutes of backward walking training	Sham AOT: watched a 10-minute landscape video + performed 20 minutes of backward walking training		5 times per week for 4 weeks	- Zebris platform: Spatiotemporal gait parameters - 5TSTS - COP - ABC Scale	- The intervention group showed significant improvements in gait velocity ($p=0.001$), step length ($p=0.007$), stride lengths ($p<0.002$), 5TSTS ($p=0.021$), COP velocity ($p=0.022$), length ($p=0.001$), weight distribution of affected side ($p=0.033$), and

		Total: 30 minutes				ABC score (p=0.023) compared to the control group.
		Additional treatment: 30 minutes conventional therapy				
Shamsi et al. (2022); Iran	2-armed RCT 14 (0)	AOT: watched videos that depicted exercises they were going to practice in each session for 12 minutes	Sham AOT: watched a 12-minute video of nature pictures without any human or animal pictures or moving content.	3 times per week for 4 weeks	- Kistler force plate: Spatiotemporal gait parameters	- Only the intervention group demonstrated significant improvements before and after the intervention in stride length (p=0.016) and step length (p=0.028). However, the between-group differences in were not significant.
		Total: 12 minutes				- Both groups demonstrated improvements in gait velocity after the intervention, yet the difference was not significant (p>0.05).
		Additional treatment: 40 minutes conventional physical training				
Oh et al. (2019); Republic of Korea	2-armed RCT 40 (5)	Functional AOT: watched functional daily walking activity videos for 15 minutes + walking training on treadmill for 15 minutes	General AOT: watched videos for 15 minutes (e.g., walking while looking at the front, left & right, up & down, etc.) + practicing for 15 minutes	5 times per week for 4 weeks	- GAITRite: Spatiotemporal gait parameters - FGA	- Step length, stride length, cadence, velocity, and FGA in the intervention group were statistically different from the control group (p<0.05).
		Total: 30 minutes				

5TSTS: 5 Times Sit-to-Stand Test; 10MWT: 10-Meter Walk Test; ABI: Anteroposterior Balance Index; AOT: Action Observation Training; ABC Scale: Activities-specific Balance Confidence Scale; COP: Centre of Pressure; CWT: Community Walk Test; DGI: Dynamic Gait Index; FAC: Functional Ambulation Category; F8WT: Figure-of-8 Walk Test; FGA: Functional Gait Assessment; FR: Fall Risk; FRT: Functional Reaching Test; LOS: Limit of Stability; MBI: Mediolateral Balance Index; MT: Mirror Therapy; mEFAP: Modified Emory Functional Ambulation Profile; MIT: Motor Imagery Training; NDT: Neurodevelopmental Training; OBI: Overall Balance Index; PT: Physical Therapy/Training; RCT: Randomized Controlled Trial; TUGT: Timed Up and Go Test; WAQ: Walking Ability Questionnaire; WDI: Weight Distribution Index.

Table 3. Study outcomes data.

Outcome Measure	Study	Post-test	Intervention Mean (SD)	Comparison/Control Mean (SD)	Between-group p-value
Spatiotemporal Gait Parameters (GAITRite, Zebris platform, Kistler force plate)					
Gait velocity	Kim and Kim (2012)	N/A	73.00 (20.00) (15)	53.00 (15.00) (15)	<0.05*
	Kim and Lee (2013)	4 weeks	78.67 (24.64) (9)	MIT: 77.92 (28.15) (9) PT: 62.88 (23.11) (9)	>0.05 <0.05*
	Park et al. (2017)	4 weeks	47.46 (19.57) (12)	43.46 (22.51) (13)	<0.05*
	Moon and Bae (2022)	4 weeks	5.15 (1.83) (12)	4.47 (1.96) (12)	0.001*
	Shamsi et al. (2022)	4 weeks	31 (25) (7)	45 (18) (7)	0.78
	Oh et al. (2019)	4 weeks	41 (8) (17)	32 (5) (18)	0.003*
Stride length	Kim and Kim (2012)	N/A	89.23 (8.45) (15)	73.74 (14.42) (15)	<0.05*
	Kim and Lee (2013)	4 weeks	91.40 (15.77) (9)	MIT: 98.19 (26.14) (9) PT: 84.12 (16.04) (9)	>0.05 >0.05
	Park et al. (2014)	4 weeks	0.16 (0.09–0.48) ^a (11)	0.26 (0.09–0.41) ^a (10)	>0.05
	Park et al. (2017)	4 weeks	76.39 (17.27) (12)	71.34 (22.32) (13)	<0.01*
	Moon and Bae (2022)	4 weeks	71.17 (23.62) (12)	75.08 (36.50) (12)	0.002*
	Shamsi et al. (2022)	4 weeks	58.29 (37.01) (7)	75.04 (23.64) (7)	0.6
Step length	Oh et al. (2019)	4 weeks	69.71 (10.51) (17)	60.23 (10.14) (18)	0.031*
	Kim and Kim (2012)	N/A	41.55 (9.12) (15)	34.37 (8.61) (15)	<0.05*
	Kim and Lee (2013)	4 weeks	46.76 (7.89) (9)	MIT: 49.92 (13.30) (9) PT: 42.92 (7.41) (9)	>0.05 >0.05
	Moon and Bae (2022)	4 weeks	32.58 (14.31) (12)	33.38 (17.70) (12)	0.007*
	Shamsi et al. (2022)	4 weeks	34.28 (17.8) (7)	43.15 (5.35) (7)	0.44
	Oh et al. (2019)	4 weeks	29.73 (6.19) (17)	24.55 (6.37) (18)	0.035*
Cadence	Kim and Kim (2012)	N/A	90.36 (13.82) (15)	75.49 (15.72) (15)	<0.05
	Kim and Lee (2013)	4 weeks	97.02 (29.70) (9)	MIT: 93.25 (19.18) (9) PT: 80.41 (15.87) (9)	>0.05 <0.05*
	Oh et al. (2019)	4 weeks	80.58 (4.96) (17)	75.05 (7.35) (18)	0.024*
Walking Ability					
10MWT	Bang et al. (2013)	4 weeks	1.01 (0.12) (15)	0.82 (0.11) (15)	0.001*, 0.57 ^b
	Park et al. (2014)	4 weeks	23.00 (14.50–36.70) ^a (11)	19.85 (13.96–38.75) ^a (10)	<0.05*
	Park et al. (2017)	4 weeks	0.60 (0.33) (12)	0.70 (0.39) (13)	<0.05*
	Park and Hwangbo (2015)	8 weeks	14.6 (2.3) (20)	15.5 (2.3) (20)	<0.05*
	Song and Lee (2016)	4 weeks	13.61 (3.26) (8)	15.96 (3.33) (8)	0.012*
	Moon and Bae (2019)	4 weeks	0.53 (0.25) (7)	0.54 (0.16) (7)	0.040*
TUGT	Bang et al. (2013)	4 weeks	12.96 (2.17) (15)	15.66 (1.75) (15)	0.018*, 1.27 ^b
	Kim and Lee (2013)	4 weeks	23.71 (10.39) (9)	MIT: 29.56 (15.95) (9) PT: 33.33 (12.10) (9)	>0.05 <0.05*
	Kim and Lee (2018)	3 weeks	16.46 (10.76) (11)	28.58 (18.57) (10)	0.152
	Park and Hwangbo (2015)	8 weeks	15.7 (3.3) (20)	17.7 (3.2) (20)	<0.05*
	Kim and Lee (2018)	4 weeks	16.29 (9.47) (6)	16.91 (7.27) (6)	0.465
	Moon and Bae (2019)	4 weeks	30.34 (19.79) (7)	27.46 18.04) (7)	0.030*
CWT	Park et al. (2017)	4 weeks	748.42 (352.75) (12)	796.38 (587.39) (13)	<0.01*

F8WT time	Park et al. (2014)	4 weeks	20.00 (14.10-31.50) ^a (11)	19.95 (15.58-40.25) ^a (10)	<0.05*
F8WT steps	Park et al. (2014)	4 weeks	26.00 (20.00-30.00) ^a (11)	28.50 (23.00-32.50) ^a (10)	<0.05*
DGI	Park et al. (2014)	4 weeks	23.00 (14.50-36.70) ^a (11)	19.85 (13.96-38.75) ^a (10)	<0.01*
	Kim and Lee (2018)	3 weeks	18.82 (4.55) (11)	13.1 (5.93) (10)	0.251
	Song and Lee (2016)	4 weeks	20.5 (3.16) (8)	16.87 (3.22) (8)	0.002*
	Kim and Lee (2015)	4 weeks	18.00 (6.19) (6)	17.40 (3.78) (6)	0.537
	Moon and Bae (2019)	4 weeks	16.00 (3.31) (7)	16.57 (5.99) (7)	0.030*
WAQ	Kim and Lee (2013)	4 weeks	47.00 (6.69) (9)	MIT: 44.78 (8.40) (9) PT: 41.78 (8.30) (9)	>0.05 >0.05
FAC	Kim and Lee (2013)	4 weeks	3.22 (0.97) (9)	MIT: 3.56 (1.42) (9) PT: 2.56 (1.01) (9)	>0.05 >0.05
mEFAP	Lee et al. (2017)	6 weeks	AOTA: 54.2 (41.4) (12)	MTA: 60.0 (22.8) (11) AOT: 101.4 (50.5) (12)	>0.05 >0.05
FGA	Oh et al. (2019)	4 weeks	23.69 ± 4.17 (17)	20.28 (2.97) (18)	0.021*
Balance Ability					
ABC Scale	Park et al. (2017)	4 weeks	63.99 (20.96) (12)	45.62 (32.43) (13)	<0.01*
	Moon and Bae (2022)	4 weeks	51.15 (15.77) (12)	44.82 (20.86) (12)	0.023*
LOS	Kim and Lee (2018)	3 weeks	64.26 (32.94) (11)	23.88 (22.37) (10)	0.01*
	Park and Hwangbo (2015)	8 weeks	70.64 (50.14) (20)	30.02 (26.29) (20)	<0.05*
WDI	Kim and Lee (2018)	3 weeks	43.35 (10.14) (11)	33.97 (11.54) (10)	0.809
FRT	Kim and Lee (2013)	4 weeks	18.21 (2.76) (9)	MIT: 17.92 (5.14) (9) PT: 16.77 (4.14) (9)	>0.05 >0.05
Biodex Balance System	OBI	Lee et al. (2017)	6 weeks	AOTA: 1.2 (0.8) (12) MTA: 1.1 (0.7) (11) AOT: 1.5 (0.9) (12)	>0.05 >0.05
	ABI	Lee et al. (2017)	6 weeks	AOTA: 0.6 (0.5) (12) MTA: 0.9 (0.7) (11) AOT: 0.9 (0.5) (12)	>0.05 >0.05
	MBI	Lee et al. (2017)	6 weeks	AOTA: 0.8 (0.6) (12) MTA: 0.5 (0.3) (11) AOT: 0.9 (0.7) (12)	>0.05 >0.05
	FR	Lee et al. (2017)	6 weeks	AOTA: 2.3 (0.5) (12) MTA: 2.1 (1.0) (11) AOT: 2.9 (1.0) (12)	>0.05 >0.05
5TSTS	Moon and Bae (2022)	4 weeks	22.65 (6.71) (12)	25.87 (10.88) (12)	0.021*
COP length	Moon and Bae (2022)	4 weeks	157.00 (68.38) (12)	127.92 (71.27) (12)	0.001*
COP velocity	Moon and Bae (2022)	4 weeks	13.83 (5.75) (12)	15.33 (7.63) (12)	0.022*
Weight Load Distribution	Moon and Bae (2022)	4 weeks	42.50 (2.93) (12)	41.42 (2.20) (12)	0.033*

5TSTS: 5 Times Sit-to-Stand Test; 10MWT: 10-Meter Walk Test; ABI: Anteroposterior Balance Index; ABC Scale: Activities-specific Balance Confidence Scale; AOT: Action Observation Training only; AOTA: Action Observation Training with activity; COP: Centre of Pressure; CWT: Community Walk Test; DGI: Dynamic Gait Index; F8WT: Figure-of-8 Walk Test; FAC: Functional Ambulation Category; FGA: Functional Gait Assessment; FR: Fall Risk; FRT: Functional Reaching Test; LOS: Limit of Stability; MBI: Mediolateral Balance Index; mEFAP: Modified Emory Functional Ambulation Profile; MIT: Motor Imagery Training; MTA: Mirror Therapy with Activity; OBI: Overall Balance Index; SD: Standard Deviation; TUGT: Timed Up and Go Test; WAQ: Walking Ability Questionnaire; WDI: Weight Distribution Index.

*Significant difference between intervention and control group

^aMedian (interquartile range)

^bEffect size

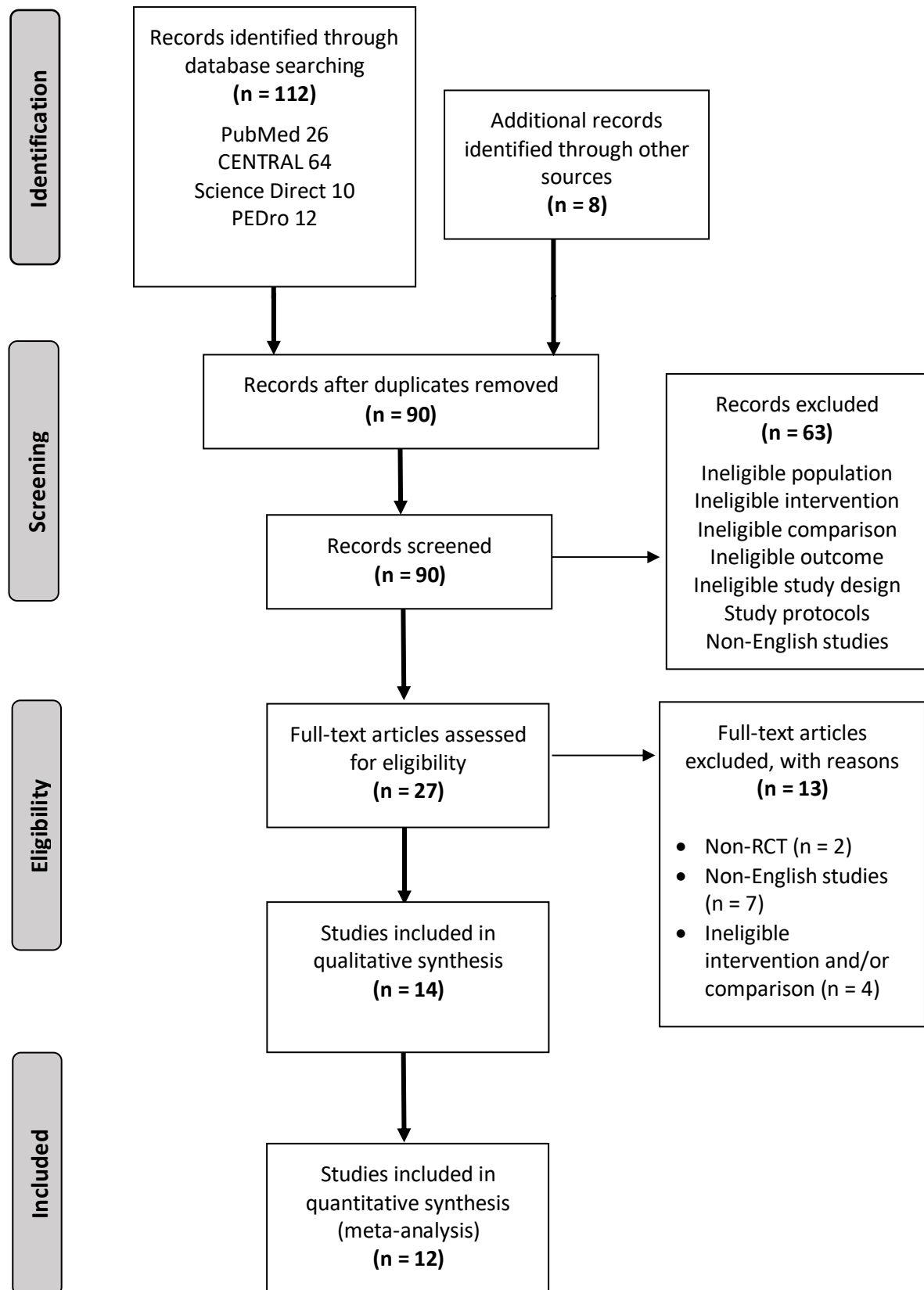


Figure 1. PRISMA flow diagram. Search date: 15 March 2024

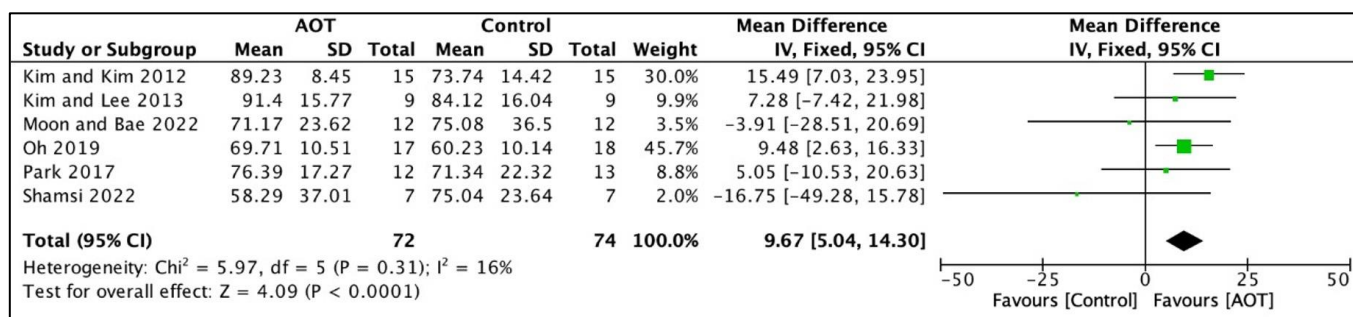


Figure 2. Meta-analysis of action observation training vs. control intervention on stride length.

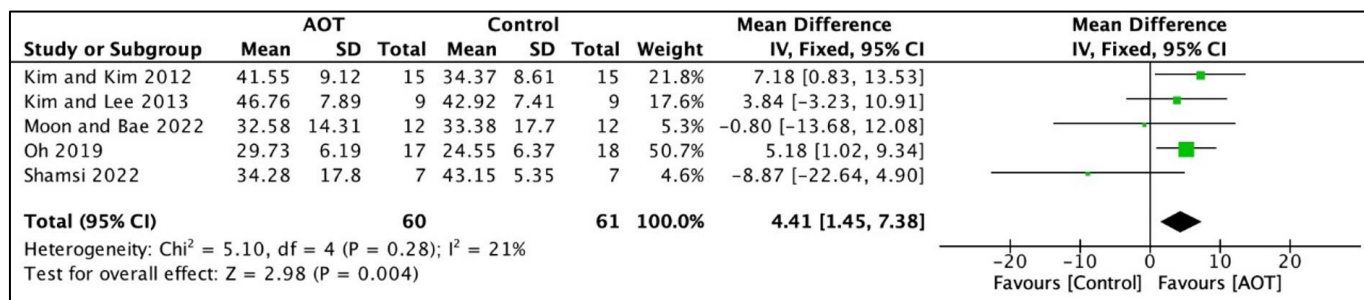


Figure 3. Meta-analysis of action observation training vs. control intervention on step length.

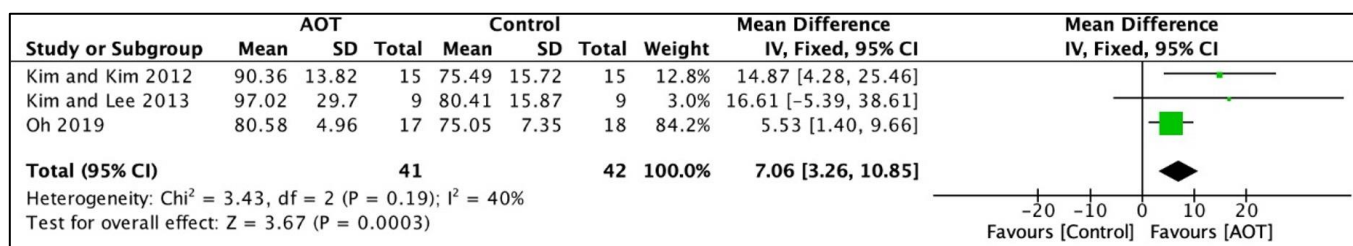


Figure 4. Meta-analysis of action observation training vs. control intervention on cadence.

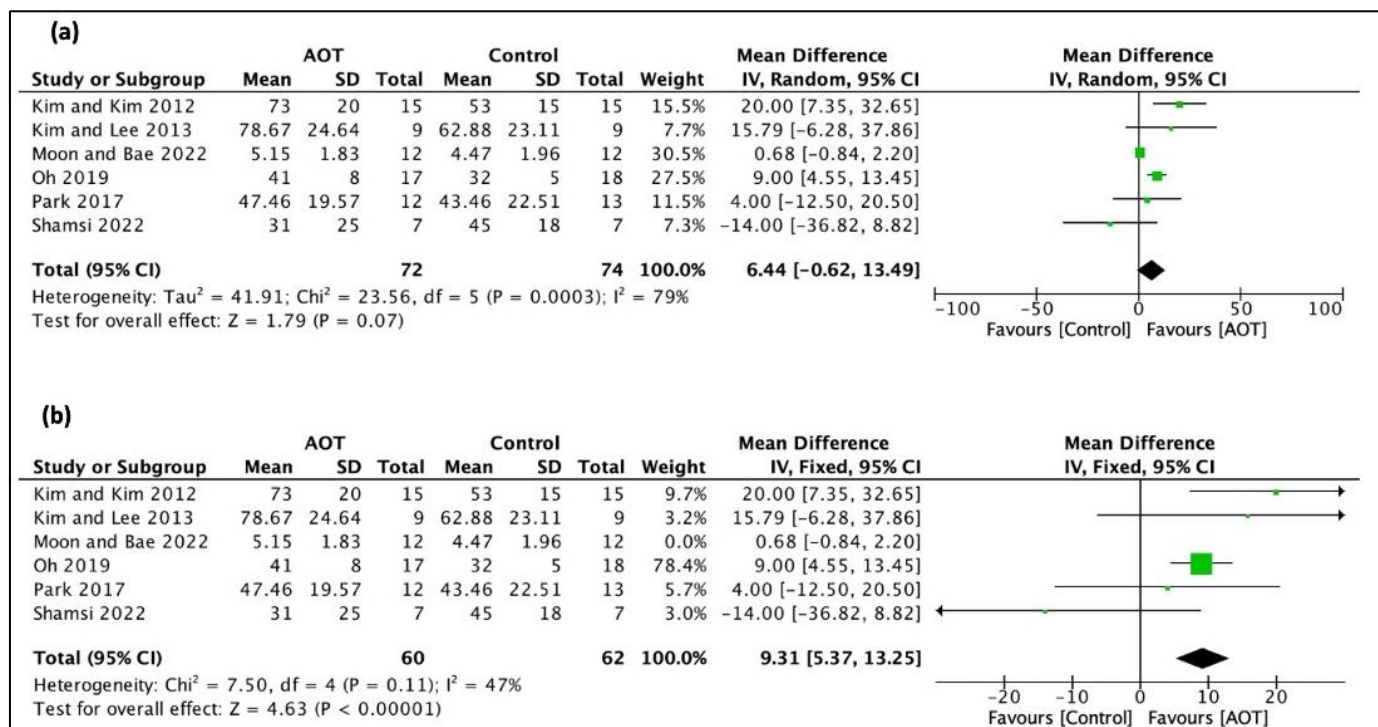


Figure 5. Meta-analysis of action observation training vs. control intervention on gait velocity: (a) with Moon and Bae(Moon and Bae, 2022) and (b) without Moon and Bae.(Moon and Bae, 2022)

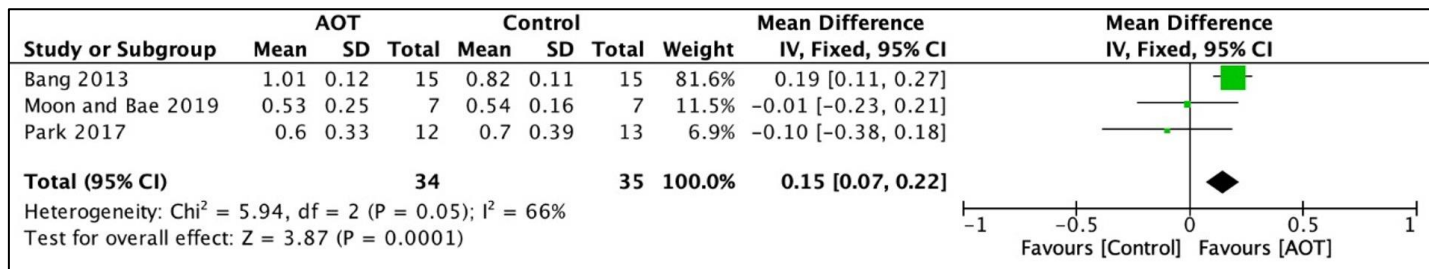


Figure 6. Meta-analysis of action observation training vs. control intervention on 10MWT.

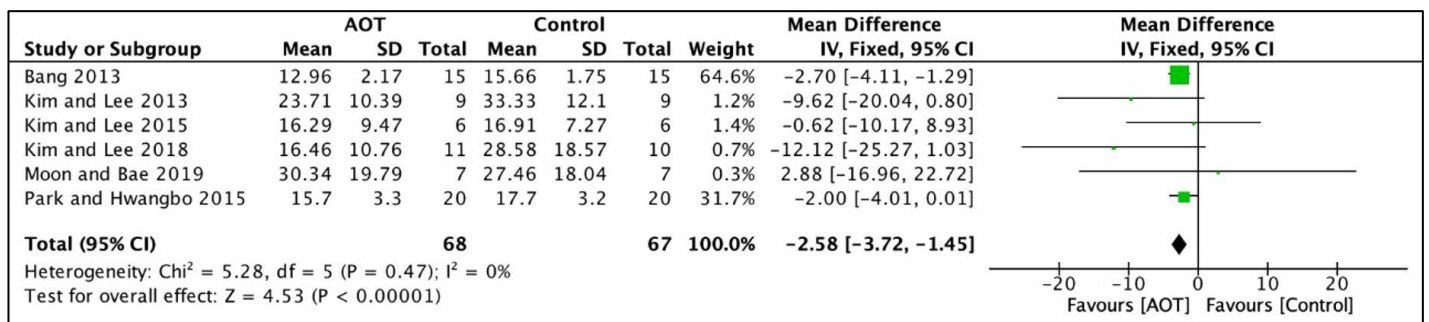


Figure 7. Meta-analysis of action observation training vs. control intervention on TUGT.

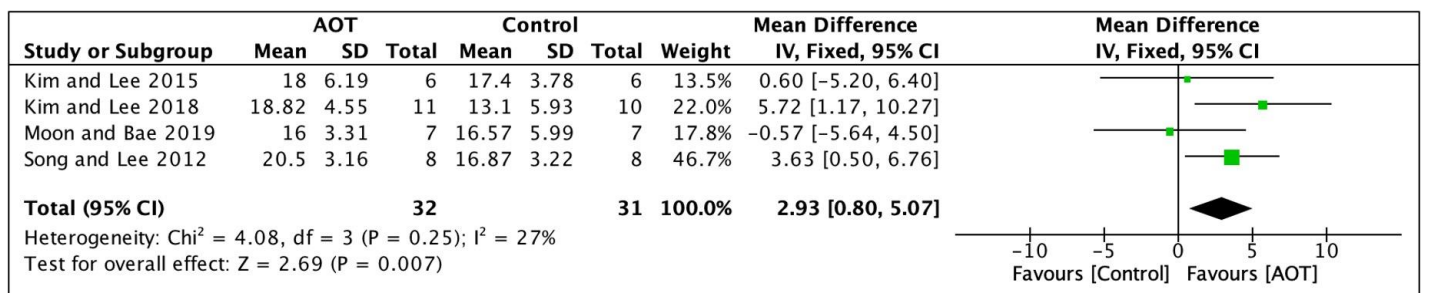


Figure 8. Meta-analysis of action observation training vs. control intervention on DGI.

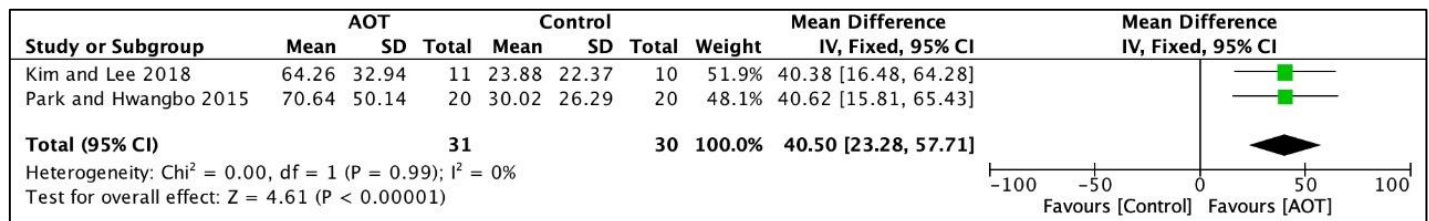


Figure 9. Meta-analysis of action observation training vs. control intervention on LOS.

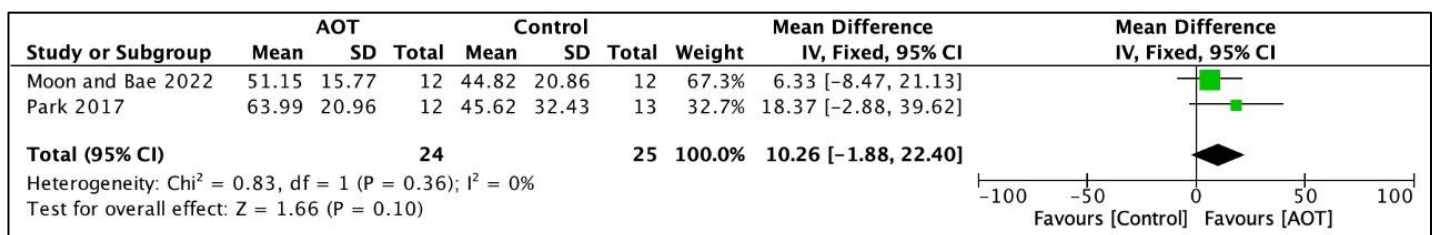


Figure 10. Meta-analysis of action observation training vs. control intervention on ABC Scale.