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Effects of mirror training on motor performance in healthy individuals: a systematic review and meta-analysis

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ABSTRACT

Objective Mirror training (MTr) is a rehabilitation technique for patients with neurological diseases. There is no consensus on its effects on motor function in healthy individuals. This systematic review and meta-analysis considers the effects of MTr on motor function in healthy individuals.

Design This is a systematic review and meta-analysis.

Data sources We searched six databases for studies assessing the effects of MTr on motor function in healthy individuals, published between January 1995 and December 2018. The Cochrane risk of bias was used to assess the quality of the studies. A meta-analysis was conducted with narrative synthesis.

Eligibility criteria for selecting studies English-language randomised controlled trials reporting the behavioural results in healthy individuals were included.

Results Fourteen randomised controlled trials involving 538 healthy individuals were eligible. Two short-term studies showed MTr was inferior to passive vision pattern (standardised mean difference 0.57 (95% CI 0.06 to 1.08), I^2=0%, p=0.03). The methods varied and there is limited evidence supporting the effectiveness of MTr compared with three alternative training patterns, with insufficient evidence to support analyses of age, skill level or hand dominance.

Conclusion The limited evidence that MTr affects motor performance in healthy individuals is weak and inconsistent among studies. It is unclear whether the effects of MTr on motor performance are more pronounced than the direct vision pattern, passive vision pattern or action observation. Further studies are needed to explore the short-term and long-term benefits of MTr and its effects on motor learning in healthy individuals.

PROSPERO registration number CRD42019128881.

What is already known?

► Although mirror training is effective for the treatment of motor dysfunction caused by neurological disorders, there is no robust evidence for its effects in healthy individuals.

What are the new findings?

► Mirror training (MTr) did not achieve statistically superior improvements in motor function compared with other approaches.
► The effects of age, skill level and dominant hand movements on motor performance in MTr could not be definitely assessed in this review.
► This review highlights the need for well-designed, high-quality, randomised controlled trials investigating the effects of MTr in healthy individuals.

INTRODUCTION

Mirror training (MTr) was first demonstrated in 1995 as a psychophysiological therapy for patients with phantom-limb pain after amputation.[1] Altschuler *et al*[2] reported that MTr is an advanced technique that improves the range, velocity and accuracy of limb and joint in patients with neurological diseases. The basic form of MTr involves superimposition of a mirror-reflected image of the active extremity over the opposite extremity by placing a midsagittal-plane mirror in front of the person. In most situations, the extremity behind the mirror is inactive. Studies involving unilateral movement of one hand showed that MTr with exercise-dependent motor tasks increased the hand strength of the contralateral side.[3 4] The placement of mirror can enhance the motor behaviour of contralateral muscle, even though it is not involved in the activity.[3] In prior studies, the tasks included ball rotation,[5] index finger abduction, a wrist or finger extension-flexion task[6] or dedicated training sequences.[7] A benefit of MTr is cross-limb transfer of motor learning, in that unilateral training induces improvements in motor performance of the contralateral limb. MTr also increases corticospinal excitability and activates the sensorimotor cortex. Some studies suggested that skilled musicians and athletes, for example, have greater motor cortex plasticity and can acquire new skills more easily than unskilled individuals.[8 9] Interconnections between the superior temporal sulcus and the frontoparietal mirror system can integrate motor signal transmission and visuospatial processing at the cortical level.[10] At the neuronal level, MTr

may activate mirror neurons in the frontoparietal cortex, which connects visual neurons receiving external visual information (ie, movement conducted by others or imitation) and motor neurons transmitting coded signals to muscle.[11] The visual inputs are encoded in the superior temporal sulcus, where higher order visual descriptions form. These descriptions are then transmitted to the frontoparietal mirror system for action learning.[12] Zult *et al*[7] reported confident interactions between MTr and the mirror neuron system in the primary motor cortex (M1) ipsilateral and contralateral to the moving hand, supporting action enforcement.[13 14] These cortices are activated when the subject conducts a simple task and imitates another person. Beyond neurophysiological research, a number of studies have demonstrated that MTr has positive therapeutic effects in patients with neurological disorders. Although MTr can activate motor function-related cortices, a prior study suggested that in the long term, MTr hardly affects the muscle morphology or strength after exercise.[15]

To date, no systematic reviews or meta-analyses have examined the clinical effects of MTr on motor performance in healthy individuals. Therefore, in this meta-analysis, we examine whether MTr improves the motor performance of tasks and investigate the clinical use of MTr for motor learning in healthy individuals.

METHODS

Search methods

This systematic review and meta-analysis was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses. We searched for relevant studies in the following six databases: Cochrane Library, MEDLINE, EMBASE, CINAHL, PsycARTICLES and PsycINFO using the following key words: 'mirror therapy' OR 'mirror training' OR 'mirror visual feedback' AND 'motor function*' OR 'strength' OR 'motor abilit*' OR 'motor skill*' OR 'motor performance' OR 'motor control' OR 'sport*' OR 'exercise' AND 'healthy individuals' OR 'healthy people'. We limited the search to studies written in English or translated into English by original study authors that were published between January 1995 and December 2018. We also searched the reference lists of included studies and previous systematic reviews in this field. YC and YW reviewed all of the titles and abstracts independently.

Study selection

Studies that satisfied the following criteria were included: (1) they were randomised controlled trials with conceivable original information (excluding descriptive research, narrative syntheses and secondary data); (2) the study involved behavioural interventions and measurements; (3) the studies enrolled healthy subjects without restriction by age or dominant hand; (4) the research topic involved motor behavioural changes; and (5) the full text was available.

Risk of bias assessment

We used the guidelines of the *Cochrane Handbook for Systematic Reviews of Intervention* to assess the risk of bias of the studies included.[16] Bias was assessed across seven domains: sequence generation, allocation concealment, blinding of participants, blinding of outcome assessment, incomplete outcome data, selective outcome reporting and other risk of bias. The risk of bias was graded as low (informed and detailed), high (no information) or unclear (insufficient detail).[17] Two researchers (YC and YW) independently assessed the risk of bias using Review Manager software (V.5.3; The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen, Denmark). Any disagreement between the two researchers was resolved by YB and PW or by consensus.

Data extraction and statistical analysis

General study information (eg, author's name, year), characteristics and number of subjects, experimental designs (eg, description of tasks, frequency, study duration, groups and measurements) and behavioural outcomes were collected in a table (see table 1 in online supplementary file 1) by YC and YW using data extraction forms. Studies with tasks trained within a day were defined as short-term studies with immediate functional gains. Long-term studies involved training sessions spread over more than 1 day. Any inconsistencies in extracted information were resolved by consensus. We pooled the data that seemed homogeneous or that permitted narrative synthesis with heterogeneous materials. We also contacted the study authors to request additional essential data if necessary.

Continuous variables were analysed as standardised mean differences (SMD) with 95% CI. Heterogeneity was assessed using the I^2 statistic by Review Manager software.

RESULTS

After searching the six databases, 8218 studies were initially identified and 3791 duplicate were excluded. The titles and abstracts of 4427 articles were reviewed for inclusion, and 4410 were excluded. Therefore, the full text of 17 studies was retrieved and assessed for eligibility, and 3 of these studies were excluded because they did not report measured data (n=2) or did not mention motor performance (n=1). Thus, 14 randomised controlled trials were included in the final analysis (figure 1). Nine studies were conducted in Germany[18–26] (including one in collaboration with China).[19] Two studies were conducted in Australia,[27 28] and the other three studies were performed in Japan,[29] the Netherlands[30] and the USA.[31] The studies were categorised according to their duration of experimental training. Five studies involved long-term tasks (more than 1 day, continuous training),[23–26 30] while the other nine studies adopted short-term training within 1 day to evaluate immediate functional effects.[18–22 27–29 31]

The studies mainly focused on the effects of MTr on the motor functional improvements of healthy individuals following various training schemes. Eleven studies

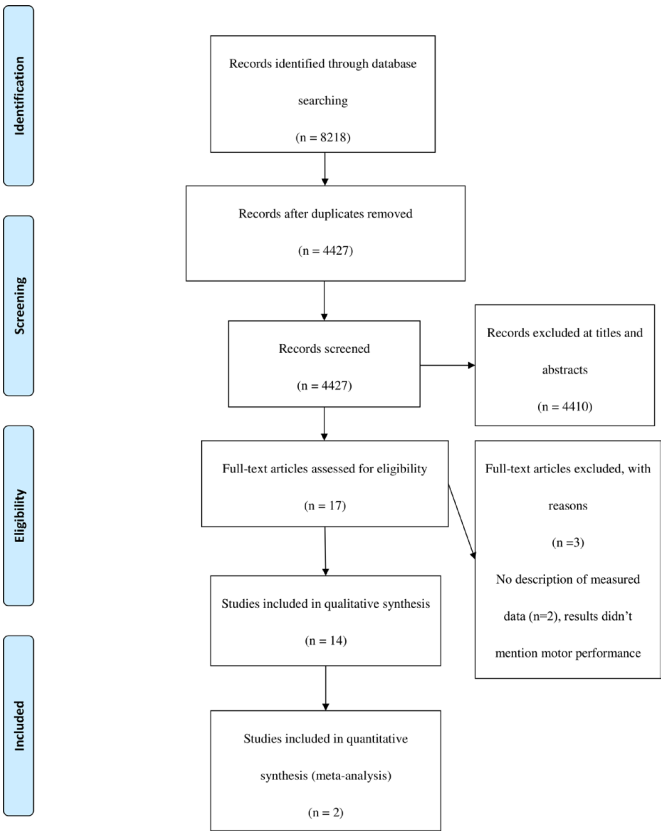

Figure 1 Flow graph of search strategy.

compared MTr with different training patterns: an active vision pattern, in which the participants only saw their moving limb; a passive vision pattern, in which the participants saw their inactive limb through glass rather than their active limb; and an action observation pattern, in which the participants saw the movements conducted by others without moving their own bilateral limb.[18 19 21 22 27–29 31] The other three studies investigated the effects of independent variables (ie, age, skill level and hand dominance) on motor performance in healthy individuals.[18 26 28] Although a funnel plot was created to assess publication bias (figure 2), the number of studies

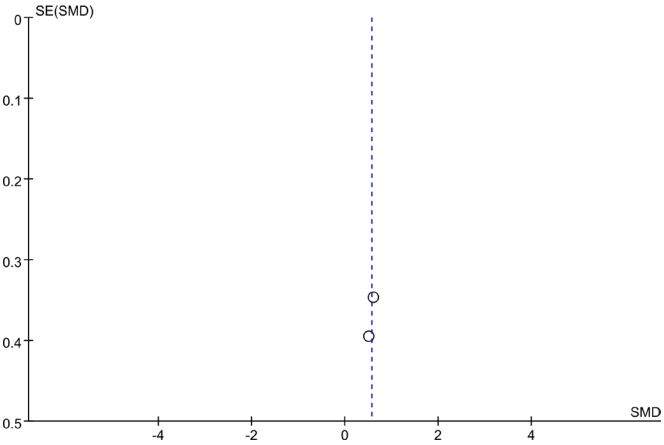

Figure 2 Funnel plot of studies. SMD, standardised mean difference.

was insufficient to reach a meaningful conclusion. Therefore, publication bias could not be assessed.

Ten studies used mirrors as a reflective tool, while the other studies used screens or virtual reality devices placed in front of the subjects. There were not additional effects of these techniques on the neurological transmission of visual perception.

Risk of bias

The studies showed low risk of bias in terms of random sequence generation (selection bias), incomplete outcome data (attrition bias) and selective reporting (reporting bias). Only 1 study showed appropriate allocation concealment, whereas 13 studies showed unclear risk of bias. Meanwhile, 10 and 12 studies showed unclear risk of bias in terms of blinding of participants and outcome assessment, respectively. YC and YW reached a consensus on their overall impression of bias. The reasons for high and unclear risk of bias were an unclear description of selection bias and incomplete blinding of participants and outcome assessment. The results of the risk of bias analysis are shown in figures 3 and 4.

Study characteristics

Fourteen studies investigated motor performance after unilateral training with a mirror. The number of participants ranged from 10 to 80 among the included studies. Finger-abduction, wrist-flexion, ballistic finger, ball-rotation, object-moving, muscle contraction and ball-dribbling tasks categorised as isometric/dynamic and continuous/phasic exercises were used to evaluate interlimb task-specific changes. The training type, duration and number of sessions varied, causing difficulty in evaluating the effectiveness of MTr on task-specific motor changes. Skill performance and strength gains were assessed in terms of task completion (ie, number and magnitude of completion of finger abduction and mean score) and the maximal voluntary contraction (MVC), respectively.

One study with an unclear risk of bias examined the effects of age on motor performance, but found no difference between younger (mean age=26.1 years, SD=5.3) and older adults (mean age=69.6 years, SD=5.6), suggesting no role of age on performance improvement.

A 2-week sport-specific task study with unclear risk of bias focused on skill levels and revealed that, after a stationary dribble task, basketball and handball athletes showed better improvements in completing a left-handed dribbling task with lower dribbling error under MTr than skilled subjects in a direct vision group ($p<0.05$). These results indicated that MTr aided motor acquisition among athletes. Additionally, the athletes displayed better performance than novices during MTr when both groups performed the same tasks with untrained hands, indicating that the effects of MTr could be modulated by the individual's skill level.[26]

To analyse whether MTr with the dominant or non-dominant hand affects motor gains in the untrained

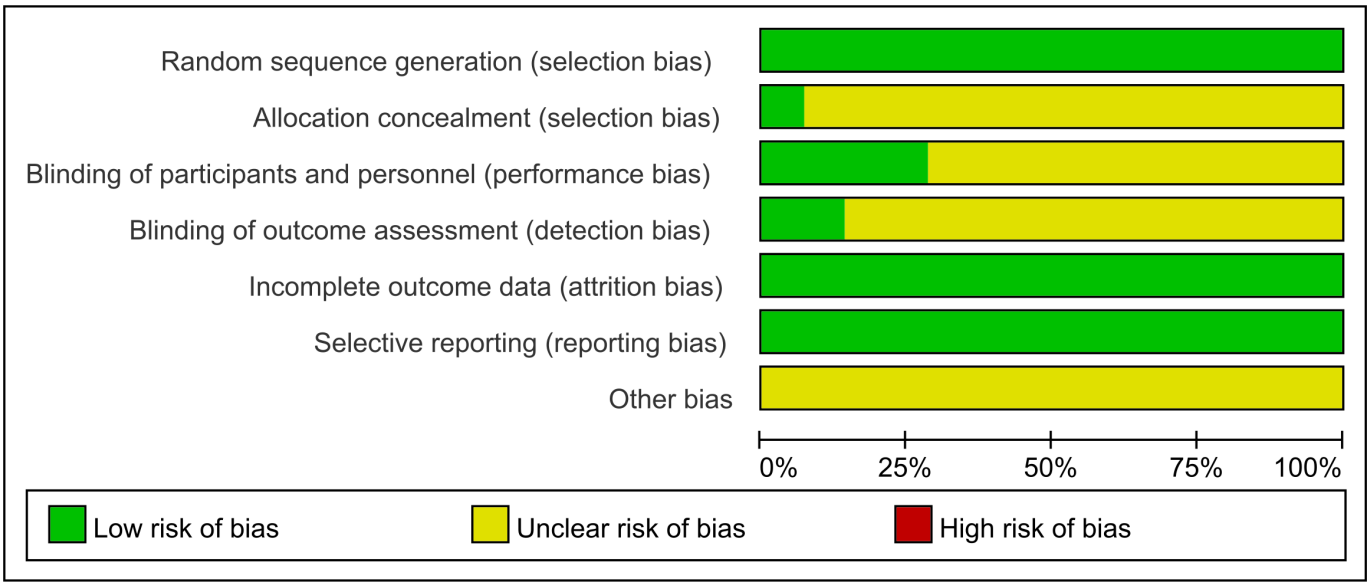

Figure 3 Risk of bias of the included studies.

limb, the study compared the motor performance of the untrained side between a dominant hand group (where the dominant hand moved with the non-dominant side behind a mirror) and a non-dominant hand group (where the non-dominant hand moved with the dominant side behind a mirror) in a study with unclear risk of bias. However, they found no significant difference in task performance by the bilateral side between the two groups.

MTr versus active vision pattern

Eight studies examined the functional performance of the untrained hand using MTr with an active vision pattern in which the participants saw their moving hand.[19 21–25 27 31] Seven studies showed an unclear risk of bias and one had a low risk of bias. The studies included two-ball rotation, ballistic finger tasks, index finger flexion and combined movement tasks. All of the studies reported better motor functional performance after MTr compared with the pretraining conditions. For the untrained hand, participants in two short-term studies completed index finger flexion tasks with seven sequences for 20 s in one study and in four 2 min blocks in the other study in 1 day. The studies reported no functional differences in that untrained hand with insufficient statistical data (the studies had unclear risk of bias).[19 31] In two short-term studies, the participants performed 10 blocks of ball rotations for 30 s in one study and 5 blocks of circular movements for 1 min in the other study, but found no significant differences between MTr and active vision pattern.[22 27] In a short-term study in which the participants performed 20 blocks of finger sequence abduction tasks for 15 s, MTr achieved greater functional improvement in the inactive limb compared with active vision pattern.[21] In three long-term studies in which participants performed comprehensive hand performance tests for 20 or 10 min daily for 4 days, there were significant improvements in motor performance in the untrained hand with MTr compared with active vision.[23–25]

For the trained hand, one short-term study in which the participants performed five blocks of circular movements for 1 min and two long-term studies in which the participants performed comprehensive hand performance tests for 10 min daily for 4 days compared the motor functional improvements between two groups.[24 25 27] All three studies showed better motor performance with MTr and the active vision pattern compared with baselines, but there were no significant between-group differences.

MTr versus passive vision pattern

Four studies compared the functional performance of the untrained hand in MTr with that in the passive vision pattern in which the participants saw their still hands through glass.[20 27 29 30] Risk of bias was unclear in two studies, low in one study and high in the other studies. In two short-term studies comparing MTr and passive vision pattern, the latter pattern achieved significantly greater functional improvement in the untrained hand following 10 trials of fast ball rotation within 1 day[20 27] (SMD 0.57 (95% CI 0.06 to 1.08), I^2=0%, p=0.03). In another short-term study involving 10 trials of fast ball rotation for 30 s, mean number of rotations with the untrained hand was increased by MTr ($p<0.05$) (figure 5).[29] One long-term study suggested that wrist flexor training of 20 min for 4 days increased the dynamic MVC torque of the static wrist flexor by 61%, and this improvement was maintained at 2-week follow-up.[30]

All four studies compared motor functional performance or strength gains of the trained hand between the groups. Nojima *et al*[29] reported a significant improvement in performance of the trained hand following MTr (10 trials of fast ball rotation for 30 s) (p=0.001). However, the other three studies found no differences in performance or strength gains between the study groups

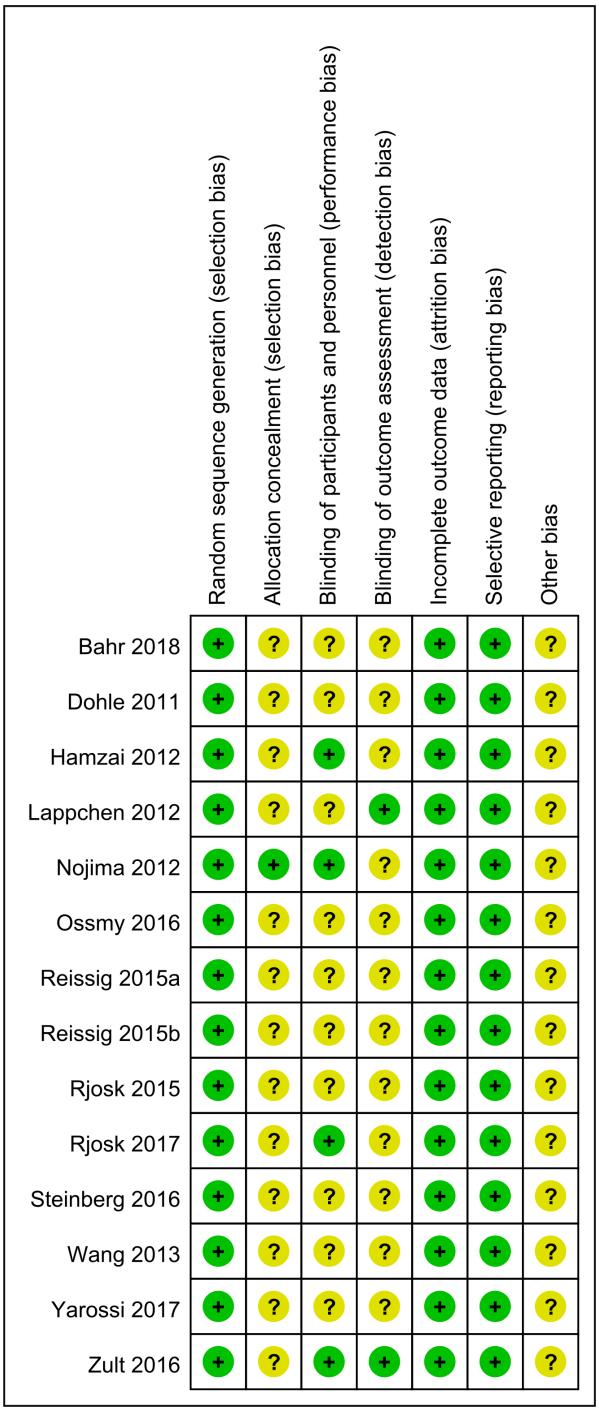

Figure 4 Summary of risk of bias. + with green circle, low risk of bias; ? with yellow circle, unclear risk of bias; - with red circle, high risk of bias.

(10 trials of fast ball rotation in 1 day, and 4 days of wrist flexor training for 20 min).[20 27 30]

MTr versus action observation

Two studies with an unclear risk of bias compared motor performance of the untrained hand between MTr and the action observation pattern.[19 29] In the study by Nojima *et al*,[29] the participants performed 10 trials of fast ball rotation for 30 s in 1 day. They compared the mean number of ball rotations performed by the untrained hand after MTr, and found no significant between-group differences, although the number of rotations increased compared with baseline. For the trained hand, there were no behavioural improvements following action observation. Wang *et al*[19] instructed the participants to watch seven video clips of movements in the mirror or other's hand performance, but found no difference between MTr and action observation.

DISCUSSION

In this systematic review and meta-analysis, we investigated the behavioural changes in motor function when healthy individuals conduct motor tasks while viewing mirror images of the trained hand. We included 14 randomised controlled trials, of which 9 studies involved short-term training (in 1 day) and 5 studies involved long-term training spread over more than 1 day. The studies used a variety of different movement tasks, measurements and methods. To date, no systematic reviews or meta-analyses have been performed in this field. This review may provide primary evidence showing the effects of MTr on motor skill learning.

The studies compared MTr performed with an active vision pattern, a passive vision pattern and an action observation. We also explored whether ageing, skill level and whether dominant hand movement shown in a mirror affected the functional improvement of upper extremities during MTr. The studies differed in terms of the training duration and outcomes, which made it difficult to compile data from all of the included studies. However, we compiled data from two short-term studies, which compared MTr with a passive vision pattern, for qualitative analysis and performed narrative synthesis for the other studies. Nearly half of the included studies compared MTr and an active vision pattern, and suggested that a quasi-ambidextrous modality accompanied by mirror viewing may confer motor improvements for the static hand in healthy individuals compared with the outcomes in the active vision group, but this

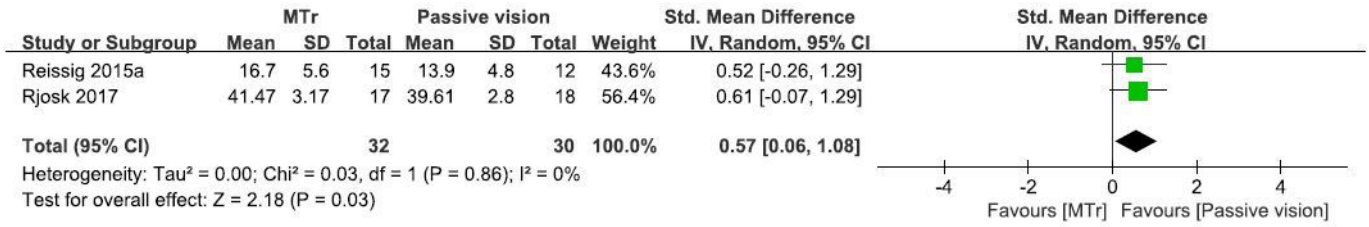

Figure 5 Statistical analysis of comparison of mirror training versus passive vision pattern.

may not be supported by the statistical evidence in this review. Because of small number of studies, there was limited evidence showing that passive vision pattern was superior to MTr in terms of improving motor function of the untrained hand in two short-term studies (SMD 0.57 (95% CI 0.06 to 1.08), I^2=0%, p=0.03). Although two studies reported motor improvement in bilateral limbs in the MTr group, there was no significant difference between MTr and action observation.

The uncertainty in findings may lie in that different experimental designs and measurements among the included studies. In some studies, MTr attenuated atrophy of homologous muscle and prevented the loss of strength of untrained limbs,[32] but there were limited changes in muscle morphology or strength after long-term exercise in other studies.[15] Many studies verified that MTr could compensate for functional deficits in hemiplegia[33–36] and elicited positive improvements in strength and bilateral motor function.[6 13 20 22] The healthy individuals who participated in the studies performed specially designed motor tasks, representing motor learning. Previous studies revealed that cross-limb transfer was pronounced with MTr.[24 25 29 37] However, we did not find definitive increases in strength and improvements in motor performance after motor task learning in healthy individuals in the studies. Therefore, the clinical applications of MTr for motor improvement in healthy individuals remain unclear.

The long-term studies seemed to report more positive motor functional changes compared with the short-term studies. The acceleration rates of the bilateral limbs in post-tests (after 300 movements) were greater in short-term studies compared with mid-tests (after 150 movements), demonstrating the potential of MTr for post-training motor functional improvement. One rodent study found that 6 days of wheel-rotation training resulted in significant improvements in performance on a rotarod task due to modification of gait compared with the baseline. The results suggest that long-term training could improve ability and change motor learning strategies.[38] Neuroimaging studies of people performing finger movements revealed that long-term training could activate finger representation in the sensorimotor cortex.[39] Diffusion tensor imaging studies also suggested that high-level, broad-skilled athletes with a long history of skill learning showed higher nodal parameters in their visual and attention networks than ordinary individuals, leading to quicker and more effective processing of visual information.[40] Thus, future research might investigate whether a longer duration of MTr can achieve improvements in motor function that are sustained for a longer time, and whether the neurophysiological changes during and after training may differ from those achieved by short-term training. Such research may shed light on the possible clinical applications of MTr for improving motor performance in healthy individuals.

Ageing is related to structural and functional recession, which affects neural plasticity in motor adjustment and behavioural plasticity.[41 42] At the neurological level, the interhemispheric communication attributed to transcallosum inhibition decreases with age due to demyelination of the corpus callosum.[4] Activation of motor cortical regions during isometric contraction is more attenuated in older adults than in younger adults.[43] However, another study showed the MTr simultaneously activates sensorimotor cortical excitability of the trained side and untrained homologous muscle in older adults after unilateral tasks within a short time.[44] At the functional level, older adults are more dependent on visual control to modulate performance accuracy. A previous study showed that MTr improved motor performance of the still limb in healthy subjects regardless of age.[45] Therefore, MTr may elicit greater improvements in motor skills and movement in older adults, in whom visual information plays an important part, than in younger adults. The included study revealed that younger and older subjects showed similar improvements in motor function with MTr after task training.[28] In this systematic review, we could not confirm a correlation between ageing and performance gains. First, based on the instantaneous neural adaptations measured using electroneurological methods, ageing predominantly influences motor improvement of the untrained limb during long-term exercise in a steady and effective manner. Although MTr significantly activated the neurological pathways compared with normal training in previous studies,[46–49] more time might be needed for the neural adaptations to support functional changes. Second, the included study did not use a continuous endurance training regimen to elicit better performance by memory consolidation compared with simple tasks in older adults.[50 51] Lastly, too few studies were included to permit quantitative analysis.

Few studies have definitively illustrated the effects of hand dominance on motor performance of the bilateral limb in MTr. Although motor performance of the non-dominant hand was usually evaluated by MTr-induced dominant hand performance, similar behavioural effects of MTr can be observed in the dominant hand by training with the non-dominant hand.[18 52 53] However, Imai *et al*[54] surmised that the effects of MTr were more pronounced in the non-dominant hand when the opposite hand moved. Further studies are needed due to insufficient research in this setting.

Steinberg *et al*[26] reported that participants showed greater learning performance on complex dribbling and slalom tasks with MTr compared with the direct/active feedback group. They also reported that experienced basketball and handball players showed fewer errors and shorter task duration following MTr, although the evidence was limited. Therefore, we hypothesises that the subject's skill level contributes to the performance gains with MTr. The skill level, associated with the acquisition of skills, improves knowledge learning[55]; for example, musicians can learn new skills more easily than unskilled individuals.[56] Bilateral limb symmetry is associated with the overall competence of athletes. There is evidence that athletes show better balance after multimodal balance

training compared with non-athletes.[57] As a modified version of classical action observation, MTr uses visual information to direct virtual movements of the untrained hand.[3] One study showed that some skilled subjects had greater dexterity of the untrained hand, with less error and faster movement together with activated structural reorganisation compared with unskilled subjects.[58] Athletes may use this pattern with a continuous training modality to learn new skills and recover from injuries.[59] Although MTr has only been used as a supplementary tool to compare skill levels between skilled and unskilled subjects,[26] better methods of improving motor function are needed. Some studies examined the effects of a mirror video, instead of an actual mirror, on efficiency of motor performance learning.[60] It will be useful to verify whether MTr can improve motor function steadily, even though it can activate cortices.[61–63] However, in this review we could not determine whether high skill level is a vital factor, and thus future studies should examine the effects of MTr on motor skill performance among athletes in the context of sports medicine and motor learning.

Strengths and limitations

To our knowledge, this systematic review and meta-analysis is the first to focus on the effects of MTr on physical strength and motor performance among healthy individuals, even athletes, revealing the clinical potential of MTr and the need for high-quality studies. Limitations include incomplete data on performance improvement, small sample size and the use of different non-comparable experimental designs. These make it difficult to reach a definitive conclusion. Differences in the inclusion criteria and subject characteristics among the studies (eg, hand dominance and gender) also make it difficult to assess motor improvement achieved by MTr fully.

CONCLUSION

This systematic review provides primary evidence that there is still uncertainty over whether MTr improves the motor function performance in healthy individuals. The high heterogeneity and low quality of the included studies limited statistical analysis. In the future, well-conducted, high-quality studies are needed to explore the short-term and long-term benefits of MTr and its effects on motor learning in healthy individuals, including athletes.

Contributors YC is the first author. YB and YW are the corresponding authors. YB obtained the grants. YC and YW investigated backgrounds, screened studies and collected the data. YC analysed the data and drafted the manuscript. YB and PW contributed to revise the manuscript. All authors have read and approved the final version of the manuscript.

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