Systematic Review

Effect of Motor Imagery Training on Motor Learning in Children and Adolescents: A Systematic Review and Meta-Analysis

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Abstract: Background: There is an urgent need to systematically analyze the growing body of literature on the effect of motor imagery (MI) training in children and adolescents. Methods: Seven databases and clinicaltrials.gov were searched. Two reviewers independently screened references and full texts, and extracted data (studies’ methodology, MI elements, temporal parameters). Two studies were meta-analyzed providing the standard mean difference (SDM). Selected studies were evaluated with the risk of bias (RoB) and GRADE tools. Results: A total of 7238 references were retrieved. The sample size of the 22 included studies, published between 1995 and 2021, ranged from 18 to 136 participants, totaling 934 (nine to 18 years). Studies included healthy pupils, mentally retarded adolescents, children with motor coordination difficulties or with mild mental disabilities. The motor learning tasks focused on upper, lower and whole body movements. SMDs for the primary outcome varied 0.33–3.10; p = 0.001; 0–74%; 0–0.59). RoB varied between some concerns and high risk. GRADE rating was low. Conclusions: MI combined with physical practice (PP) might have a high potential for healthy and impaired children and adolescents. However, important reporting recommendations (PETTLEP, TIDieR, CONSORT) should be followed. The systematic review was registered with PROSPERO: CRD42021237361.

Keywords: motor imagery training; mental practice; PETTLEP; children and adolescents; randomized controlled trial; systematic review and meta-analysis

1. Introduction

Motor imagery (MI) is essential in everyday life for numerous human motor activities [1]. It refers to the mental simulation of action in the absence of any evident motor output [2,3] and can be defined as a dynamic cognitive process in which an individual mentally simulates an action without the external manifestation of the motor act [4,5]. According to Jeannerod [6], MI is the representation of the action involved in the planning, execution and modulation of the movements. It does not depend on residual motor function but on an internal representation of the motor act to imagine, and can thus provide a substitute for executed movement by activating the motor network [7]. It is an accepted notion that MI provides insight into an individual’s ability to generate forward models of action that subserve a target-oriented movement [2,8,9].
Neuroimaging studies have shown a similar activation during MI compared to the activation during the actual movement [10–12]. The crucial role of the parietal cortex in that process was revealed by an experiment which used transcranial magnetic stimulation to produce a brief suppression of the local neural activity, which in turn resulted in an impaired accuracy of MI [13]. Imagining motor acts can furthermore also activate subcortical structures, i.e., the excitability of presynaptic interneurons, without activating alpha-motoneurons [14].

MI was initially used to improve athletic performance [15,16] and has subsequently been suggested for the rehabilitation to promote motor re-learning [17]. It has become a recognized and frequently used form of training or therapy for different purposes (cognitive, strength, and motor-related tasks) and individuals [18]. It was reported that MI may substantially enhance motor rehabilitation in patients following stroke [19,20], spinal cord injury [21], orthopedic surgeries [22–24] and sport injuries [25,26]. The acquisition of psychomotor skills can be promoted by MI as well [27–29] and ideokinetic imagery was found to have a positive influence on posture and pain level in low back pain patients [30]. However, evidence was, for instance, still found insufficient to estimate the effect of MI on gait, motor function and functional mobility after stroke compared to placebo or no intervention [31]. Nonetheless, MI has been widely supported as an effective way to enhance the actual performance of motor actions [32].

MI can be stimulated mentally by using either the kinesthetic mode, which refers to the sensation of the motor act, or the visual mode by just visualizing the movement [33–35]. A distinction is usually also made in terms of the perspective chosen, which can be either internal or external. The Internal perspective refers to the process of imagining a movement from the first-person perspective, as if seeing a body part in motion with one’s own eyes. In contrast, with the external perspective, it is a third-person view of oneself [36,37].

The capability to image one’s own movement can influence the performance and learning of motor tasks [38–41]. An important question that has arisen in this context in the past has been how well children are able to imagine their movements. There has been a debate about the minimum age a child would be able to perform MI tasks [4,42–45]. No definitive consensus could be found on the age at which children reach the capability to imagine movements comparable to the capability of adults. Studies in six-year-olds investigating mental rotation tasks revealed that their reaction time patterns were comparable to those of adults [46]. Mental rotation training in six- to eight-year-olds led to significant improvements in the trained mental rotation tasks. Furthermore, the mental rotation training had a general effect on spatial ability. Contradictory results have been reported regarding a transfer effect in terms of a possible positive influence of spatial training on mathematics performance [47,48]. In another study, about 60% of children aged five to six years were able to use MI, compared to adults [49]. However, Butson et al. (2014) [43] found that most of the children five to six years old included in the study were only able to perform with an accuracy of below 50% of that of adults. In general, the accuracy of performance in mental rotation tasks increases with age during childhood while children aged ten and over eleven perform similar to adults [50].

The development of MI ability has been extensively studied in children without impairments [42,50]. More recently, a few studies on MI ability in children with motor deficits such as development coordination disorder (DCD) [51–53] or cerebral palsy (CP) have been conducted [54]. DCD is a neurodevelopmental condition that is characterized by the inability to acquire and execute well-coordinated movements at an age-appropriate level [55], reflected by slow, effortful, inaccurate and ill-coordinated movements [56,57]. The deficits in skill learning and motor coordination in such children were suggested to be the consequence of a deficient predictive motor control and perceptual-motor coupling [57]. For children with DCD, it was proposed that the associated impairments are directly related to a diminished MI ability [41,58–63]. As MI provides insight into a person’s ability to generate a forward model of an imaged action, children with DCD may have a deficit implementing a forward model into the MI process [58].
The use of MI as a tool for rehabilitation of motor function in children and adults with DCD led to the suggestion that MI might also be a useful therapeutic tool for rehabilitation of children with CP [63]. As is the case for individuals with DCD, action planning and thus MI can be severely compromised in children suffering from hemiparetic CP [64,65]. In a recent study, Errante et al. investigated the mental chronometry paradigm to study the relationship between execution and imagination of grasping actions in children with unilateral CP, and to investigate the process underlying explicit MI ability for that action [55]. The authors provided evidence that an explicit MI ability for grasping actions was preserved in these children. Consequently, their capability to retrieve motor representations should equally be preserved. Furthermore, they suggested that the application of explicit MI training could support the development of upper limb manipulation function in the cerebral palsy rehabilitation of children [54].

There is a growing body of literature on children’s ability to perform MI tasks and on the effect of MI training in various patient populations at a young age. However, to date, a systematic review of randomized-controlled trials (RCT) on these issues is still missing in the literature. Our main aim is to conduct a comprehensive systematic review and meta-analysis including the evaluation of the methodological quality of the studies. To support evidence-based clinical decision, the present review will provide an overview on RCTs on the effect of MI training (MIT) on motor (re-)learning in children of various ages without or with deficient motor function due to different diseases.

2. Materials and Methods

The protocol for this review was registered with PROSPERO (International Prospective Register of Systematic Review) under the registration number CRD42021237361. The review was written and reported using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA checklist) guideline [66].

2.1. Search Strategy, Selection Criteria and Process

A professional librarian of the University of Zurich conducted the systematic search on the 5 March 2021 since their inception to present in the following databases:

- Cochrane Library
- Embase
- PsycInfo
- Scopus
- Web of Science
- Cinhal
- Clinicaltrials.gov

The second author (VZ) also searched SPORTDiscus on the 15 April 2021.

The search terminology regarding MI and mental practice (MP) was based on recently published Cochrane reviews in the field of rehabilitation and a peer-reviewed systematic review protocol [31,66,67]. Furthermore, the search strategy deployed followed recommendations for searching and selecting studies designed by Cochrane for identifying RCTs and controlled clinical trials (as described in the Cochrane Handbook for Systematic Reviews of Interventions) [68] of published trials if allocation of interventions was random. Studies were included regardless of publication date, if they included children or adolescents up to 18 years of age, used any kind of motor imagery training (MIT) or MP that was movement oriented, influencing any motor skill and applied one or more control interventions.

Studies were excluded if they described interventions with animals, when full texts from authors were not available or were not formally peer reviewed. To decrease the risk of missing relevant studies, reference lists in the included studies were screened. We excluded quasi-experimental or non-randomized studies using MIT or MP with technology devices, relaxation techniques or MIT with biofeedback.

The search terms and strategy were adapted for each database. An example is provided in Table 1. Two review authors (VZ and CSA) independently screened titles and
abstracts of the references obtained from the database searches, excluded irrelevant reports and removed duplicates from eligible studies. Then they retrieved the full-text articles for the remaining references. The same two review authors independently screened the full-text articles to identify studies for inclusion, and identified and recorded reasons for exclusion of the ineligible studies. In case of disagreement, a third reviewer was consulted (FB) to decide on inclusion or exclusion of the study. Finally, reference lists of the included full-text articles were screened for additional references that could yield further relevant articles. Cohen’s Kappa statistic was used to evaluate the reviewer agreement [69]. Further, a PRISMA flow diagram was generated (Figure 1).

Table 1. Search terms and strategy of the Embase session.

| No. | Query | Results |
|-----|-------|---------|
| #5  | #1 AND #2 AND #3 NOT [conference abstract]/lim NOT ([animals]/lim NOT [humans]/lim) | 1388 |
| #4  | #1 AND #2 AND #3 | 1695 |
| #3  | ‘controlled clinical trial’/exp OR crossover*:ti,ab,kw OR ‘cross-over*’:ti,ab,kw OR placebo*:ti,ab,kw OR sham:ti,ab,kw OR ((single OR double) NEAR/2 blind*):ti,ab,kw OR random*:ti,ab,kw OR allocat*:ti,ab,kw | 3,145,824 |
|     | OR factorial*:ti,ab,kw OR assign*:ti,ab,kw OR (((clinical OR controlled) NEAR/2 (trial* OR stud*)):ti,ab,kw) OR trial:ti | |
| #2  | ‘motor imagery’/exp OR ‘motor imagery training’/exp OR ‘imagery’/exp OR ‘imagination’/exp OR (((motor OR locomot* OR mental OR kinesthetic* OR kinaesthetic* OR movement*) NEAR/2 (image* OR simulation* OR ideation* OR visual*)):ti,ab,kw) OR (((mental* OR cognitive* OR covert*) NEAR/2 (movement* OR rehearse* OR imag* OR practic* OR practis* OR training* OR represent* OR stimulation* OR ideation* OR visual*)):ti,ab,kw) OR imagery:ti,ab,kw | 64,715 |
| #1  | ‘child’/exp OR ‘adolescent’/exp OR ‘pediatrics’/exp OR ‘cerebral palsy’/exp OR ‘developmental coordination disorder’/exp OR child*:ti,ab,kw OR boy:ti,ab,kw OR boys:ti,ab,kw OR girl*:ti,ab,kw OR pediatric*:ti,ab,kw OR paediatric*:ti,ab,kw OR adolescent*:ti,ab,kw OR teens*:ti,ab,kw OR ‘preschool*:ti,ab,kw OR (((cerebral OR brain OR spastic) NEAR/2 (palsy OR paralys* OR pares* OR diplegia)):ti,ab,kw) OR ‘developmental coordination disorder*:ti,ab,kw OR dcd:ti,ab,kw | 4,523,492 |

Legend: ab = abstract; dcd = developmental coordination disorder; exp = exploded; kw = keyword heading; lim = limit; ti = title.

2.2. Data Extraction

All authors were involved in the data extraction process. The data of each included study were independently extracted from two of the authors. When there was disagreement regarding data extraction, a third review author checked the data (CSA). A complete overview of extracted data is provided in Tables 2 and 3. In case of incomplete data (e.g., only graphical presentations) in the selected studies, the corresponding authors were contacted to obtain the missing details. The data extraction was based on Schuster et al. (2011) [70] and focused on (1) trial-related and (2) MIT-related information:

1. Trial-related information included: First author, year of publication, kind of randomization, blinding, sample size and study groups, age, and gender of participants, participants’ description, study setting, task to imagine, measurement events, outcomes and outcome measures, study results, number of dropouts, recognition of an included participant flow chart and the risk of bias evaluation.

2. MIT-related information included: MI experience, MI familiarization, MI manipulation check, PETTLEP (physical, environment, timing, task, learning, emotion, perspective) approach used, MIT intervention and control interventions descriptions, MIT session and order of MIT and physical practice, location of MIT and position of the individual during MI, MI supervision and instructions’ medium, instruction individualization yes/no, perspective (internal/external), mode (kinesthetic/visual), eyes open/closed and temporal parameters: number and frequency of MIT sessions and duration and number of MI trials (per session and total).
2.3. Assessment of Risk of Bias and GRADE

Two reviewers (FB and CSA) assessed risk of bias within studies using the Cochrane Collaboration risk of bias (RoB) 2.0 assessment [71]. Six domains of bias were rated for every study with each domain having three rating categories. The judgement can be ‘Low’ or ‘High’ risk of bias, or can express ‘Some concerns’. Discussion between the two reviewers resolved disagreement if needed. We assessed the risk of bias according to the following six domains: (1) Randomization process, (2) Deviations from intended interventions, (3) Missing outcome data, (4) Measurement of the outcome, (5) Selection of the reported results, and (6) Overall bias.

The Grades of Recommendation, Assessment, Development and Evaluation (GRADE) was conducted by two independent rater (ZS and FB) and was used to rate the overall quality of the evidence and the strength of the recommendations for the studies and data that could be pooled in a meta-analysis [72]. In accordance with the GRADE Working Group recommendations, the evidence was classified on four levels of quality: ‘very low’, ‘low’, ‘moderate’, and ‘high quality’.

We additionally searched for study protocols to identify any deviations from the pre-planned data analysis.
Table 2. Characteristics of included studies.

| First Author | Year | Country | Randomization and Kind of Randomization | Blinding | Study Groups | Number and Gender of Participants and per Group [Years] | Participants | Study Setting | Focus of Imagery | Measurement Events | Outcomes and Outcome Measures | Results EG vs. CG | Dropouts/ Flow Chart/ RoB Rating |
|--------------|------|---------|----------------------------------------|---------|--------------|--------------------------------------------------------|-------------|--------------|----------------|-------------------|-------------------------|----------------|----------------------|
| Abraham [73] | 2017 | IL      | RCT, R. stratified for age and dancing level | Investigator and participants during pre-assessment | 2 | Total: 25 Females EG: 15 F CG: 12 | Healthy dance students, at least 3 years of dancing experience | Dance studio | Elevate movement | Protocol Posttest | Ankle PF ROM in degrees | No sign. between-group difference | Dropout: 1 Flow chart: No RoB rating: SC |
| Aus [74]    | 2014 | BRA     | RCT, R. stratified for gender | N.R. | 3 | Total: 36 (F = 13, M = 23): MT: 12 (F = 4, M = 8): PP: 12 (F = 5, M = 7): NP: 12 (F = 4, M = 8) | Healthy, right-handed pupils from a private school, average education [years]: MT and NP: 4.3 ± 0.5 PP: 4.5 ± 0.4 | N.R. | FOV: TS 4-3-2-1 | BL 1: Day 1 2: Day 2 3: Day 7 4: Day 10 | Speed and accuracy of TS and URS: Number of correct sequences per min. recorded by a computer-monitored device attached to fingertips | MIT and PP equally effective in immediate and long-term learning, MIT leads to more efficient transfer to URS | Dropout: N.R. Flow chart: No RoB rating: SC |
| Barthma [75] | 2021 | IR      | RCT, R. N.R. | N.R. | 2 | Total: 156 Males EM: 47 M IM: 71 F | Healthy boys, who were naive to the purpose of the study | N.R. | Overtarm tennis ball toss with non-dominant hand | Protocol: day 1 Posttest: day 2 | Tossing accuracy: Ratio of individual's scoring for total score divided by number of completed MI ability: Persian MIQ-C | No significant effect produced superior motor learning | Dropout: No Flow chart: No RoB rating: SC |
| Battaglia [76] | 2014 | Italy | RCT, R. N.R. | Assessor | 2 | Total: 72 Females EG: 36 F CG: 36 F | Female rhythmic gymnasts, competing at national level | Summer training camp | Vertical jumps | Protocol Posttest | Vertical jump performance (FT, CT, HL, DJ, Counter Movement Jump): Optojump system MI ability—MIQ-R | FT and CT jumping parameters of the FT and DJ tests improved significantly in MIT compared to PP only | Dropout: N.R. Flow chart: No RoB rating: SC |
| Cabral-Sequeira [77] | 2016 | BRA     | RCT, R. N.R. | N.R. | 4 | Total: 31 (F = 13, M = 16): EG: 13 F CG: 18 F | Adolescents with mild cerebral palsy | N.R. | Aiming as fast and accurately as possible at a 2 cm diameter target | Day 1: Protocol 1 Day 2: Retention test, Posttest 2: Retention 2 | Movement time, Movement straightness, Frequency of sub-movement, Peak height, Average joint angular velocity, Radiolar error Four opto-electronic cameras (Yoon, MEVa) | No effect associated with side of hemiparesis to achieve equivalent motor performance, MIT induced faster and straighter movements in comparison with controls | Dropout: 2 Flow chart: No RoB rating: SC |
| de Sousa Fortes [79] | 2019 | BRA     | RCT, R. stratified for passing decision-making performance at IL | N.R. | 2 | Total: 33 Males EG: 17 CG: 16 | Volleyball players, with at least 2 years of experience, training for 60–7 × 45 min/day, 5 × /week, enrolled in the U-37 Volleyball State Championship | Training site | Passing decision-making performance in volleyball | TI: 48 h before Intervention T2: 48 h after intervention | Decision-making performance—Game Performance Assessment Instrument and Decision-making index Heart rate—heart rate monitor Video recording of EG and CG sessions | Moderate positive effect of MIT on passing decision-making performance of the young volleyball players | Dropout: N.R. Flow chart: No RoB rating: SC |
| de Sousa Fortes [79] | 2020 | BRA     | RCT, R. stratified by website | Statistician | 2 | Total: 28 Males MT: 14 CG: 14 | Tennis players (training 2h/day, 4 × /week) enrolled in the State Tennis Championship | Tennis court | Tennis service performance | TI: 48 h before intervention T2: 48 h after intervention | Accuracy—total sum of achieved points Speed (km/h)—radar gun MI ability—MIQ-R | MIT might be an elective strategy to enhance tennis service performance among young male tennis players | Dropout: No Flow chart: Yes RoB rating: SC |
| Deossain [68] | 2011 | CL      | RCT, R. N.R. | Assessor | 3 | Total: 64 (N.R.) EG: 22 CG: 22 CG: 21 | Urban elementary school from Barcelona (Catal) | BL protocol during first trainings TI: posttest after sixth training session | Run and throw a ball towards a distant target | Learning—Score of Standardized Basic and Combined Movements Scale Distance reached on each ball throwing—outcome measures not mentioned | All training forms were effective in improving motor task performance, MIT and modelling were more effective to obtain a significantly higher final performance than PP | Dropout: N.R. Flow chart: No RoB rating: High |
Table 2. Cont.

| First Author | Year | Country | Randomization and Kind of Randomization | Blinding | Study Groups | Number and Gender of Participants and per Group | Age of Participants (years) | Participants | Study Setting | Focus of Imagery | Measurement Events | Outcomes and Outcome Measures | Results EG vs. CG | Dropouts/Flow Chart/Rob Rating |
|--------------|------|---------|----------------------------------------|----------|--------------|-----------------------------------------------|-----------------|-------------|---------------|----------------|------------------|-----------------------------|----------------|------------------------|
| Feikhabad     | 2020 | TUN     | RCT, N.R.                              | N.R.     | 2            | Total: 36 Males                               | MIT: 16.9 ± 0.6 | Young male tennis players, volunteered, training regularly in tennis clubs for 2 h/day, on average 5 x/wk | Usual training session | Tennis service | T0: 48 h before Ramadan | Tenis service performance as a product of accuracy and speed, measured with total scores of the Service Performance Test and radar gun | MI ability with MQ-RS | MIT could be effective strategy to optimize tennis service performance during Ramadan fasting, MIT could counter/mitigate negative and detrimental effects of fasting on tennis-service performance | Dropouts: N.R. Flow chart: No Flow Rating: SC |
| Hemayattalab  | 2010 | IR      | RCT, N.R.                              | N.R.     | 5            | Total: 40 (N.R.)                               | PP: 8 MIT: 8     | Adolescents with mental retardation (AMR)   | School for mentally retarded pupils of Tehran | Basketball free throws | T1: pretest T2 posttest T3 retention test 10 days later | Basketball free throw performance: Free throw test (10 attempts) MI ability: EMG | In adolescents with mental retardation: MIT by itself or less effective than PP for motor task learning enhancement, MIT + PP is more effective than MP alone | Dropouts: N.R. Flow chart: No Flow Rating: SC |
| Kanthack      | 2014 | BRA     | RCT, N.R.                              | N.R.     | 2            | Total: 36 females                              | MIT-CI: 15 PP-CI: 12 PP: 13 | Young basketball players from one team in the junior league of the Federação Paulista de Basquete | Room near basket-ball court, and basketball court | Basket-ball free throws | T1: pretest T2 posttest | Basketball throwing performance: Scoring in 10 free throws Self-efficacy: General Perceived Self-Efficacy Scale Imagination level: customized scale ranging (0–3) | There was no significant difference between groups: medians, SJC statistic indicates 94% likelihood that MIT had a beneficial effect on performance in the first two free throws | Dropouts: N.R. Flow chart: No Flow Rating: SC |
| Mohammadhosseini | 2017 | IR      | RCT, N.R.                              | N.R.     | 3            | Total: 12 years old                           | School of Shiraz city | Both-grade elementary school pupils | A school of Shiraz city | Tech skill (the first kata Taekyoku Sonno ichi) | T1: pretest T2 posttest × last training session T3: 48 h after last training session T4: in a competitive condition | Kata skill learning and performance: Kata-evaluation form scores 0–20 | The systematic increase in the CI had highest effectiveness, MIT + PP with a systematic increase in CI had long-term positive effects on performance and learning a kata skill | Dropouts: N.R. Flow chart: No Flow Rating: High |
| Nourani       | 2019 | IR      | RCT, R. computer-generated random-number sequence | N.R.     | 3            | Total: 45 Males                               | MIT: 15 MITZ: 15 | Adolescent novice players in a summer camp | Football summer camp from Farhang Football School in Jahrom | Football pass skill performance | Prettest Posttest | Football pass skill performance: Mes and Christian’s test MI ability: MK | Among adolescent novice football players, external PETTLEP imagery led to the highest improvement in football-passing skill performance | Dropouts: 0 Flow chart: No Flow Rating: SC |
### Table 2. Cont.

| First Author | Year | Country | Randomization and Kind of Randomization | Blinding | Study Groups | Number and Gender of Participants and per Group | Age of Participants and Per Group [Years] | Participants | Study Setting | Focus of Imagery | Measurement Events | Outcomes and Outcome Measures | Results EG vs. CG | Dropouts/ Flow Chart/ RoB Rating |
|--------------|------|---------|----------------------------------------|----------|-------------|-------------------------------------------------|------------------------------------------|-------------|--------------|----------------|------------------|---------------------------|---------------|------------------------|
| Pernetta [67] | 1995 | USA     | RCT, R. N.R.                            | N.R.     | 2           | Total: 32 (F = 17, M = 15) PP + MIT: 16 PP: 16 | PP + MIT: 15 years 4 months ± 1 year 8 months PP: 14 years 7 months ± 1 years 6 months | Adolescents with mild mental retardation | N.R. | Sticking with a baseball bat | During each training session on 5 consecutive days (Monday to Friday) | Timing accuracy [one measured as discrepancy between arrival of light stimulus at a certain location and striking the string: Bascom Anticipation Timer | Participants using PP + MIT were significantly more accurate on the striking task than participants in the PP group | Dropout: N.R. Flow chart: No RoB rating: SC |
| Quinton [68]  | 2014 | UK      | RCT (paired by age), R.N.R.             | N.R.     | 2           | Total: 36 (F = 2, M = 34) EG: 18 CG: 18 | Total: 9/22, 2.05 EG: N.R. CG: N.R | Futsal player | Gymnasium | Dribbling and passing soccer task | Pretot Posttest | Players’ ball control and decision-making skills; Dribbling and passing soccer task | MI ability: MKQ-C | Dropout: N.R. Flow chart: No RoB rating: SC |
| Screws [89]  | 1997 | USA     | RCT, R. N.R.                            | N.R.     | 6           | Total: 30 (N.R.); EG: 10 (5 peg board; 5 pursuit rotor) PP: 10 (F = 5) CG: 10 (F = 5) | Total: 12.5 ± N.R. | Children with MMD Rural School in Alabama | Cognitively-oriented task (peg board) ± Skill on motoric-oriented task (pursuit rotor) | Pretot Posttest | | | | Participants using PP + MIT produced no significant improvements in imagery ability or motor task performance. Significant correlation at post-test for the MIT group between age and external visual and kinesthetic imagery ability. | Dropout: N.R. Flow chart: No RoB rating: SC |
| Seif-El-Raghi [90] | 2012 | IR      | RCT, R. N.R. | Coaches | 2            | Total: 56 Males, U16:17, U19:18 EG: U16: 9, U19: 9 CG: U16: 8, U19: 9 | Total: 18.99 ± 14 years 7 months 1 year 8 months ± 12.5 | No significant differences were found. | No significant differences were found. | | | Players in the MIT group could observe an increase in the successful pass rate compared to CG. | Dropout: 19 Flow chart: Yes RoB rating: SC |
| Simonsmeier [91] | 2017 | GER     | RCT, by software before BL assessment | Judges   | 2           | Total: 96 Females MIT first: Low Expertise: 22 High Expertise: 9 MIT last: Low Expertise: 12 High Expertise: 13 | Total: 9/6.3 ± 2.43 | Gymnasts participating in their sport between 1 and 14 years between 3.5 and 25.5 h/week | The cast to handstand on bars: T1: prior to first training phase T2: between two training phases T3: after training phase | Pretot Posttest | The cast to handstand on bars: Performance: Coding system Mental representation: SDA-M Imagery ability: SIAQ | MIT had positive effects on performance only for the high-expertise athletes in MIT last condition | Dropout: 2 Flow chart: No RoB rating: SC |
| Starburg [92] | 1995 | USA     | RCT, R. N.R.                            | N.R.     | 4           | Total: 40 (F = 22, M = 18) | Total: 15.65 ± 6.65 | Forty students with mild mental retardation (20 students from Indiana, 20 students from Ohio) High school pupils | An under-hand baseball throwing task | Pretot Posttest | | | Successful execution of an underhand throwing task with the non-dominant arm | Two types of cognitive demands did not affect imagery. MIT did improve motor performance of students with mild mental retardation. | Dropout: N.R. Flow chart: No RoB rating: SC |
| Takeasano [93] | 2018 | BRA     | RCT, R. N.R.                            | N.R.     | 3           | Total:18 (both gender) PP: 6 PP + MIT: 6 CG: 6 | Total: 9/35 ± 0.49 | Right handed, healthy pupils | N.R. | Holding a plastic block and insert it in the support with the right hand | Pretot: before training Posttest: immediately after PP Retention test: 24 h after training | Task performance: Movement between the non-dominant and dominant hand PP group achieved a persistent performance gain in the “transport”, but not in the “teaching” task PP + MIT group achieved performance gains in both components No significant differences were found for CG. | Dropout: N.R. Flow chart: No RoB rating: SC |
Table 2. Cont.

| First Author | Year | Country | Randomization and Kind of Randomization | Blinding | Study Groups | Number and Gender of Participants and per Group | Age of Participants and Per Group (Years) | Participants | Study Setting | Focus of Imagery | Measurement Events | Outcomes and Outcome Measures | Results EG vs. CG | Dropouts/Flow Chart/ROB Rating |
|--------------|------|---------|----------------------------------------|---------|-------------|---------------------------------|--------------------------------------|-------------|-------------|----------------|-----------------|------------------|-----------------|------------------------|
| Wilson [46]  | 2002 | AUS     | BLC: R. blocked to ensure similar numbers of children within ± percentile ranges of total impairment and similar age | Assessor | 3 | Total: 54 (N.R): EG:18 PP: 18 NP: 18 | Total: Range 7–12 | Children with motor coordination difficulties | Six schools in Brisbane | Catching and throwing a tennis ball; Seeking a softball; Jumping to a target using a two-leg take-off, balancing a ball on a bat while walking, placing objects using thumbs and hands | Peri-test Posttest | Motor function: Movement Assessment Battery for Children | Imagery training, delivered in a multimedia format, can be equally effective to perceptual-motor training in developing the motor skills of children referred with coordination problems | Dropouts: N.R. Flow chart: No ROB rating: SC |

Legend: CG = control group; FOS = finger opposition sequence; N.R. = not reported; min = minute; MIT = motor imagery training; MITG = motor imagery training group; MITS = motor imagery training session; sec = seconds; TS = training session; WBD = weight bearing distribution; wk = week.

Table 3. Motor imagery training interventions of included studies.

| First Author | MI Experience, MI Familiarization and MI Manipulation Check | PETTLEP Approach and MI Intervention Description | Control Interventions | MIT Session and Order | Location and Position during MIT | MIT Supervision and MI Instructions | MI Mode, MI Perspective, Eyes | Number of MITS and Intervention Duration | Trials per MITS and Total Trials |
|--------------|------------------------------------------------------------|-------------------------------------------------|------------------------|-------------------------------|-------------------------------|-------------------------------|--------------------------|--------------------------------------|-------------------------------|
| Abraham      | MI experience: N.R. MI familiarization: N.R. MI check: N.R. | PETTLEP: yes | MITG: Specific components of elevé performance, emphasis on ankle PP and foot movements, biomechanics, equal WBD | PP: Upper body exercises with focus on postural awareness, joint mobility and strengthening of neck, shoulders, arm, elbows, wrists | Session: N.R., probably group Order: N.R. | Location: Dance studio Position: MITG: Lying down on mattress CG: Sitting on a chair in a circle | Supervision: Yes Instructions: Live, detailed, descriptive with changing tones of voice, and using arousing mental images | Mode: Visual then kinesthetic Perspective: N.R. Eyes: Closed or open, according to personal preference | Total: 12 MITS lasting 20–25 min each per week Duration: 6 weeks | Progressions: (1) Number of mental elevé 30–80; (2) tempo of performance: 20–40 movements per min. and for static elevé 8–14 s; (3) complexity of imagery environment |
| Asia          | MI experience: N.R. MI familiarization: N.R. MI check: N.R. | PETTLEP: N.R. | MITG: Kinesthetic imagery of the FOS trained sequence 4–2–5 | PP: Physical practice of FOS TS using the trained hand | N.P.: No practice on any of the movement sequences, practiced a non-sequential painting task for the same length of time as PP and MIT | Session: N.R., probably individual Order: MIT only | Location: N.R. Position: Comfortably seated in front of a desk with supported elbows and forearms | Supervision: Yes Instructions: Live | Mode: Emphasized kinesthetic imagery and prevented use of visual imagery Perspective: N.R. Eyes: Closed | Total: 5 MITS lasting 4PP 25 mm Duration: 1 day | MITS: Four blocks of 120 mental trials with rest intervals of 2 min between blocks Total trials: 120 |
| Balsami       | MI experience: N.R. MI familiarization: N.R. MI check: N.R. | PETTLEP: N.R. | MITG: Internal focus | NP: Four blocks of 120 mental trials with rest intervals of 2 min between blocks | Session: N.R. Order: PP before MIT | Location: N.R. Position: Standing, 6.3 m away from target | Supervision: N.R. Instructions: N.R. | Mode: N.R. Perspective: Internal and external Eyes: N.R. | Total: 12 MITS Duration: 1 day | MITS: Six blocks à 10 mental sessions Total trials: 60 |
| Battaglia     | MI experience: N.R. MI familiarization: N.R. MI check: N.R. | PETTLEP: Yes | MITG: Motor imagery for finger opposition sequence | CG: Light core training (abdominal muscle exercises) and active flexibility training = 5 min 5 PP of each vertical jump | Session: N.R. Order: MIT before PP | Location: N.R., probably gym Position: N.R. | Supervision: N.R. Instructions: N.R. | Mode: Visual Perspective: N.R. Eyes: N.R. | Total: 12 Two MITS per day for 6 days/week Duration: 6 weeks | MITS: Five mental trials of each of the 5 vertical jumps = 15 MITS Total trials: 180 |
| First Author                  | MI Experience, MI Familiarization and MI Manipulation Check | PETTLIEP Approach and MI Intervention Description | Control Interventions | MIT Session and Order | Location and Position during MIT | MIT Supervision and MI Instructions | MI Mode, MI Perspective, Eyes | Number of MITS and Intervention Duration | Trials per MITS and Total Trials |
|-----------------------------|-------------------------------------------------------------|---------------------------------------------------|-----------------------|-----------------------|-----------------------------------|-------------------------------------|-------------------------------|----------------------------------|----------------------------------|
| Dalali-Sequeira             | N.R. MI familiarization: N.R. MI check: Participants signaled initiation and end of trials by tapping their index finger of the resting (less affected) arm on supporting table | CG: Day 1: Manipulation of a keyboard of a personal computer with less affected hand to play a game called ‘Tetris’ Day 2: PP of aiming task | Session: N.R. Order: PP before MIT | Location: Laboratory Position: Seating position on a height adjustable chair, hands relaxed and supported on table | Supervision: Yes Instructions: Live | Mode: N.R. Perspective: Internal Eyes: Closed | Total: 2 1 MITS lasting app. 34 min Duration: 2 days | MITS: Two sets of 5 × 10 mental trials with app. 10 min between sets Total trials: 100 |
| de Sousa Fortes             | N.R. MI experience: N.R. MI familiarization: N.R. MI check: N.R. | CG: Watching videos of advertisements related to sports equipment (e.g., cap, t-shirt, and shorts). No communication allowed during sessions | Session: N.R. Order: PP before MIT | Location: Quiet environment in gym, close to court. Participants wore competition outfits Position: N.R. | Supervision: Yes Instructions: N.R. | Mode: N.R. Perspective: Internal Eyes: N.R. | Total: 26 Three MITS/wk lasting app. 10 min Duration: 8 weeks | MITS: N.R. Total trials: N.R. |
| de Sousa Fortes             | N.R. MI experience: Yes MI familiarization: N.R. MI check: Participants were asked to provide information about the technique adopted and the magnitude of the perceived emotions Timer to control for MIT trials | CG: Watching videos about the history of the Olympics | Session: N.R. probably individual Order: PP before MIT | Location: Quiet environment close to the tennis court, participants wore competition outfits Position: N.R. | Supervision: Yes Instructions: N.R. | Mode: N.R. Perspective: Internal Eyes: N.R. | Total: 26 Three MITS/wk lasting app. 10 min Duration: 8 weeks | MITS: N.R. Total trials: N.R. |
| Douassoulin                 | N.R. MI familiarization: N.R. MI check: N.R. | CG: Modeling condition: Watching a video recording of ball throwing performance while running being performed by an expert CE2: PP of ball throwing performance while running | Session: N.R. Order: PP before MIT | Location: N.R. Position: N.R. | Supervision: N.R. Instructions: N.R. | Mode: N.R. Perspective: N.R. Eyes: N.R. | Total: 6 MITG Duration: N.R. | MITS: Sixty mental trials Total trials: 60 |

**Table 3. Cont.**
| First Author | MI Experience, MI Familiarization and MI Manipulation Check | PETTLEP Approach and MI Intervention Description | Control Interventions | MIT Session and Order | Location and Position during MIT | MIT Supervision and MI Instructions | MI Mode, MI Perspective, Eyes | Number of MITS and Intervention Duration | Trials per MITS and Total Trials |
|--------------|-------------------------------------------------------------|-------------------------------------------------|----------------------|----------------------|-------------------------------|-----------------------------------|-------------------------------|---------------------------------|---------------------------------|
| Fekih_a      | MI experience: Yes, MI familiarization: N.R., MI check: Chronometer for each athlete to control the duration of mental trials of the 10 tennis service | PETTLEP: N.R., probably partially MITG: (a) PP: Watching videos of tennis players performing technical gestures (b) Cognitive imagery: athletes were asked to imagine themselves while performing tennis service • Imagine a first-person situation • Imagine the task performed at speeds close to reality, with actions interrupted by an interval of about ten seconds • Imagine positive situations during a competition • Reproduce emotions similar to those felt during competitions | CG: PP + watching videos about the history of the Olympic Games | Session: Individual Order: CP before MIT | Location: Quiet environment near the tennis court, participants wore competition outfits | Supervision: Yes Instructions: N.R. | Mode: N.R. Perspective: Not clear 'first person situation' Eyes: N.R. | Total: 12 Three MITS/wk lasting 10 min = app. 120 min Duration: 4 weeks | MITS: 10 mental trials Total trials: 120 |
| Fekih_b      | MI experience: N.R., MI familiarization: N.R., MI check: Chronometer for each athlete to control the duration of mental trials of the 10 tennis service | PETTLEP: N.R., MITG: (a) PP: Watching videos of tennis players performing technical gestures (c) MIT mode visual • Think of a situation in first person • Imagine moving quickly to the next striking point • Imagine changing direction in different axes • Imagine firm solid supports to the ground and quickly leaving these supports to start in motion • Imagine performing powerful and precise services (d) MIT mode kinesthetic: Participants experimented and felt sensations that were evoked in a real situation of PP; participants, could speak softly or mimic the movement and use techniques of body simulation of movement • Informal discussions with experimenter about usefulness and effects of imagery | CG: PP + watching videos about the history of the Olympic Games | Session: N.R. Order: CP before MIT | Location: Quiet environment near the tennis court, participants wore competition outfits | Supervision: Yes Instructions: N.R. | Mode: Visual before kinesthetic Perspective: External before internal Eyes: N.R. | Total: 12 Three MITS/wk lasting 15 min = app. 180 min Duration: 4 weeks | MITS: Ten mental trials Total trials: 120 |
| First Author | MI Experience, MI Familiarization and MI Manipulation Check | PETTLEP Approach and MI Intervention Description | Control Interventions | MIT Session and Order | Location and Position during MIT | MIT Supervision and MI Instructions | MI Mode, MI Perspective, Eyes | Number of MITS and Intervention Duration | Trials per MITS and Total Trials |
|--------------|-------------------------------------------------------------|------------------------------------------------|-----------------------|----------------------|----------------------------------|--------------------------------------|-------------------------------|---------------------------------|---------------------------------|
| Hemayattalab | MI experience: N.R. MI familiarization: Yes, 1 MI training session including internal kinesthetic imagery MI check: After pretreatment and before intervention a MI training session including internal kinesthetic imagery and N.R. | PETTLEP: N.R. MITG: | Two different control groups: PP: M.I physical practice of basketball free throw for 24 MITS CG: no training at all | Session: N.R. Order: Only MIT or PP in 1 TS | Location: N.R. | Supervision: N.R. | Mode: Kinesthetic Perspective: Internal Eyes: N.R. | Total: 24 Duration: 30 min per MITS | MITS: 30 Total trials: MIT only: 720 PP followed by MIT: 500 MIT followed by PP: 360 |
| Kanthack     | MI experience: No previous MIT experience MI familiarization: N.R. MI check: Three open-ended questions | PETTLEP: N.R. MITG: | Watching a 1 min video of great players from the NBA scoring free-throws | Session: N.R. Order: MIT before PP | Location: Room off the basketball court, less than 20 m from the basket | Supervision: Yes | Mode: N.R. Perspective: N.R. Eyes: Closed | Total: 5 Duration: 3 min | MITS: N.R. Total trials: N.R. |
| Mohammadshasani | MI experience: N.R. MI familiarization: N.R. MI check: N.R. | PETTLEP: N.R. MITG: | PP1: Participants physically practiced the kata skill with systematically increasing contextual interference for five sessions and five attempts each session in groups PP2: Participants practiced the kata skill for five sessions and five attempts each session in groups | Session: N.R. probably group Order: MIT before PP | Location: N.R. | Supervision: Yes | Mode: N.R. Perspective: N.R. Eyes: Closed | Total: 5 Duration: N.R. | MITS: 5 Total trials: 25 |

Table 3. Cont.
Table 3. Cont.

| First Author | MI Experience, MI Familiarization and MI Manipulation Check | PETTLEP Approach and MI Intervention Description | Control Interventions | MIT Session and Order | Location and Position during MIT | MIT Supervision and MI Instructions | MI Mode, MI Perspective, Eyes | Number of MITS and Intervention Duration | Trials per MITS and Total Trials |
|--------------|----------------------------------------------------------|------------------------------------------------|-----------------------|-----------------------|--------------------------------|-----------------------------------|-------------------------------|--------------------------------|----------------------------------------|
| Norsuzi      | MI experience: N.R. MI Familiarization: N.R. MI check: N.R. and 2 opened-ended questions | PETTLEP: Yes. If participants wished to modify their imagery activity, such modifications were incorporated in subsequent imagery sessions (learning). Two different MIT groups. | PP: Participants practiced physically only | Session: Group Order: MIT before PP | Location: Football field Position: N.R. | Supervision: Yes, once a week Instructions: Verbal, audio | Mode: N.R. Perspective: N.R. Eyes: N.R. | Total: 12 5 MITS/wk lasting 10 × 2 min = 20 min Duration: 4 weeks | MITS: N.R. Total trials: N.R. |
| Perreta      | MI experience: N. R. MI Familiarization: Explanation until participants understood MIT and MIT for 4 trials MI check: Participants were asked how they actually imaged the task after familiarization and after each practice day | PETTLEP: N.R. MITG: (a) Mit with seeing and feeling, opening the hat and hitting the string themselves (b) PP of opening the hat and hitting the string | PP: Participants were opening the hat and hitting the string | Session: Individual Order: MIT before PP | Location: N.R. Position: N.R. | Supervision: N.R. Instructions: Live, acoustic | Mode: Visual and kinesthetic Perspective: N.R. Eyes: Closed | Total: 5 Duration: 5 days | MITS: 25 × 4; 4 mental trials Total trials: 110 |
| Quinton      | MI experience: N.R. MI Familiarization: Participants were given a stimulus-response training in the first session to help them be more aware of what they were seeing and feeling during their imagination MI check: N.R. | PETTLEP: Yes, partially Participants were dressed in soccer kit, foot placed on the ball, usual environment same gymnasium, changing session content MITG: (a) PP of soccer performance task dribbling and passing MIT of soccer performance task: dribbling and passing, MITG: were designed as a layered PETTLEP approach, with more elements introduced as the intervention progressed. | CG: PP + participants received sport-specific nutritional advice | Session: N.R. Order: PP before MIT | Location: Gymnasium Position: Standing, foot placed on ball, dressed in soccer kit | Supervision: N.R. Instructions: Live, acoustic | Mode: according to personal preferences Perspective: according to personal preferences Eyes: according to personal preferences | Total: 10 Two MITS/wk Duration: 5 weeks | MITS: N.R. Total trials: N.R. |
| Scavoni      | MI experience: N.R. MI Familiarization: Imagery training orientation: instruction on the meaning of MIT and explained how to use MIT for motor task enhancement Participants were given MIT activities to acquaint them with MIT procedures. MI check: N.R. | PETTLEP: N.R. MITG: (a) PP of 20 trials on peg board or pursuit rotor game MIT of 20 mental trials on peg board or pursuit rotor game | Two control groups CG1: Participants physically practiced 20 trials on peg board or pursuit rotor game + mode different geometric shapes CG2: no PP or MIT at any time, spent same amount of time with researcher | Session: N.R. Order: N. R. | Location: N. R. Position: N. R. | Supervision: N.R. Instructions: N.R. | Mode: N.R. Perspective: N.R. Eyes: N.R. | Total: 8 Five days/wk until prescribed number of sessions were completed Duration: 8 MITS, total 164 min | MITS: 20 Total trials: 160 |
| Seif-Barghi  | MI experience: Little experience MI Familiarization: Introduction session for defining and explanation of sport imagery, its application in soccer Participants completed exercises to develop external and internal imagery, real-time speeds of images and create images applying all senses. MI check: Feedback sessions at the end of each MITS Weekly interviews instantly before MIT: Randomly asked questions about training course | PETTLEP: N.R. MITG: (a) MIT with specific and general cognitive elements: • Participants were reminded to focus on foot movements, angles, velocity, point of the ball stroke, kick force and following the ball toward the recipient CG: N.R. × neutral task group + × normal training and match activities | CG: N. R. probably group Order: N. R. | Location: N.R. | Supervision: Yes Instructions: N.R. | Mode: N.R. Perspective: N.R. Eyes: Participants were recommended to start MIT with eyes closed. With increasing experience they could continue with eyes either open or closed | Total: 8 One MITS/wk lasting 10–15 min = 150 min. MIT should be used on daily basis Duration: 8 weeks | MITS: N.R. Total trials: N.R. |
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### Table 3. Cont.

| First Author | PETTLEP Approach and MI Manipulation Check | Control Interventions | MIT Session and Order | MIT Supervision and MI Instructions | MI Modes, MI Perspective, Eyes | Interventions Duration | MITs and Total Trials |
|--------------|-------------------------------------------|-----------------------|-----------------------|-------------------------------------|-------------------------------|------------------------|----------------------|
| Simonsmeier  | PETTLEP: **Yes** MI: (a) MI—participants used kinesthetic cues and imagined the movement at different speeds (see time delay compared to physical execution of the task and two times in real-time); (b) normal PP training | CG: normal PP training | Session: N.R. probably individual | Location: Regular training gym wearing regular clothes | Supervision: N.R., probably unsupervised | N.R. | MITs: Three mental trials Total trials: 48 |
|              | MITG: (a) MI—participants used kinesthetic cues and imagined the movement at different speeds (see time delay compared to physical execution of the task and two times in real-time); (b) normal PP training |                          | N.R. | N.R. | Eyes: Closed | N.R. | 16 | |
| Sitzgberg    | PETTLEP: N.R. MI: (a) PP of the underhand baseball throw | Two different PP groups were participants practiced an underhand throw with the non-preferred hand: | Session: N.R. Order: MIT before PP | Location: N.R. | Supervision: N.R. | N.R. | N.R. | Total: 1 Duration: 1 day MITs: N.R. Total trials: N.R. |
|              | (b) MI—participants used kinesthetic cues and imagined the movement at different speeds (see time delay compared to physical execution of the task and two times in real-time); (b) normal PP training |                          | N.R. | N.R. | Eyes: Closed | N.R. | 240 | Total trials: 240 |
| Takazono     | PETTLEP: N.R. MI: (a) MIT of 180 trials of the experimental task: holding a plastic block with the index and thumb fingers and inserting it into a support PP of 60 physical trials of the task | Two different control groups PP: 240 physical trials of the experimental task CG: 180 mental trials of another visual rotation + 40 physical trials of the experimental task | Session: N.R., probably individual Order: MIT before PP | Location: N.R. Position: Seated in a chair in front of a table, starting with the palm of the right hand downwards resting on the starting point | Supervision: N.R., probably yes | Instructions: Live, acoustic | N.R., probably kinesthetic Perspective: N.R., probably yes Eyes: N.R. | Total: 5 Duration: 5 MITS/next week MITs: 50 Total trials: N.R., probably 250 |
| Wilson       | PETTLEP: N.R. MI: software-based MIT Dynamic stimulus materials were presented in increasing complexity: (a) visual imagery exercises involving predictive timing relaxation protocol and mental preparation; (c) visual modeling of fundamental motor skills = watching videos; (d) MI of skills from external perspective; (e) MI of skills from internal perspective | Two different control groups PP: traditional perceptual-motor training of the experimental task NP: walk-list control | Session: Individual Order: MIT before PP | Location: N.R., probably sitting in front of a computer screen | Supervision: N.R. | Instructions: Live | N.R. | Total: 5 1 MITS/next week MITs: 50 Total trials: N.R., probably 250 |

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**Legend:** CG = control group; FOS = finger opposition sequence; min = minute; MI = motor imagery; MIT = motor imagery training; MITG = motor imagery training group; MITS = motor imagery training session; NP = no practice; N.R. = not reported; PETTLEP = acronym for physical, environment, timing, task, learning, emotion, perspective; PP = physical practice; sec = seconds; TS = training session; WBD = weight bearing distribution; wk = week.
2.4. Data Analysis

Primary Outcomes

Data were analyzed using the Review Manager 5 software [95] and were pooled for meta-analysis when we considered studies to be sufficiently similar in terms of participants, interventions, comparisons, and outcomes. The weighted standardized mean differences (SMD) and their corresponding 95% confidence intervals were extracted from the individual studies and were visualized in forest plots. The analysis included the main outcome measure for motor function as specified by the original study investigator. For the meta-analysis, it was specified to analyze the results using the random-effects model with the inverse-variance method due to likely heterogeneity between studies. To test for heterogeneity, the Q-test with its corresponding degrees of freedom (df) and p-value for an alpha level of 5% was used. Higgins’ I² statistic [96] was chosen as a measure of heterogeneity, indicating how much of the total observed variance can be explained by the true variation between studies and to measure the actual dispersion of variance [78]. Further analyses were planned if data were sufficient for a sensitivity analysis or an analysis of secondary outcomes.

3. Results

Our searches identified 7238 references. After removal of duplicates, we screened titles and abstracts, and identified 79 potentially eligible references for full-text reading. All available abstracts were in English. After reading the full texts of the obtained references, we selected 22 studies for inclusion in this review and meta-analysis. The procedure of the search is depicted in the PRISMA study flowchart (Figure 1).

Two reviewers (VZ and CSA) separately examined whether the relevant studies fitted the population, intervention, comparison, outcome and study design (PICOS) strategy of our research question. Two authors were contacted for missing data. Disagreement of selected full texts was resolved with mutual consent. The kappa statistic after full text screening was 0.81. The reviewers could not agree on four studies and therefore a third reviewer (FB) was consulted to decide on the studies’ eligibility resulting in two studies that were included and two that were excluded.

3.1. Characteristics of the Included Studies

All 22 studies included in this review, identified as randomized controlled trials, are listed with their characteristics in Table 2. Included studies were conducted in ten different countries with six studies coming from Brazil and were published between 1995 and 2021 covering a period of 26 years. The sample sizes ranged from 18 to 136 participants with a total of 934 and a mean age ranging from nine to 18 years. Overall, the studies with stated gender distribution included 40.7% female and 59.3% male children or adolescents. For six studies, a gender distribution was not reported. Two studies included mentally retarded adolescents [83,86], one study included children with motor coordination difficulties [94] and one study children with mild mental disabilities [89]. The majority of studies included healthy pupils with 10 studies focusing on children practicing sports, e.g., tennis, gymnastic, basketball, and dance. The motor tasks under investigation varied greatly. Eight out of 22 studies focused on the upper extremity with a throwing task (e.g., basketball, tennis, baseball). Soccer passing performance was evaluated in three studies [86,88,90] and four studies focused on whole body movements (e.g., kata skill, the cast to hand-stand on bars, vertical jumps, élévée movement (‘... a core dance movement during which the dancer rises up while bearing weight on the fore-feet’. Thomas (2003) from Abraham, Dunsky, Dickstein, [73], page 2)) [73,76,85,91].

Study descriptions revealed inhomogeneity with respect to the intervention setting which was not described in three reports. Almost all studies performed a pre- and posttest for the motor task under investigation that was evaluated by a blinded assessor, judge or coach in five studies only. Fifteen of the 22 included studies did not report on blinding. Furthermore, only two studies performed a follow up retention test after ten or 28 days [74,83].
A participant flow chart was provided in two out of 22 studies [78,90] and dropouts were reported in four studies [73,77,90,91].

3.2. Characteristics of Included Motor Imagery Training Interventions

Table 3 provides an overview about the trial-related characteristics of the studies included. All studies used MIT alone or associated with action observation (AO) or PP in the experimental groups. Three studies applied the PETTLEP approach [76,78,86]. The PETTLEP model of motor imagery provides guidance for the effective delivery of such interventions [93]. According to this model, seven key components are to be considered when developing an intervention (Physical, Environment, Task, Timing, Learning, Emotion, and Perspective).

Before starting an MIT, participant’s experience with MIT was evaluated in seven out of 22 studies. A MI familiarization or introduction session before MIT was reported in seven studies and a manipulation check during or after the MIT intervention to ensure participants’ engagement in MIT was described in 14 studies with a focus on open-ended questions regarding the MIT content. Further important MIT session elements can be described as follows:

- MIT as individual one-to-one session or group session was reported in four studies only (2 × group session, 2 × one-to-one session),
- A combination of MIT with PP was reported in 16 studies with an equal distribution whether MIT was performed before or after PP,
- Nine studies reported the location of the MIT and eight studies reported the position of the participant during MIT,
- Supervision during MIT session was reported and provided in eleven studies,
- Used instructions to guide the participants in their MIT was stated in ten studies using mainly live and acoustic instructions,
- The MI mode was described in seven studies reporting both visual and kinesthetic modes, which is similar to MI perspective. MI perspectives (internal, external) were described in nine studies. Both MIT session elements, mode and perspective, were used separately or in combination,
- Authors reported in ten studies whether participants had open or closed eyes during MIT,
- Surprisingly, participants were evaluated regarding their MI ability in twelve studies only. Authors used different standardized (MIQ, MIQ-R, MIQ-RS, MIQ-C) or customized MI ability questionnaires or EMG recordings,
- Temporal parameters regarding MIT sessions can be summarized as follows: Number of total MIT sessions varied between one and 24 with an intervention duration between one day and eight weeks. One MIT session took about three to 34 min, while between three and 80 MI trials were performed, summing up to 720 MI trials over one MIT intervention period.

Overall, the reporting of the MIT elements and temporal parameters was incomplete, which reduces the chance of a high replicability or successful transfer to the routine use of MIT in children and adolescents in sports and health care.

3.3. Risk of Bias

The results of the RoB evaluation (low, high, some concerns) regarding the six domains (randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome, selection of the reported results, overall bias) are depicted in Figures 2 and 3. The RoB evaluation was exclusively or predominantly categorized as low risk in the domains deviations from the intended interventions, missing outcome data and measurement of the outcome. Moreover, evaluation of the studies prevailingly revealed some concerns for Randomization process and Selection of the reported result. Only two studies were of high risk for overall bias [80,85]. A problematic baseline imbalance was found for the study of Doussoulin et al. (2011), whereas Mohammadhasani et al. (2017)
revealed a likely influence on the assessments by knowledge of the intervention. None of the studies was judged low risk overall. We identified no information associated with other potential sources of bias.

| Study ID          | D1 | D2 | D3 | D4 | D5 | Overall |
|-------------------|----|----|----|----|----|---------|
| Abraham 2017      |    |    |    |    |    | ![Low risk](green) |
| Asa 2014          | ![Green](green) |    |    | ![Green](green) | ![Green](green) | ![Low risk](green) |
| Bahmani 2021      | ![Green](green) | ![Green](green) | ![Green](green) | ![Green](green) | ![Low risk](green) |
| Battaglia 2014    | ![Green](green) | ![Green](green) | ![Green](green) | ![Green](green) | ![Low risk](green) |
| Cabral-Sequeira 2016 | ![Green](green) | ![Green](green) | ![Green](green) | ![Green](green) | ![Low risk](green) |
| de Sousa Fortes 2019 | ![Green](green) | ![Green](green) | ![Green](green) | ![Green](green) | ![Low risk](green) |
| de Sousa Fortes 2018 | ![Green](green) | ![Green](green) | ![Green](green) | ![Green](green) | ![Low risk](green) |
| Doussoulin 2011   | ![Red](red) | ![Green](green) | ![Green](green) | ![Green](green) | ![Low risk](green) |
| Fekih 2020a       | ![Green](green) | ![Green](green) | ![Green](green) | ![Green](green) | ![Low risk](green) |
| Fekih 2020b       | ![Green](green) | ![Green](green) | ![Green](green) | ![Green](green) | ![Low risk](green) |
| Hemayattalab 2009 | ![Green](green) | ![Green](green) | ![Green](green) | ![Green](green) | ![Low risk](green) |
| Kanthack 2014     | ![Green](green) | ![Green](green) | ![Green](green) | ![Green](green) | ![Low risk](green) |
| Mohammadhasani 2017 | ![Green](green) | ![Green](green) | ![Red](red) | ![Green](green) | ![Low risk](green) |
| Norouzi 2019      | ![Green](green) | ![Green](green) | ![Green](green) | ![Green](green) | ![Low risk](green) |
| Porretta 1995     | ![Green](green) | ![Green](green) | ![Green](green) | ![Green](green) | ![Low risk](green) |
| Quinton 2014      | ![Green](green) | ![Green](green) | ![Green](green) | ![Green](green) | ![Low risk](green) |
| Screw 1997        | ![Green](green) | ![Green](green) | ![Green](green) | ![Green](green) | ![Low risk](green) |
| Seif-Barghi 2012  | ![Green](green) | ![Green](green) | ![Green](green) | ![Green](green) | ![Low risk](green) |
| Simonsmeier 2017  | ![Green](green) | ![Green](green) | ![Green](green) | ![Green](green) | ![Low risk](green) |
| Surburg 1995      | ![Green](green) | ![Green](green) | ![Green](green) | ![Green](green) | ![Low risk](green) |
| Takazono 2018     | ![Green](green) | ![Green](green) | ![Green](green) | ![Green](green) | ![Low risk](green) |
| Wilson 2002       | ![Green](green) | ![Green](green) | ![Green](green) | ![Green](green) | ![Low risk](green) |

**Figure 2.** Risk of bias rating for each study. Legend: D1 = Randomization process, D2 = deviations from intended interventions, D3 = missing outcome data, D4 = measurement of the outcome, D5 = selection of the reported results.

**Figure 3.** Risk of bias rating within domains Domain 1 to Domain 5 as percentage of all studies. Legend: D1 = Randomization process, D2 = deviations from intended interventions, D3 = missing outcome data, D4 = measurement of the outcome, D5 = selection of the reported results.
3.4. Primary Outcomes—Effect of Motor Imagery Training Interventions

An overview of the findings of every included study in our review is provided in Table 2, indicating a general positive effect of MIT compared to a control group. However, the combination of MIT and PP was more successful than MIT only. Only three out of 22 studies reported no significant differences between MIT group (MITG) compared to a control group [73,84,88]. Due to the diversity of the studies’ methodologies regarding intervention protocols, participants and outcome parameters, only two out of 22 included studies could be considered for the meta-analysis regarding the effect of MIT on motor learning [78,82]. Both studies with 66 participants in total investigated the effect of MIT versus no intervention (watching videos) in young tennis players on the tennis service performance. Tennis service performance was the product calculated from measurements of the ball stroke velocity and accuracy.

For the evaluation of the effect of MIT on the accuracy (Figure 4), the weighted SMD was 1.05 (95% CI; 0.53 to 1.57; Z = 3.96; p < 0.0001). Heterogeneity was very low (I² = 0.00%; Q = 0.23; df = 1, p = 0.45). The variance of the distribution of the effect sizes in this sample of the two studies was T² = 0.00.

![Figure 4. Effect of motor imagery training on tennis service accuracy versus watching videos as control intervention.](image)

For the evaluation of the effect of MIT on tennis stroke velocity (Figure 5), the weighted SMD was 0.83 (95% CI; 0.33 to 134; Z = 3.22; p = 0.001). Heterogeneity was very low (I² = 0.00%; Q = 0.23; df = 1, p = 0.63). The variance of the distribution of the effect sizes in this sample of the two studies was T² = 0.00.

![Figure 5. Effect of motor imagery on tennis stroke velocity versus watching videos as control intervention.](image)

For the evaluation of the effect of MIT on the tennis service performance (the product of accuracy and speed velocity, Figure 6), the weighted SMD was 1.87 (95% CI; 0.64 to 3.10; Z = 2.99; p = 0.003). Heterogeneity was higher for this combined parameter (I² = 0.74%; Q = 3.86; df = 1, p = 0.05). The variance of the distribution of the effect sizes in this sample of the two studies was T² = 0.59.

![Figure 6. Effect of motor imagery training on tennis service performance versus watching videos as control intervention.](image)
3.5. GRADE Evidence Profile Table

After the evidence was summarized, small sample sizes, the width and overlap of confidence intervals, heterogeneity and generalizability were taken into consideration. Two reviewers (ZS and FB) created a GRADE evidence profile table (Table 4) to present key information [97]. Both examiners cross-checked each other’s assessments. Disagreements were solved by discussion.

Table 4. Evidence profile table.

| No. of Studies | Study Design | Risk of Bias | Inconsistency | Indirectness | Imprecision | Other Considerations | MI | Control | Relative (95% CI) | Absolute (95% CI) | Quality of Evidence | Importance |
|----------------|--------------|--------------|---------------|--------------|-------------|----------------------|----|---------|-----------------|-----------------|-------------------|------------|
|                |              |              |               |              |             |                      |    |         |                  |                 |                   |            |
| Accuracy (Follow-up range 3 to 4 weeks) | 2 | RCT | serious <sup>a</sup> | not serious | not serious <sup>b</sup> | serious <sup>c</sup> | none | 32 | 34 | - | SMD 1.05 (0.53, 1.57) | ++ + + | LOW | not important |
| Ball stroke speed (Follow-up range 3 to 4 weeks) | 2 | RCT | serious <sup>a</sup> | not serious | not serious <sup>b</sup> | serious <sup>c</sup> | none | 32 | 34 | - | SMD 0.83 (0.33, 1.34) | ++ + + | LOW | not important |
| Tennis service performance (Follow-up range 3 to 4 weeks) | 2 | RCT | serious <sup>a</sup> | serious <sup>d</sup> | not serious <sup>b</sup> | serious <sup>c</sup> | none | 32 | 34 | - | SMD 1.87 (0.64, 3.10) | ⚫⚫⚫⚫ | VERY LOW | not important |

RCT = randomized controlled trial, SMD = standard mean difference, CI = confidence interval, <sup>a</sup> = some concerns regarding randomization process and selection of the reported results, <sup>b</sup> = indirectness of population, only male tennis players investigated, <sup>c</sup> = serious imprecision (i.e., total number of participants <300 for each outcome), <sup>d</sup> = significant statistical heterogeneity.

3.6. Further Analyses

Subgroups for secondary analyzes could not be defined due to the lack of standardized evaluation at every measurement event (e.g., imagery ability was not always assessed before and at the end of an MIT). Imagery ability was mainly used as a screening criterion or to distinguish between high-level and low-level images. Furthermore, a sensitivity analysis (e.g., does not include a study with a high RoB or studies that included videos as MIT preparation) was not conducted because only two studies were included in the primary meta-analysis.

4. Discussion

This systematic review aimed to assess the effects of a MIT with or without PP on motor learning of various motor tasks to be trained, compared with different measures in the control condition. Physical practice or watching videos of a topic not related to MIT were the most applied interventions in the control groups. The number of included studies was 22, which involved 934 children and adolescents in total. None of the included studies reported adverse events. Only two studies could be included in a meta-analysis that revealed a high training effect with a low certainty of the evidence for the outcomes.

4.1. Motor Imagery Training Interventions

MIT use varied among intervention groups, with a majority of them using MIT in combination with PP. Some authors additionally used videos to prepare the mental simulation and illustrate the task to be imagined [76,84,94]. This might be perceived as a significant deviation from the other studies, as it may already correspond to a combined approach of AO and MI (AOMI). Similar to MI, AO also requires the activation of brain areas that are involved in generating body movements [98,99]. There are a large number of clinical trials that have investigated the use of either MI or AO alone in neurorehabilitation, but studies on the combination are still quite rare, especially in children or adolescents. Only recently; however, two studies reported on the positive effect of AOMI in children.
with DCD [100,101]. Scott et al. (2020) reported that effect also for typically developing children without DCD and found a significant enhancement in the outcome measure compared to the usage of MI alone [101].

Surprisingly, the PETTLEP approach was used in only three of the studies for an enhancement of the MI intervention [76,86,88]. In this respect, there was some inhomogeneity between the studies in terms of intervention design. Holmes and Collins (2001) developed the PETTLEP approach as a seven-point evidence-based checklist [102]. The authors’ aim was to enhance the efficacy of MIT interventions by using a systematic approach for their design, research and reporting. So far, the promising potential of the PETTLEP model was widely neglected in the MIT interventions in the included studies.

Temporal parameters reporting (e.g., regarding MIT duration and MI trials per session) was sparse. However, if reported, the parameters were comparable with MIT reviews from other disciplines [70,103]. Focusing on children, some of the MIT sessions (3 min) and MIT interventions might be shorter (one to several days).

In our review, five studies included children starting at the age of nine and children with different levels of sports proficiency. Caeyenberghs et al. (2009) investigated the development of movement imagery over the childhood between the age of seven and twelve [104]. Authors found a relationship between MI and a motor skill becoming stronger with age. Furthermore, Mulder et al. (2007) also highlighted a possible relationship between level of physical activities and MI capacity and MI perspective selection [105]. Therefore, the design of MIT parameters (e.g., internal or external MI perspective), visual or kinesthetic mode, and the MI familiarization might differ for different age groups and should be considered for further research.

Unexpectedly, participants’ MI ability was not evaluated systematically in all 22 studies. MI is a multidimensional construct and the ability to create and manipulate a mental image is an essential criterion for an efficient MIT intervention. It is, thus, advised to use several assessments to evaluate the quality of participants’ MI ability [106,107]. Furthermore, information whether participants are novices to the MIT technique or already professional users should be evaluated and reported.

4.2. Methodology of the Included Studies

The quality of description of the study design and intervention are essential aspects in the evaluation process of RCTs. The CONSORT (2010) guideline was introduced to improve the reporting of RCTs [108]. For the included studies in this review, we found that the CONSORT recommendations were not fully implemented by any report, in part of course because the studies were conducted before the guideline was published. A flow diagram for instance that displays the progress of all participants through the trial as recommended was only provided in two reports [78,90]. The partially inadequate description of the studies according to CONSORT influenced the risk of bias evaluation due to missing information. For domain 1, which concerns the randomization process, the lack of information on the question whether the allocation sequence was concealed until participants were enrolled and assigned to intervention (RoB 1.2) could automatically only result in some concerns or an even lower judgment. Insufficient information about the awareness of the assessors regarding the intervention received for the RoB rating process in domain 4 also led to some concerns. A detailed study protocol would have been beneficial.

The TIDieR checklist was developed to improve the quality of the intervention description and thus its replicability [109]. It is an extension of the CONSORT 2010 statement with the aim of providing a practical tool for authors, reviewers and readers. None of the studies followed or complied with the TIDieR guideline for reporting an intervention. Additionally, in terms of methodological quality and interventional approach, it is worth noting that no study included a follow-up measurement to evaluate a potential long-term effect.
4.3. Strengths and Limitations

The underlying systematic review process of this report may have been influenced by the approach of searching English-language databases only. However, the language-based confounding factor is probably mitigated by the fact the main literature sources are English-speaking peer-reviewed journals. The composition of the search strategy was based on recently published Cochrane reviews and other review protocols in the field of MI and mental practice [31,66], and the database searches itself were conducted by a professional research librarian providing a comprehensive search and detailed knowledge of different databases with a medical focus. The systematic searches were conducted in seven databases and one trial registry covering different disciplines, for example, sports, psychology and populations (e.g., healthy children, children with a high proficiency in a sport or with a coordination disorder). The inclusion of only published, peer-reviewed data was due to the attempt to make a truly reliable statement about the effectiveness of MIT.

A further strength is that we were able to include studies from different parts of the world and thus reports on trials conducted in different cultural settings. Included studies represent children from different countries and continents (North and South America, the Middle East, Europe and Australia) with an emphasis on South America.

We performed important and recommended study appraisals and classifications (e.g., RoB, GRADE), to provide the reader a comprehensive evidence evaluation. Additionally, we could pool results from two studies from Sports focusing on tennis stroke performance in a meta-analysis revealing a high MIT effect. Here; however, the results of $I^2$ should be interpreted with caution. Due to the small number of pooled studies, $I^2$ might be biased and under- or overestimate the true level of heterogeneity [110].

Finally, for the interested clinician and researcher, we extracted and described conducted MIT interventions into detail and included important MIT elements and temporal parameters.

4.4. Implications for Further Research

The promising results of our systematic review encourage further and intensive research in the field of MIT in children and adolescents. (1) We recommend comprehensive investigations regarding MIT session elements and their temporal parameters in relation to age. (2) Further research should include a routinely evaluation of participants’ MI ability quality with standardized assessment tools. (3) A MI introduction session at the beginning of the MIT intervention is advised to ensure similar level of MI knowledge of all participants. (4) To evaluate participants’ engagement in MIT, a MI check on a regular basis should be integrated. Based on our results, open-ended questions might be helpful. (5) Longer follow-up periods to evaluate MIT’ retention would be desired. (6) Finally, a detailed reporting based on the CONSORT, PETTLEP and TIDieR checklists is highly recommended to ensure replicability and transfer to clinical use of MIT in children and adolescents.

5. Conclusions

With regard to children and adolescents, the method of motor imagery training has not received much attention in research in the recent past. Only a few high quality RCTs exist and reporting on motor imagery training elements and temporal parameters should be improved. However, there are indications that motor imagery training might have a high potential for healthy and impaired children and adolescents if combined with physical practice to enhance motor learning in sports and in general. With regard to the treatment of children with neurological disorders using MI, a further three ongoing studies registered on clinicaltrials.org (accessed on 15 April 2021) have been identified, and will hopefully provide new results in this field. There is also a growing body of literature concerning the effect of MI in children and adolescents in the treatment of psychological disorders such as stress or anxiety, which; however, was not within the scope of this review.
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