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The use of motor imagery in locomotor rehabilitation and training: a systematic review and meta-analysis

Eva Tamburro

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FACULTE DE MEDECINE MONTPELLIER-NIMES

THESE

Pour obtenir le titre de
DOCTEUR EN MEDECINE

Présentée et soutenue publiquement

Par

Eva TAMBURRO

Le 15.10.2020

TITRE

The use of motor imagery in locomotor rehabilitation and training:
a systematic review and meta-analysis

Directeur de thèse : Monsieur le Docteur Alexis HOMS

JURY

Président : Madame la Professeure Isabelle LAFFONT

1^{er} assesseur : Monsieur le Professeur Arnaud DUPEYRON

2^{ème} assesseur : Monsieur le Professeur Bertrand COULET

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2) Préambule

L'imagerie motrice (IM) est la représentation mentale d'une action sans aucun mouvement corporel concomitant (1). L'IM est basée sur le principe d'équivalence neuro-fonctionnelle (2,3) selon lequel penser à une action équivaut à l'exécuter. On peut distinguer deux modalités d'imagerie motrice.

Premièrement, l'IM explicite consiste à visualiser un mouvement ou une action spécifique, soit du point de vue de la première personne (imagerie kinesthésique) (4), soit du point de vue de la troisième personne (imagerie visuelle) (5). Il existe des questionnaires pour évaluer la capacité de la personne à « imager » et donc son profil sensoriel dominant: Kinesthetic and Visual Imagery Questionnaire (KVIQ), Movement Imagery Questionnaire (MIQ), Vividness of Movement Imagery Questionnaire (VMIQ) (6–8).

Deuxièmement, les tâches de jugement de latéralité (LJT) font référence à une méthode implicite d'IM, dans laquelle les sujets doivent reconnaître la latéralité des parties du corps par des exercices de rotation mentale et de visualisation (9). Malgré cette distinction, les études d'imagerie cérébrale (10,11) indiquent que des réseaux cérébraux comparables sont activés par l'IM explicite et implicite (12,13).

Au niveau neuro-anatomique et neurophysiologique, des aires motrices corticales et sous-corticales similaires sont impliquées au cours d'une pratique mentale et physique (14) (*figure 1*). Celles-ci recrutent les aires frontales (gyri inférieurs, gyrus pré central et moyen, la partie antérieure de l'insula et les aires motrices supplémentaires), pariétales (lobes supérieurs et inférieurs), les ganglions de la base, et le cervelet (15,16). L'activation de l'aire motrice primaire au cours de l'IM est quant à elle controversée (15).

En plus des études neurophysiologiques, la neuroplasticité induite par l'IM est observée surtout dans les domaines moteur et sensoriel, mais aussi au niveau spinal. Par conséquent, elle pourrait être utilisée comme un outil pour améliorer les performances motrices, récupérer une fonction motrice et favoriser la neuroplasticité (17).

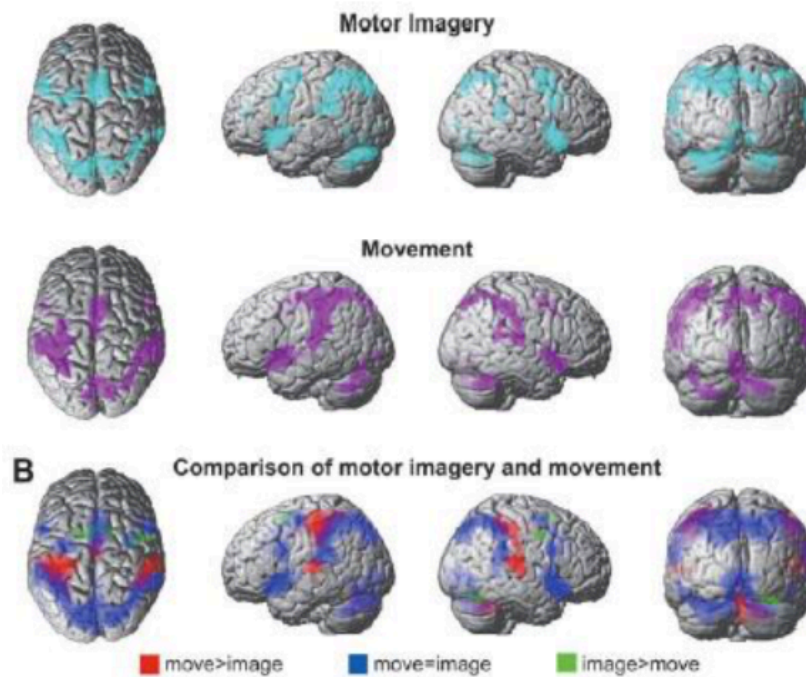


Figure 1 : Comparaison de l'activité cérébrale entre un mouvement exécuté et simulé

Hanakawa et al. 2008 (14)

En pratique, l'IM a été initialement développée pour les athlètes afin d'atteindre plusieurs objectifs: apprentissage et performance motrice, motivation, confiance en soi et anxiété, stratégies et résolution de problèmes et rééducation des blessures (1,18). Plus tard, l'IM a également été utilisée en rééducation neurologique, notamment après un accident vasculaire cérébral, afin d'améliorer la fonction motrice du membre supérieur (19).

Plusieurs études ont examiné les effets de l'IM sur la déficience motrice après des lésions musculo-squelettiques. Après une blessure, une immobilisation prolongée peut entraîner une perte de force et d'endurance avec un enraidissement progressif des articulations. Les techniques de rééducation standard nécessitent un grand nombre de mouvements pour améliorer les amplitudes articulaires et les capacités de renforcement ou d'endurance musculaire (20) et doivent être appliquées directement à la région lésée. Par conséquent, un programme de rééducation peut être douloureux et répétitif, ce qui réduit le risque d'efficacité et d'adhérence. L'utilisation d'outils activant des zones du cerveau qui commandent des effecteurs périphériques spécifiques (muscles ou articulations) et

qui évitent ensuite la perte de contrôle ou préservent la programmation centrale semble prometteuse.

En 2019, Yap et al (21) ont mené une revue systématique et une méta-analyse sur les effets de l'IM sur la douleur et l'amplitude de mouvement dans les troubles musculo-squelettiques. Nous allons ajouter la force motrice comme dimension supplémentaire, actualiser et compléter leur recherche. En effet, les résultats des études de Yue & al. et Ranganathan & al. (22,23) fournissent des preuves de l'origine centrale du gain de force qui se produit avant l'hypertrophie musculaire, entraînant ainsi les unités motrices à une intensité plus élevée et/ou conduisant au recrutement d'unités motrices qui restent autrement inactives. Une réorganisation neuronale similaire après le pratique de l'IM est censée expliquer la perte minimale de force pendant l'immobilisation (24).

En outre, l'augmentation de la commande neuronale corticale descendante et l'excitabilité des réseaux spinaux au repos pourraient expliquer le taux plus élevé de développement du couple et le couple isométrique maximal après une semaine d'entraînement par IM (25).

L'objectif principal de cette revue systématique avec méta-analyse est de comparer les effets de l'IM en plus de la rééducation classique sur la réduction de la douleur, le gain de force et la récupération des amplitudes articulaires chez des sujets sains ou pathologiques présentant des troubles musculo-squelettiques. Comme objectifs secondaires, nous visons à comparer les différentes modalités de l'IM - type de technique, nombre de séances - et les caractéristiques de la population - sujets sains ou pathologiques, état aigu ou chronique.

3) Article

The use of motor imagery in locomotor rehabilitation and training: a systematic review and meta-analysis

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3.1 Abstract

Objectives: Motor imagery (MI) consists in mentally picturing an action without any motor execution. Whether in its explicit or implicit form, MI implies the activation of the same cortical networks as motor execution. MI is increasingly used in various contexts – locomotor rehabilitation, physical training or neurological diseases. This systematic review aimed to investigate the effects of MI in addition to standard practice in non-neurological conditions, on pain, range of motion, and strength. Additionally, we aimed to evaluate the influence of different modalities of MI practice on outcomes' improvements.

Methods: Eight databases and grey literature were searched from the earliest record to March 2020. Two independent reviewers screened search results to include randomized controlled trials only. Data concerning pain, range of motion, and strength were retrieved. Methodological quality was assessed using the Cochrane Risk of bias 2 tool. Meta-analyses were conducted with random-effects model after testing for heterogeneity.

Results: Forty-six studies met the required criteria and forty-one were included in the quantitative analysis, representing 470 subjects in the MI group and 455 in the control group. There was a significant pooled standardized mean difference in favour of MI for reducing pain (SMD -1.14 , 95% CI, -1.80 to -0.48 ; $P < 0.01$), promoting strength gain (SMD 0.48 , 95% CI, 0.22 to 0.74 ; $P < 0.01$) and improving range of motion (SMD 0.65 , 95% CI, 0.11 to 1.18 ; $P < 0.01$).

Conclusion: Motor imagery significantly reduce pain with a large effect size, even if clinical significance is not reached. It also promotes muscular strength gain and help range of motion recovery with a moderate effect size.

Keywords: Mental imagery, mental practice, motor imagery, locomotor rehabilitation, musculoskeletal disorders, physical training.

3.2 Introduction

Motor imagery (MI) is the mental representation of an action without any concomitant body movement (1). MI is based on the principle of neuro-functional equivalence (2,3) whereby thinking of an action is equivalent to performing it. Two modalities of MI can be distinguished. Firstly, explicit MI consists in visualizing a specific movement or action, either from a first-person point of view (kinesthetic imagery) (4), or from a third-person point of view (visual imagery) (5). Secondly, laterality judgement tasks refer to an implicit method of MI, wherein subjects have to recognize laterality of body parts through mental rotation and visualization exercises (9). Despite this distinction, brain imaging studies (10,11) indicate that comparable brain networks are activated by explicit and implicit MI (12,13). In addition to neurophysiological studies, MI-driven neuroplasticity is observed especially in motor and sensory areas (26,27) but also at a spinal level (28). Consequently, it could be used as a tool to enhance motor performance or recover motor function and promotes neuroplasticity (17).

In practice, MI was initially developed for athletes to achieve several goals: motor learning and performance, motivation, self-confidence and anxiety, strategies and problem-solving, and injury rehabilitation (1,18). Later, MI was also used for neurological rehabilitation especially after stroke to improve the motor function of the upper limb (19). Several studies have investigated the effects of MI on motor impairment after musculoskeletal damages. After injury, extended immobilization can lead to loss of strength and endurance with progressive joint stiffening. Standard rehabilitation techniques require a large number of movements to improve joint amplitudes and muscle strengthening or endurance capacities (20) and need to be directly applied to the damaged region. Therefore, a rehabilitation program may be painful and repetitive providing less risk of efficacy and adherence. The use of rehabilitation tools that activate brain areas which command specific peripheral effectors (muscle or joint) and then avoid loss of control or preserve central programming seems promising.

In 2019, Yap et al (21) conducted a systematic review and meta-analysis on the effects of motor imagery on pain and range of motion in musculoskeletal disorders. We will add strength as an

extra dimension, update and complement their research. Indeed, Yue & al. and Ranganathan & al. (22,23) study results supply evidence of the central origin of strength gain that occurs prior to muscle hypertrophy, hence driving the motor units to a higher intensity and/or leading to the recruitment of motor units that remain otherwise inactive. Similar neural reorganization following MI is supposed to explain minimal strength loss during immobilization (24). Besides, the increased cortical descending neural drive and the excitability of spinal networks at rest could explain the greater rate of torque development and maximal isometric torque after one week of MI training (25) .

The main objective of this systematic review with meta-analysis is to compare the effects of MI in addition to conventional rehabilitation on pain reduction, strength gain and joint amplitudes recovery in healthy or pathological subjects with musculoskeletal disorders. As secondary objectives, we aim to compare different MI modalities – type of technique, number of sessions – and population characteristics – healthy or pathological subjects, acute or chronic condition.

3.3 Methods

This review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (29). Study protocol was registered on PROSPERO (N°CRD42020135279).

3.3.1 Eligibility criteria

The following inclusion criteria were applied to all articles collected from each database according to a standardized Population / Intervention / Comparison / Outcome / Study design (PICOS) format: (1) *Population*: pathological subjects with motor impairment in relation with musculoskeletal conditions or healthy subjects; (2) *Intervention*: explicit or implicit motor imagery; (3) *Comparison*: 'current practice' shared by the 2 groups (either rehabilitation, physical practice, or no practice); (4) *Primary outcome measures*: pain, range of motion and strength; (5)

Study design: only human randomized controlled trials (RCTs) were included. Exclusion criteria were: other designs than RCTs, neurological or psychiatric disorders, studies investigating the effects of one single session of MI, of MI not related to movement (auditory, olfactory, tactile, or gustatory modalities), of guided imagery only based on relaxation techniques, MI based on computer-animated techniques (virtual reality). No restriction was made regarding age of the study population.

3.3.2 Search strategy

A comprehensive online search was conducted using several databases: PubMed, Web of Science, Scopus, PsycInfo, PsycArticle, Cochrane Central Register of Controlled Trials (CENTRAL), Google Scholar, Physiotherapy Evidenced Database (PEDro) and Grey literature (OpenGrey). Electronic searches were performed from the inception date of each database to March 2020. Key search terms used for the PubMed search strategy are exposed in *Figure 1* and were adapted to individual databases to account for specific vocabulary and syntax rules.

3.3.3 Selection of articles

Screening of articles was carried out by two researchers (E.T. and A.H.). Firstly, titles and abstracts were evaluated to select potentially eligible studies. Then, all the potentially eligible full-text studies were screened. In case of disagreement between the 2 reviewers after trying to reach a consensus, a third reviewer (A.D.) was consulted.

3.3.4 Data extraction

Data extraction shown in **Table 1** was independently performed by two reviewers (E.T. and A.H.). We used a standardized form, the Consolidated Standards of Reporting Trials (CONSORT) 2010 checklist of information to include when reporting a randomized trial (30). Were reported: the body part that was studied, population characteristics (age and sex ratio), detailed description of intervention including study duration and number of MI sessions, description of control practice,

presence or absence of a motor imaging ability assessment, and type of outcomes that were measured.

Pre and post-intervention results were also extracted by the 2 reviewers, blinded from each other. Post-intervention outcome was the one measured at the end of the MI sessions. If there was no information, authors and/or editors were contacted, and if results remained unavailable, studies were excluded.

3.3.5 Study quality rating

Finally, methodological quality for each study was evaluated by two blinded reviewers (E.T. & A.H.) using the Cochrane Risk of bias 2 tool (ROB2) for randomized trials (31), assessing bias arising from the randomization process, bias due to deviation from the intended interventions (effect of assignment to intervention), bias due to missing outcome data, bias in measurement of the outcome, and bias in selection of the reported result. Disagreements not reaching consensus were resolved by a third reviewer (A.D.).

3.3.6 Quantitative data analysis

Results on different outcomes such as pain, range of motion and strength of the studies included were combined for meta-analysis. Only studies considered to be at low or intermediate risk of bias were taken into account. Data were pooled using a random-effects model. To provide some clarification, to study the ROM outcome, we used only one degree of mobility per joint. Indeed, if we averaged the different degrees of mobility, the obtained variance would be between several measures and would not be independent. It is therefore more appropriate to take only one of the measures. We have thus chosen the one we thought was functionally the most interesting for the considered joint and/or condition.

In the collection of studies considered, the effect sizes were estimated. A general model was then specified by both standard and random effects models to incorporate the between-study variance. The Inverse variance weighting was used for pooling. This method allows maximizing

the accuracy of the estimate of the common effect, minimizing the variance of the pooled result. Heterogeneity between studies was explored using I² statistic to estimate the percentage of total variation across studies arising from heterogeneity rather than chance. A low, moderate, and substantial heterogeneity was considered in case of value of I² superior or equal to 25%, 50%, and 75% respectively. Sensitivity analysis without concerned trials was performed. Subgroup analysis were performed as planned according to acute or chronic disease, number of sessions, MI modalities (internal, external, both, or implicit), and part of the body that was studied. Statistical analysis was produced using General Package for Meta-Analysis “meta” Version 4.9-1 with R software version 3.5.1.

3.4 Results

3.4.1 Selection and quality of included studies

Initial research on electronic databases included 11 978 publications. After screening titles, abstracts and excluding duplicates, 95 articles were selected following the PRISMA selection strategy. The flow diagram (*Figure 2*) summarizes the screening process. Finally, 46 articles reporting randomized and controlled studies were retained after reading the full texts and 41 were included in the quantitative analysis because there were missing data, either because the authors or publishers did not reply to our request or because they no longer had the data.

3.4.2 Study characteristics

Table 1 illustrates the articles chosen for this systematic literature review with their key characteristics. Of the 41 studies (MI group, $n = 470$ and Control, $n = 455$), 15 involved pathological subjects and 26 involved healthy subjects. 22 studies were based on the practice of internal motor imagery, only one on external motor imagery, 14 on both together and 4 on laterality recognition task. 18 studies assessed participant’s motor imagery ability.

3.4.3 Methodological quality

Figure 3 shows the results of risk of bias assessment. Of the 41 selected studies, 4 were assessed as having a low risk of bias. 5 were assessed as having a high risk of bias because the allocation sequence wasn't concealed until participants were enrolled and assigned to intervention, or because of high drop-out rates. The 32 remaining studies were assessed as having "some concerns" mainly because of the lack of information about concealment of the randomization process and because assessment of outcomes could have been influenced by knowledge of the intervention received.

3.4.4 Main outcomes

There was a significant pooled standardized mean difference in reducing pain (SMD -1.14 , 95% CI, -1.80 to -0.48 ; $P < 0.01$), promoting strength gain (SMD 0.48 , 95% CI, 0.22 to 0.74 ; $P < 0.01$) and improving range of motion (SMD 0.65 , 95% CI, 0.11 to 1.18 ; $P < 0.01$) (*Figure 4*) between the MI and Control groups. There was a substantial level of heterogeneity for each outcome: pain $I^2 = 67\%$, strength $I^2 = 58\%$ and ROM $I^2 = 75\%$. For pain, this corresponds to a decrease of 1,65 cm (95% CI, -2.39 to -0.91 ; $P < 0.01$) on the visual analogue scale (VAS), which is less than the Minimal clinically important difference, considered to be 2 cm. When studies with a high risk of bias are included in the analysis, MI, compared to conventional rehabilitation, also allowed a significant improvement in pain (SMD -1.08 , 95% CI, -1.62 to -0.54 ; $P < 0.01$), muscle strength (SMD 0.47 , 95% CI, 0.22 to 0.72 ; $P < 0.01$), and range of motion (SMD 0.66 , 95% CI, 0.24 to 1.07 ; $P < 0.01$), with comparable levels of heterogeneity (pain $I^2 = 61\%$, strength $I^2 = 57\%$, ROM $I^2 = 67\%$).

Funnel plots were well balanced for the 3 outcomes (*Figure 5*).

3.4.5 Secondary outcomes

Sensitivity analysis didn't find significant differences between acute and chronic conditions on pain and range of motion (Appendix 1). There also wasn't any difference when subgrouping MI effects depending on body parts that were treated.

Considering number of MI sessions, there was a trend for higher SMD in the subgroups with fewer sessions, for pain and range of motion outcomes, but not for strength outcome (Appendix 2).

Sensitivity analysis on MI type showed a strong trend for higher SMD when using both external and internal modalities rather than one modality alone, but no difference compared to implicit MI, for pain and range of motion outcomes. There was no difference considering strength outcome (Appendix 3).

Finally, MI SMD effect on range of motion and strength was higher in pathological population than in healthy subjects (Appendix 4).

These previously highlighted differences remained when including high risk of bias studies in the sensitivity analysis.

3.5 Discussion

Our results show with level 1 evidence that motor imagery in addition of standard practice significantly reduces pain, promotes muscular strength gain and helps joint range of motion improvement in musculoskeletal disorders and in locomotor training. Effect size for pain can be considered as large, whereas it is moderate for strength and range of motion. Nevertheless, when considering only results of pathological conditions, we find a large effect size for strength and range of motion. Sensitivity analysis outline some trends for higher effects in pathological population rather than healthy subjects, and for differences depending MI type and number of MI sessions.

MI effect on pain could be explained by normalizing cortical representation of movement (32) and on central sensitization associated with chronicization of pain (33). In that sense, MI should have

higher effect on chronic than acute pain. Sensitivity analysis on pain outcome did not reinforce this hypothesis, as close values of SMD were found between acute and chronic conditions. Therefore, another possible mechanism explaining MI effect on pain could be the dissociation of movement and pain induced by MI rehearsals (34), allowing motor networks activation without concomitant nociceptive signal. Even if we found a large effect size, we can notice that the extent of difference in pain levels between MI and controls does not reach minimal clinical important difference (35).

Our meta-analysis found statistically significant but moderate effects of MI on range of motion, contrary to Yap et al. (21). Among plausible hypothesis, reduction of anticipatory protective mechanisms such as kinesiophobia (36) and normalization of the proprioceptive representation (37), and of muscle synergies (38) are commonly proposed.

We found moderate to large effect sizes on muscular strength gains induced by MI, depending on healthy or pathological condition. Mechanisms underlying these gains are not totally understood, however some propose it may be a result of increased motor programming, and/or increases in neurological adaptation of the muscle (23,39–43). Mental imagery has been reported to induce a performance improvement in skilled movements in a comparable way to physical training, which could be explained in terms of adaptation in motor cortex neurons (44). This effect is linked to an elevation of time-locked cortical potentials and has been explained in terms of stronger cortical signals to muscles, generated by repetitive mental attempts at maximal muscle activation (23). Moreover, the effect is not limited to an improvement of motor execution but also involved muscle strength. Research on motor imagery conducted without specific guidelines has shown that motor imagery has no effect on isometric force production (45,46). These results differ from recent research highlighted in our meta-analysis, in which MI training has been reported to increase the performance of strength-based tasks (e.g., voluntary muscular contraction: VMC) (23,40,43). This difference can be attributed to the variations in moderators' factors, such as mental imagery perspectives, the intensity of mental effort, weight to be lifted, training duration (47). The fact that MI in pathological subjects is more efficacy than MI in healthy subjects may be related to the

extent of central perturbations of motor execution networks that are disturbed in musculoskeletal disorders (32). Underlying pathophysiological mechanisms explaining this difference are not fully understood yet and could be a perspective for future research.

In our meta-analysis, subjects did not necessarily perform the same amount of MI from one study to another. This is why we carried out subgroup analyses taking into account the number of sessions. We have shown that doing less than 10 MI sessions is significantly more efficient than doing more than 15 sessions to reduce pain, and that the same trend in favour of a smaller number of sessions could be observed in range of motion outcome. As all the studies didn't follow the same protocols of MI implementation in subjects' trainings or patients' rehabilitation, we propose that this difference should be interpreted in terms of delay of outcome evaluation since the beginning of the MI sessions. MI effect as an adjunct to standard practice seems to be higher in the earliest stages of rehabilitation or training, suggesting that MI should ideally be performed during early stages of the rehabilitation process (post-surgery for example) when both passive and active motor executions are still limited by the injury (48). Moreover, as MI is offering a significant amount of pain reduction, it could facilitate the implementation of other rehabilitative strategies in musculoskeletal disorders contexts, such as immediate post-surgical weeks.

Only 18 studies out of 41 assessed participant's motor imagery ability which could have contributed to a bias. This ability can be evaluated by some tools as the revised version of the Movement Imagery Questionnaire (MIQ-R) which is an 8-item self-report questionnaire in which the participants rate the vividness of their mental representation (very hard to feel or very easy to feel) (7). Athletes and healthy subjects who have high imagery ability are supposed to have greater control of their images and to create more vivid images than participants with poor imagery ability, such as pathological subjects whom imagery ability might be disturbed and more variable (49,50). Some studies selected good imagers only, representing ideal results rather than real life practice or motor imagery in standard population. This point has to be clarified in future studies evaluating MI, and for providing utilization guidelines. In our meta-analysis, subjects were good imagers. We can therefore ask ourselves the question of bad imagers for whom MI would be less or not so

effective. Use of implicit MI could have an advantage over explicit MI in that population as it does not depend on an individual's ability to consciously imagine the movement (11,51,52). For future research, it might be interesting to study the effectiveness of implicit versus explicit MI, especially for bad imagers.

Hall et al. (1997) and Gregg et al. (2007) (7,53), both shown that participants scored higher on the visual than the kinesthetic subscale on the MIQ-R and MIQ-RS, which means that it is easier for them to carry out visual (external) MI than kinesthetic MI. The ability to perform internal MI improves with practice time (54). This could explain why using both types of MI seems more effective on pain reduction rather than just internal imagery, in order to avoid excluding participants with low abilities to perform internal MI.

Finally, this meta-analysis evaluated the effects of MI guided by health professionals, as only 3 studies (Stenekes et al. 2009, Baird et al. 2010 and Frenkel et al. 2014) (55–57) leave the patient to autonomous practice of MI at home. It might be interesting in the future to study the effectiveness of MI in complete autonomy, as it could provide an opportunity to increase the extent of participants and the feasibility of such a technique.

Practicing a motor task mentally with MI could increase the amount of rehabilitation or of physical training with limited negative consequences, as few side effects or harm were described in the literature (58), especially in non-neurological populations or healthy subjects where cognitive efforts allocated to MI are basically low. The limited impact of MI on the improvement of pain, range of motion and strength has to be faced with the low cost and high tolerance of such techniques, especially in the early stages of a rehabilitation, or as a complement of physical training. Besides, MI enables the rehearsal of more demanding or complex motor tasks (e.g., walking, writing) when physical practice is impossible or too difficult (59). We might think that MI training could be an effective adjunct to standard physiotherapy care in older adults. Nicholson & al 2019 (60), showed that MI training improves balance and mobility in older adults who do not have a neurological condition, although it is unclear whether or not the effects are clinically worthwhile.

Despite a rigorous methodology, our study suffers from several limitations. MI sessions did not follow the same protocol and did not last the same duration, bringing substantial level of heterogeneity and making them difficult to compare. Establishing guidelines on the quantity of effective MI to be achieved in order to obtain significant results would be interesting, but this question remains unexplored in the literature. Then, all studies included limited amounts of patients, and explored various parts of the body, that may contribute to the heterogeneity explored, and may limit the generalization of our results, even if sensitivity analysis failed to show a difference of MI effect depending on this factor.

3.6 Conclusion

In our meta-analysis, motor imagery significantly reduces pain with large effect size, however clinical significance is not reached. It also promotes muscular strength gain and help range of motion recovery with a moderate effect size. Nevertheless, it is a promising technique with a favorable risk/benefit ratio, in locomotor rehabilitation and training. Results of this meta-analysis should be interpreted with caution as there was a high level of heterogeneity between protocols and modalities of MI practice. There is a high need of larger studies, for example to compare different MI modalities.

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4) Conclusion

Notre étude confirme que l'imagerie motrice réduit significativement la douleur chez des sujets sains ou atteints de pathologies musculo-squelettiques avec une taille d'effet importante. Toutefois, la différence minimale cliniquement pertinente n'est pas atteinte. Elle favorise également le gain de force et aide à la récupération des amplitudes articulaires avec une taille d'effet modérée. Néanmoins, c'est une technique prometteuse avec un rapport bénéfice/risque favorable et à moindre coût énergétique sur le long terme. En effet, cette dernière correspond à une technique cognitive de simulation du mouvement. De ce fait, il n'existe pas d'arguments dans la littérature pour une mauvaise tolérance au niveau algique et fonctionnel. Des cas d'augmentation de douleur à la suite d'une telle pratique ont été relevés, mais chez des sujets blessés médullaires (61).

Les résultats de cette méta-analyse doivent être accueillis avec prudence étant donné que les études sont hétérogènes et comportent certaines limites. L'absence de calcul préalable du nombre de sujets nécessaires, l'absence de protocole concernant la durée d'intervention, le nombre de séances et de répétitions en IM, l'absence d'évaluation systématique préalable des capacités en IM et le non-respect permanent des critères de bonnes pratiques les rendent difficilement comparables entre elles et limitent l'interprétation des résultats.

Ceci ouvre des perspectives avec un intérêt de réaliser de nouvelles études pour déterminer un protocole de traitement optimal. L'objectif serait d'étudier l'influence de différents protocoles sur l'efficacité de l'IM, en faisant varier, par exemple, la durée d'intervention en IM, le nombre de séances et le nombre de répétitions.

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Figure 1: Pubmed search strategy

<p>("Eidetic Imagery"[Mesh]) OR "eidetic imagery" OR "mental practice" OR "mental imagery" OR "motor imagery" OR "guided imagery" OR "mental rehearsal" OR "visual imagery" OR "mental training" OR "movement representation techniques" OR "kinesthetic imagery"</p>	<p>AND</p>	<p>"Pain"[Mesh] OR "Musculoskeletal Pain"[Mesh] OR "strength" OR "Muscle Strength"[Mesh] OR "force" OR "Range of Motion, Articular"[Mesh] OR "joint flexibility" OR "mobility" OR "function" OR "Proprioception"[Mesh] OR "position sense" OR "equilibrium" OR "Kinesthesia"[Mesh] OR "kinesthesia" OR "kinesthesia" OR "Movement Sensation" OR "Kinesthetic Sense" OR "apprehension" OR "kinesiophobia" OR "Muscle Fatigue" [Mesh] OR "fear of reinjury" OR injur* OR "Musculoskeletal Diseases"[Mesh] OR "Orthopedic Disorders" OR "Complex Regional Pain Syndromes"[Mesh] OR "Sports"[Mesh] OR athleti* OR "Rehabilitation"[Mesh] OR "Recovery of Function"[Mesh] OR "physical therapy"</p>	<p>NOT</p>	<p>Stroke [TI] OR "Cerebrovascular Accident" [TI] OR "Brain Injury" [TI] OR "Traumatic Brain Injury" [TI] OR "spinal cord injury" [TI] OR "Cord Trauma" [TI]</p>
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Figure 2: Flow-chart

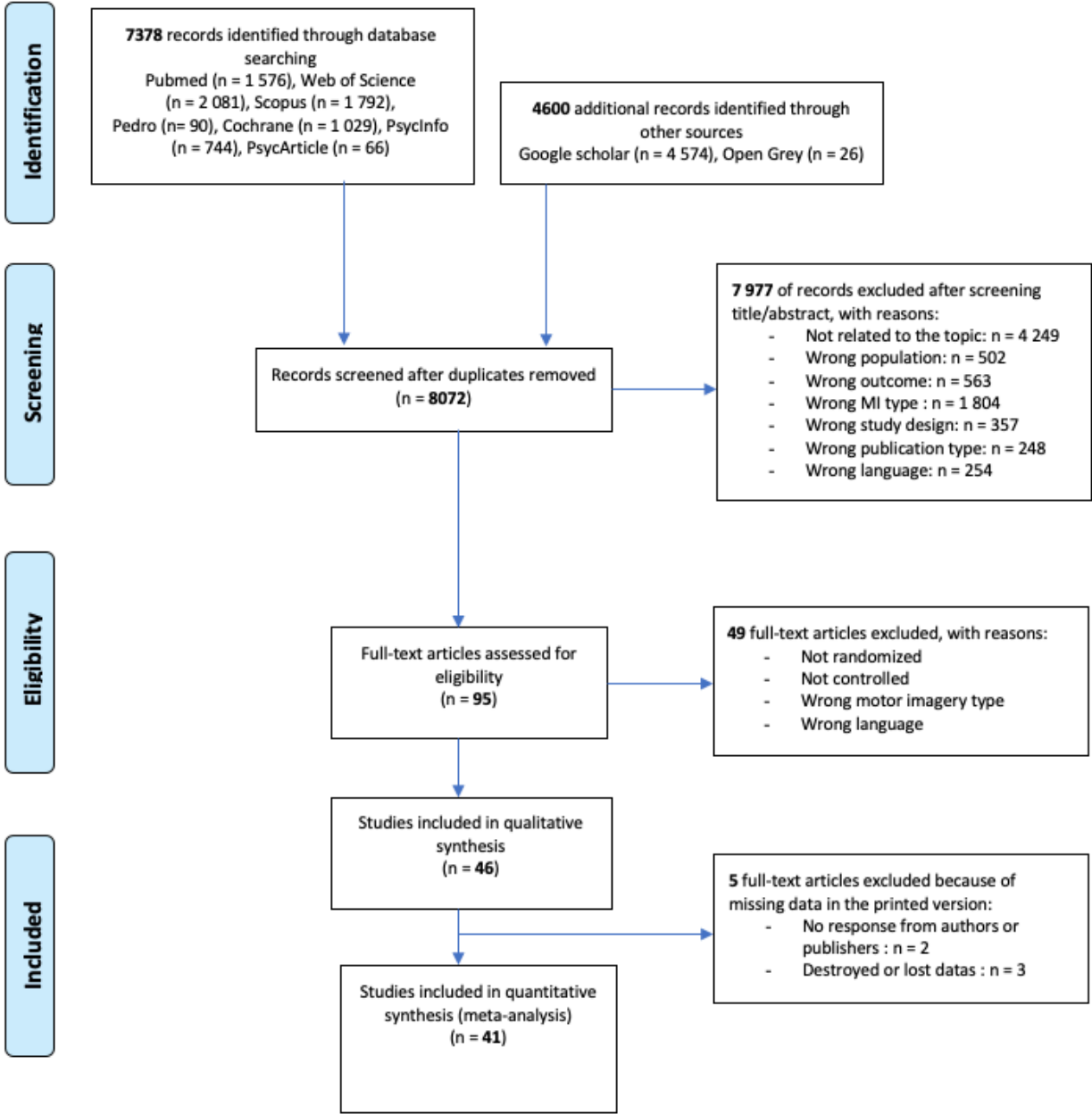


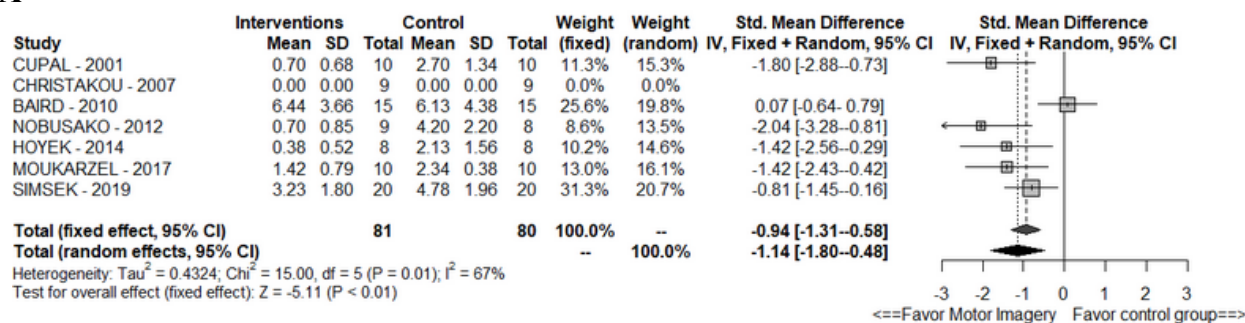
Figure 3: Methodological quality of included studies assessed with Cochrane Risk of bias 2 tool (ROB2) for randomized trials

2 tool (ROB2) for randomized trials

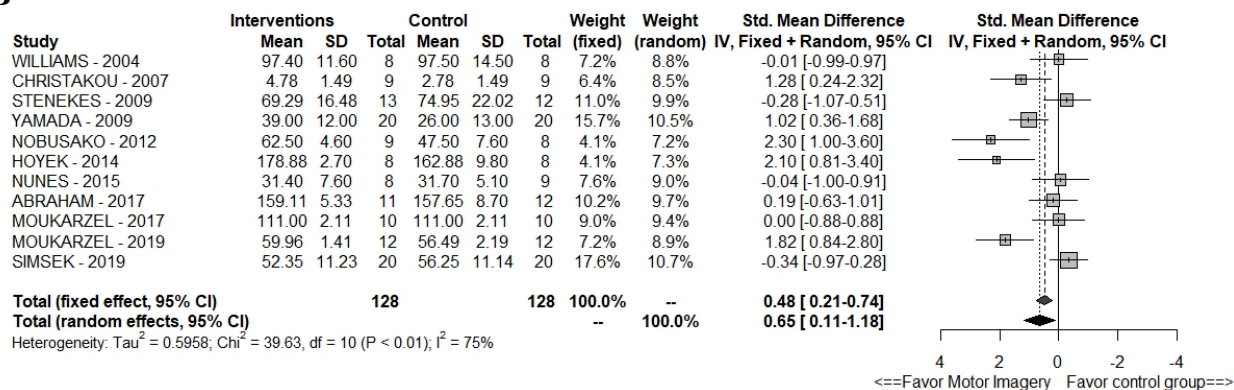
Unique ID	Randomization process	Deviations from intended interve	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
1 Abraham - 2017	+	?	+	+	+	!
2 Adams - 2013	+	?	+	+	+	!
3 Alagesan - 2010	+	+	+	+	+	+
4 Alenezi - 2018 (1)	+	?	+	?	+	!
5 Alenezi - 2018 (2)	+	?	+	?	+	!
6 Bahari - 2001	?	?	+	?	+	!
7 Baird - 2010	?	+	+	?	+	!
8 Christakou - 2007	+	+	+	?	+	!
9 Cornwall - 1991	?	?	+	?	+	!
10 Cuenca - Martinez - 2019	+	+	+	+	+	+
11 Cupal - 2001	+	+	+	?	+	!
12 Frenkel - 2014	-	+	+	?	+	-
13 Darvishi - 2013	?	+	+	?	+	!
14 Goudarzian - 2017	?	-	+	?	+	-
15 Grosprêtre - 2018	?	+	+	?	+	!
16 Hoyek - 2014	?	+	+	?	+	!
17 Lebon - 2010	?	?	+	?	+	!
18 Lebon - 2011	-	+	+	?	+	-
19 Leung - 2013	?	+	+	?	+	!
20 Losana-Ferrer - 2018	+	+	+	+	+	+
21 Maddison - 2011	+	+	?	+	+	!
22 Mahmoud - 2016	-	+	+	+	+	-
23 Moukarzel - 2017	+	+	+	+	+	+
24 Moukarzel - 2019	?	+	+	+	+	!
25 Newsom - 2003	?	+	+	?	+	!
26 Nobusako - 2012	+	?	+	+	+	!
27 Nunes - 2015	+	?	+	+	+	!
28 Paravlic - 2019	+	+	+	?	+	!
29 Prati - 2007	?	+	+	?	+	!
30 Rathod - 2013	+	+	+	?	+	!
31 Saumur - 2018	+	+	+	?	+	!
32 Scott - 2017	+	?	+	?	+	!
33 Schackell - 2007	?	+	+	?	+	!
34 Sidaway - 2005	?	+	+	?	?	!
35 Simsek - 2019	+	+	+	?	+	!
36 Slimani - 2017	?	+	+	?	+	!
37 Stenekes - 2009	?	+	+	?	+	!
38 Vergeer - 2006	?	-	?	+	+	-
39 William - 2004	?	+	+	?	+	!
40 Yamada - 2009	?	?	+	?	+	!
41 Yue - 1992	?	?	+	?	+	!

Figure 4: Results of meta-analysis on pain (A), range of motion (B) and strength (C)

A



B



C

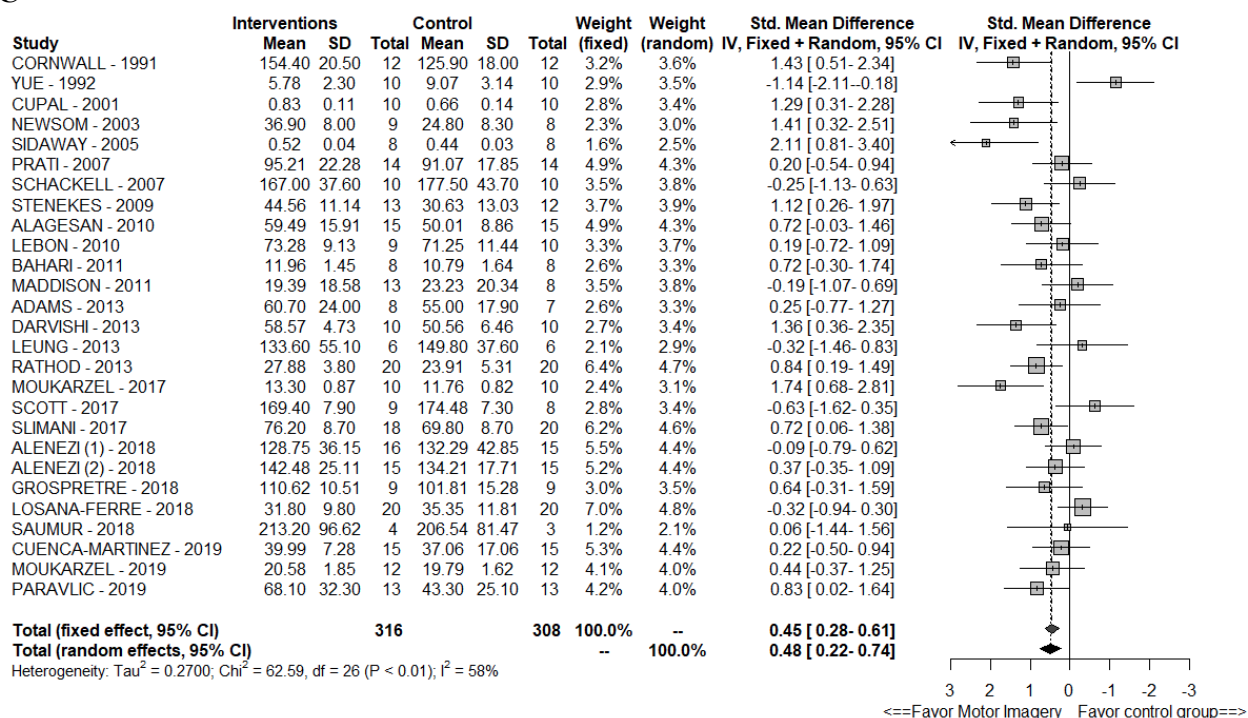


Figure 5: Funnel plots for pain (A), range of motion (B) and strength (C)

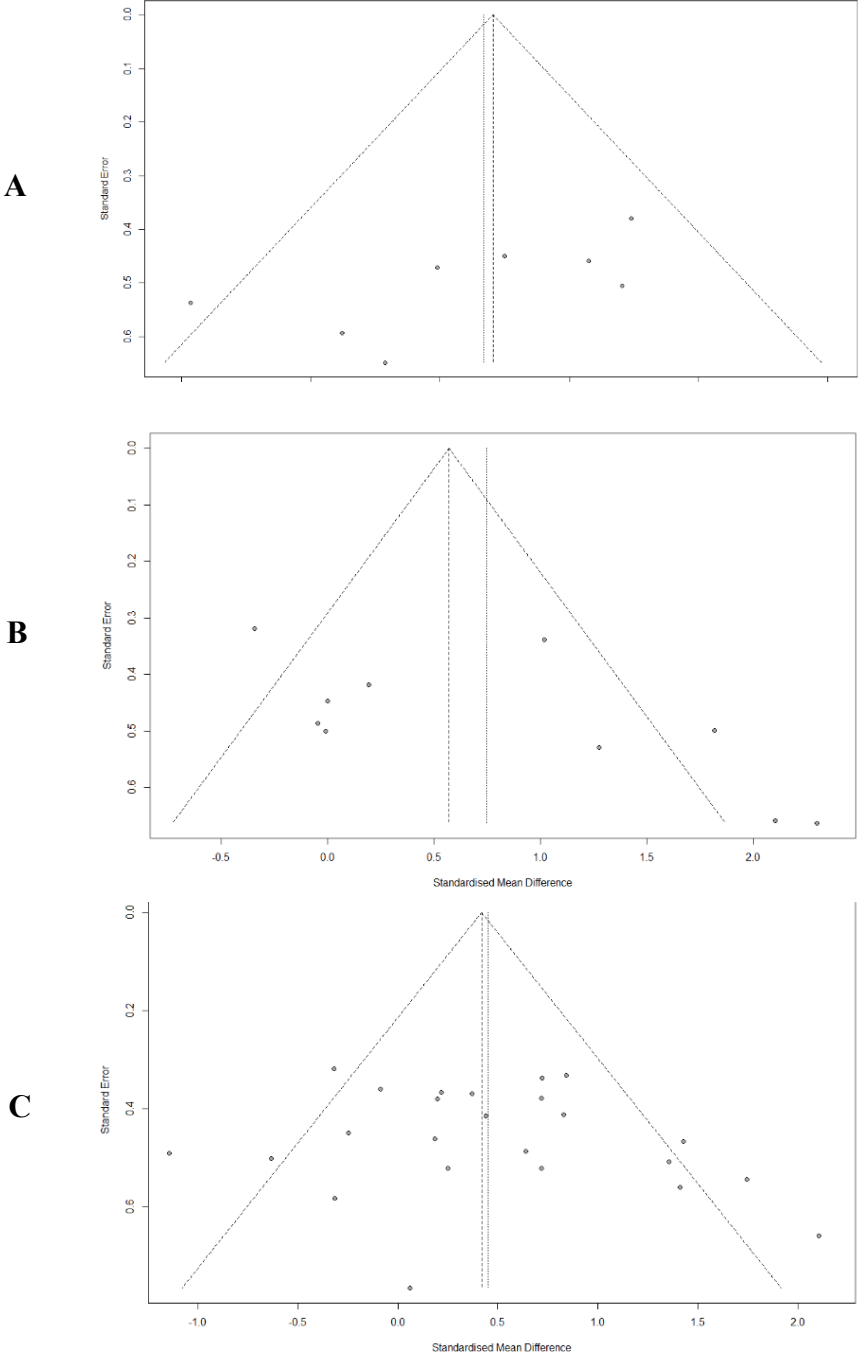


Table 1: Study characteristics

Author/Study	Year	Body part	Population (age, sex, n)	Study duration	Population/Context	Motor imagery intervention	Evaluation of the ability	Control	Outcomes
Abraham & al	2017	Ankle	MI group: 13.51 (\pm 0.49) yo & Control : 13.63 (\pm 0.52) yo ; F ; 25	6 weeks (12 sessions)	Healthy dance students and its effect on performance of repeated and static elev�	Visuo-kinesthetic MI of elev� performance with each exercise/task performed first visually and then kinesthetically (20-25 min each session, twice a week)	Yes; MIQ	Upper body exercises relevant for dance students and focused on postural awareness, joint mobility, and strengthening of the neck, shoulders, arms, elbows, and wrists with no pelvic, abdominal, or lower limbs exercises or involvement	Ankle PF maximal angle, ankle PF ROM
Adams & al	2013	Upper and lower body	15-24 yo; M & F; 24	11 weeks (30 sessions)	Healthy athletes and its effects on strength performance of the upper and lower body	Strength training + MI during rest periods (one set of 4 repetitions of maximal muscle contraction for each exercise were imaged: 10-20 min)	Yes; MIQ-R	Motivational music placebo group : strength training + listening motivational music	Strength: back squat / bench press (kg)
Alagesan & al	2010	Quadriceps femoris	19-24y; F; 30	4 weeks (12 sessions)	Healthy subjects	Kinetic mental imagery : imagine lifting the same weight without producing actual movement or visible muscle contraction at knee	No	Control group: active knee extension in high sitting position with hip and knees flexed to 90 degrees without any resistance.	Quadriceps strenght (Matt Brzycki's formula)
Alenezi & al	2018	Hip	24.43 (\pm 5.75) yo; M & F; 41	2 weeks (10 sessions)	Healthy subjects	Contract hip abductors muscles to maximum strength without physical execution, using kinaesthetic imagery alone (KIN group) or kinaesthetic combined with visual imagery (KIN + VI group). ~30 min/day, 5 days/week for 2 weeks)	Yes; VMIQ-2	Control group: non intervention	Hip abductors maximal isometric torque (humac dynamometer)
Alenezi & al	2018	Hip	25.50 (\pm 3.99) yo; M; 33	2 weeks (10 sessions)	Healthy subjects	KIN + VI (10 sessions) : imagine maximal contractions of the right hip abductors	Yes; VMIQ-2	Exercise group: maximal isometric contractions of the right hip abductors against a static dynamometer arm (35 contractions/session)	Hip abductors maximal isometric torque (humac dynamometer)
Amin & al	2019	Hand	PNFMP group : 19.27 (\pm 1.49) yo & PNF group: 18.53 (\pm 6.4) yo; F; 30	5 weeks (15 sessions)	Healthy subjects	Proprioceptive neuromuscular facilitation with mental practice (PNFMP) group (3 x 30 min training sessions/week)	No	Proprioceptive neuromuscular facilitation (PNF) group	Handgrip strength an pinch strength (dynamometer)
Bahari & al	2011	Elbow	22.5 (\pm 1.36) yo ; M; 16	4 weeks (20 sessions)	Healthy subjects	Mental contractions of elbow flexor muscles 5 sessions a week, and 50 contractions in each session	Yes; MIQ	No physical exercise	Stenght (MVC) of elbow flexor muscles
Baird & al	2004	Hip and knee	MI group 72.06 (\pm 7.32) yo & Control 74.8(\pm 9.75) yo ; F; 28	12 weeks (168 sessions)	Older women with osteoarthritis	Guided imagery with progressive muscle relaxation (participants were verbally guided to relax and to visualize moving in the scene without stiffness, hesitancy, or pain)	No	Standard care	Pain (AIMS2)
Baird & al	2010	Hip and knee	MI group 71.93 (\pm 8.74) yo & Control 68.59 (\pm 8.29) yo ; F; 30	16 weeks (196 sessions)	Older women with osteoarthritis	Guided imagery with relaxation (GIR) group (12-minute audiotape-guided GIR twice a day) : 1) relaxation induction; 2) use of senses; 3) progressive relaxation; 4) imaging oneself moving easily; and 5) end-state sug- gestion	No	Sham intervention : planned rest for 12 minutes twice a day; audiotape teaching the participants the planned rest, maintaining of a daily log of sham intervention and medication use, and recording of weekly pain measurements.	Pain (NRS)

Author/Study	Year	Body part	Population (age, sex, n)	Study duration	Population/Context	Motor imagery intervention	Evaluation of the ability	Control	Outcomes
Christakou & al	2007	Ankle	26 (\pm 4.47) yo; M; 18	4 weeks (12 sessions)	Athletes with ankle sprain injury grade II	Relaxation and imagery group : standard physiotherapy program + sessions of imagery (12 individual sessions, each lasting 45min: the content of every imagery session was similar to the content of the daily physiotherapy session)	Yes; MIQ	Standard physiotherapy program : ROM and strengthening exercises, proprioceptive training, cycling and stretching	Pain, Range of motion
Cornwall & al	1991	Quadriceps femoris	21-25; F; 24	4 days (4 sessions)	Healthy subjects	Internal MI. Mentally practice isometric contractions of their right quadriceps muscle (four, 30-minute covert practice sessions)	No	Control group: no physical activity or MP	Quadriceps strenght (isokinetic dynamometer)
Cuenca-Martínez & al	2019	Trunk	MI group 30.15 (\pm 13,24) yo & Control 27.4 (\pm 11.2) yo; M & F; 45	3 weeks (18 sessions)	Healthy subjects	Motor control exercises combined with motor imagery (MI): mental practice tasks based on kinesthetic mental MI	Yes; MIQ-R	Motor control exercises combined with action observation (AO) : series of 1-min videos for each exercise shown in third-person perspective prior to the actual execution of each exercise . Control group (CG): motor control exercises: intensive training program of stabilization exercises of the lumbopelvic region	Lumbopelvic motor control, trunk muscle strength (dynamometer)
Cupal & al	2001	Knee	28,2 (\pm 8,2) yo; 16 M & 14 F; 30	24 weeks (10 sessions)	Anterior cruciate ligament (ACL) reconstruction	Relaxation and Guided imagery group (varied imagery modalities: internal, external, visual, kinesthetic) : 10 individual sessions + physical therapy	No	Control group: physical therapy. Placebo group: attention, encouragement, and support from the clinician + physical therapy	Knee strength, pain
Darvishi & al	2013	Hand	70,93 y; M & F ; 30	3 weeks (15 sessions)	Healthy elderly subjects, right-handed	Motor imagery group: imagine that they were contracting their non dominant hand muscles (5 session/week)	Yes; VMIQ & VVIQ	Isometric action group : squeeze the dynamometer with maximum isometric effort (non dominant hand). Control group : no MI and no isometric action	Grip strength (dynamometer)
Frenkel & al	2014	Wrist	25 (\pm 4,29) yo; M; 20	3 weeks (21 sessions, but most on their own)	Healthy subjects, 3 weeks of cast forearm immobilization to simulate a distal radial fracture	Visual and kinesthetic imagery of flexion-extension and adduction abduction of the radiocarpal joint (at least 15 min every day)	No	No training, immobilization group	Range of motion of the wrist joint (dorsal extension, palmar flexion, radial and ulnar abduction)
Goudarzian & al	2017	Lower body	68 (\pm 5.78) yo ; M; 42	8 weeks (24 sessions)	Healthy elderly subjects	Mental training (MT) group: imagine to walk a distance of 3 m towards a special goal, and then turn back and sit down on the armchair.	No	Whole body vibrations (WBV) group: exercices on a vibration machine. WBV + MI group. Control group: no intervention	Leg isometric strength (press dynamometer)
Gröspretre & al	2018	Lower limb	MI group 22.2 (\pm 2.6) yo & Control 23.2 (\pm 2.8) yo ; 9 M & 9 F; 18	1 week (7 sessions)	Healthy subjects	MI training group: each training session lasted 20 min and involved 4 series of 25 imagined maximal isometric contractions of the plantar flexors of the right leg.	Yes; MIQ-R	Control group did not engage in any physical or mental training	Plantar flexion torque (MVC)

Author/Study	Year	Body part	Population (age, sex, n)	Study duration	Population/Context	Motor imagery intervention	Evaluation of the ability	Control	Outcomes
Hidalgo-Peréz & al	2015	Neck	MCTE + MI 33,05 (± 12,87) yo & MCTE 33,66 (± 10,47) yo	4 weeks (20 sessions)	Healthy subjects	MCTE + MI group : a) kinesthetic imagery (first week); b) visual imagery (second week); c) movement obser- vation therapy plus MI (third week); and d) exercise execution with mirror feedback (fourth week).	No	MCTE group : motor control therapeutic exercises for the cervical region (once a day, 5 days a week)	Cervical kinesthetic sense, cervical ROM
Hoyek & al	2014	Shoulder	46,31 (± 9.02) yo ; 8 M & 8 F; 16	4 weeks (10 sessions)	Stage II shoulder impingement syndrome	MI group: physical therapy + imagine the same movement that was actually performed beforehand (10 individual sessions of physical therapy of one hour each, scheduled three times per week)	Yes; MIQ-R	Control group: physical therapy.	ROM (goniometer), pain (H-VAS)
Lebon & al	2010	Lower body	19,75 (± 1.72) yo; M & F; 22	6 weeks (12 sessions)	Healthy sport students	M group: imagined themselves performing the motor sequence (kinaesthetic and internal visual imagery) + actual contractions (sled leg press movement) (during 12 training sessions)	Yes; MIQ	Control group = similar physical practice + neutral task during equivalent time	Maximal Voluntary Contraction and Maximum Number of Repetitions
Lebon & al	2011	Knee	28,5 (± 5.0) yo ; 10 M & 2 F; 12	4 weeks (12 sessions)	Anterior cruciate ligament (ACL) reconstruction (Kenneth Jones-technique)	Kinesthetic imagery: imagining maximal isometric contraction of a full knee extension during 10 s, without moving (12 sessions: every 2 days with every session lasting 15 min) + traditional rehabilitation	No	Control group: traditional rehabilitation only	Pain (VAS), Knee ROM (goniometer)
Leung & al	2013	Elbow	Strength training group (1 male, 23 yo and 5 females, 24.6 ± 1.1 yo), MI strength training (5 males, 24.5 ± 4.3 y and 1 female, 24 yo) and Control (2 males, 33.0 ± 1.5 yo and 4 females, 29.0 ± 6.2 yo). ; 8 M & 10 F; 18	3 weeks (9 sessions)	Healthy subjects	Motor imagery strength training : same protocol as the strength training group without performing any over movement of the biceps curl exercise.	No	Stength training: flexion and extension of the elbow with a weighted dumbbell (3 times a week). Control group: no training	Maximal voluntary dynamic elbow flexor muscle strength (isokinetic dynamometer)
Losana-Ferrer & al	2018	Hand	MI group 27.40 (± 11.20) yo ; Control 33.30 (± 15.28) y ; 31 M & 29 F; 60	2 weeks (10 sessions)	Healthy subjects	MI group: imagine maximal isometric hand grip contractions with a tennis ball	Yes; MIQ	AO group: watch and then performed the 10 maximal isometric contractions with the tennis ball while they watched the video a video. Control group: maximal isometric hand grip contractions	Hand grip strength (Jamar dynamometer)
Maddison & al	2011	Knee	34,86 y; M & F; 21	24 weeks (9 sessions)	Anterior cruciate ligament (ACL) reconstruction	Guided imagery and relaxation program : cognitive imagery (visual and kinaesthetic) was used to rehearse rehabilitation exercises + standard rehabilitation	No	Standard rehabilitation care	Knee strength (isokinetic dynamometer), pain
Mahmoud & al	2016	Knee	64,7 yo ; 4 M & 6 F; 10	8 weeks (9 sessions)	Total knee arthroplasty secondary to osteoarthritis	MI group: MI of a Knee Flexion Stretch on the stairs, MI of a seated knee flexion stretch where they imagined themselves using their unaffected leg to stretch their affected leg into knee flexion while sitting supported (twice a day)	No	Control group : standard physical therapy	Knee range of motion

Author/Study	Year	Body part	Population (age, sex, n)	Study duration	Population/Context	Motor imagery intervention	Evaluation of the ability	Control	Outcomes
Moukarzel & al	2017	Knee	69.60 (\pm 3.25) yo ; 4 M & 16 F; 20	4 weeks (12 sessions).	Total knee arthroplasty (end-stage osteoarthritis or grade 4) / acute phase	MI group had 15 min of visual and kinesthetic imagery + standard physical therapy, 3 sessions per week	No	Standard physical therapy, 3 sessions per week + a general free discussion related to their rehabilitation during this time.	Pain, range of motion, quadriceps strength
Moukarzel & al	2019	Knee	70 (\pm 2.89) yo; 4 M & 20 F; 24	4 weeks, starting 6-months after surgery (12 sessions)	Total knee arthroplasty (end-stage osteoarthritis or grade 4) / chronic phase	3 sets of MI exercises including each five repetitions, using both visual imagery: self-visualization of a movement from a first (internal visual imagery) and third-person (external visual imagery) perspective, and/or kinesthetic imagery + physical therapy program	No	Control group : physical therapy program	Quadriceps strenght (hand-held dynamometer)
Newsom & al	2003	Wrist	18-30 yo ; 5 M & 13 F; 18	10 days (30 sessions (three 5-min MI sessions daily))	Healthy subjects, 10 days of forearm immobilization	Motor imagery of flexion / extension of the wrist while immobilizing the upper limb	Yes	No training, Immobilization group	Grip strength, wrist flexion and extension strength (Jamar and dynamometer)
Nobusako & al	2012	Neck	GDR group: 50,3 (\pm 17,5) - Control group: 54,4 (\pm 11,6) y; 8 F & 9 M, 17	3 weeks (11 interventional sessions)	Chronick neck pain	The gaze direction recognition task group : physical therapy and GDR task sessions	No	Control group : physical therapy only	Active range of motion (goniometer) and cervical pain (VAS)
Nunes & al	2015	Ankle	MI group : 17.2 (\pm 1.6) yo & Control 17.4 (\pm 1.8) yo ; M; 20	2 weeks (10 sessions)	Soccer players with acute lateral ankle sprain	Intervention group: physical therapy + MI : 40 different ankle-foot images were randomly projected (20 left and 20 right), in different angles and with different ankle-foot positions. The participant has to identified if it is a right or a left foot	No	Control group: physical therapy	ROM in ankle plantar and dorsal flexion
Paravlic & al	2019	Knee	61,1 (\pm 5,3) yo; 19 M & 15 F; 34	4 weeks (20 sessions)	Total knee arthroplasty (tricompartamental, cemented, with a medial parapatellar surgical approach)	MI practice group + RPT (routine physical therapy): imagine maximal voluntary isometric contractions (15 minutes per day/5 days per week)	Yes, MIQ-3	Control group : RPT only	Maximal isometric knee extension,
Prati & al	2007	Lower body	18-30 yo, M, 28	4 weeks (12 sessions)	Healthy subjects	Heavy resistance training and mental training group: to simulate mentally the bench press movement before beginning the exercise and during the interval series	No	Heavy resistance training group: 3 sets of 4 maximum repetition using 90% of 1-RM	Bench press strength (kg)
Rathod & al	2013	Knee	18-25 yo ; F; 40	4 weeks (12 sessions)	Healthy subjects	Strengthening exercises + Motor imagery (imagine the same exercises)	No	Strengthening group : wall slide, bent leg raise, isometric static quadriceps (5 sessions' sets of 10 repetitions, 3 times a week.)	Quadriceps strenght (RM)
Saumur & al	2018	Knee	MI group 21.3 (\pm 2.1 yo) & control 20.3 (\pm 1.5) yo ; 6 M & 4 F; 10	3 weeks (15 sessions)	Healthy subjects	Motor imagery training: "imagined" 15 maximal voluntary isometric contractions (MVC) performed during knee extension (5 individual training sessions per week)	No	Strength training group : 15 maximal voluntary isometric contractions (MVC) performed during knee extension (5 individual training sessions per week) . Control group: no intervention	Quadriceps strenght (pic torque Nm/kg)

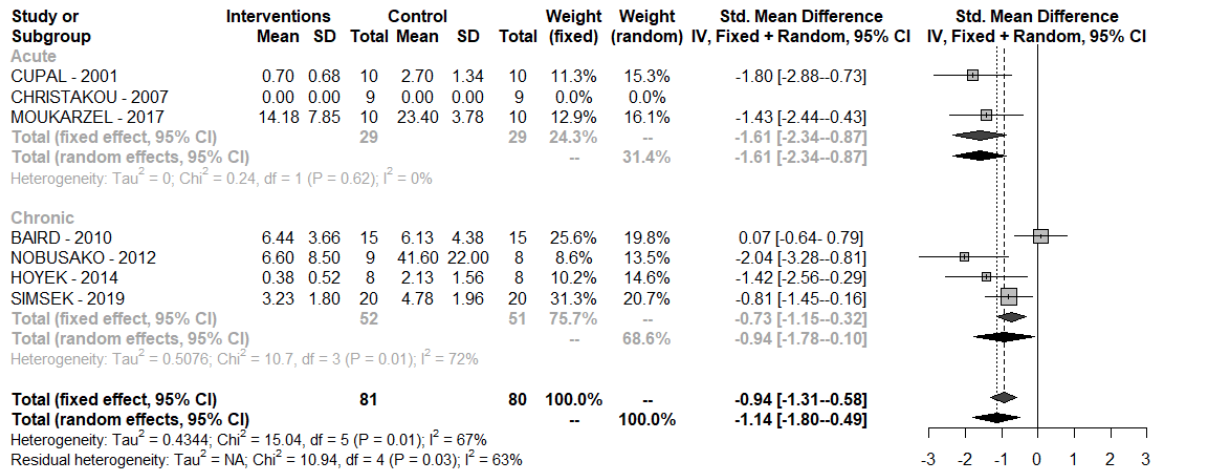
Author/Study	Year	Body part	Population (age, sex, n)	Study duration	Population/Context	Motor imagery intervention	Evaluation of the ability	Control	Outcomes
Scott & al	2017	Knee	MI group : 24,6 (\pm 4,4) yo & Control : 20,6 (\pm 2,1) yo; 16 M & 10 F, 26	3 weeks (9 sessions)	Healthy subjects	Pure MI: imagine (with eyes closed) the effort and sensation involved in executing the Nordic exercise.	Yes, MIQ-3	AO+MI: imagine the effort and sensation involved in executing the Nordic exercise with eyes open, and to additionally synchronize their motor simulation with the demonstration of this action .Pure MI-control: imagine an upper-limb action with eyes closed	Maximal voluntary eccentric contraction of the hamstrings
Shackell & al	2007	Hip	MI group : 19,8 (\pm 1,4) yo & control : 21,3 (\pm 2,45) yo; M; 30	2 weeks (10 sessions)	Healthy sport students	Mental training : mentally envision himself using the hip flexor machine for four sets of eight repetitions (5 training sessions of 15 min each per week.)	No	Physical practice: same as the mental training, except that each step was physically carded out by the subject. Control group : no intervention	Hip strength (lb)
Sidaway & al	2005	Ankle	22,7 yo ; M & F ; 24	4 weeks (12 sessions)	Healthy physical therapists students	Mental practice group: mentally practiced maximal isometric contractions (3 sets of 10 repetitions, 3 times per week)	No	Physical practice group: maximal isometric contractions (3 sets of 10 repetitions, 3 times per week). Control group: no intervention	Ankle dorsiflexors peak isometric torque (isokinetic dynamometer)
Simsek & al	2019	Neck	MI group 43.95 (\pm 7.14) yo & Control 46 (\pm 5.5) yo; 8 M & 32 F; 40	6 weeks (15 sessions)	Chronick neck pain > 3 months	Gaze Direction Recognition Tasks + physical physiotherapy (15 sessions of therapy during 3 weeks, 5 days per week)	No	Control group: physical physiotherapy (15 sessions of therapy during 3 weeks, 5 days per week)	Pain intensity (VAS), range of motion (goniometer)
Slimani & al	2017	Lower body	24.2 (\pm 4.4) yo ; M; 53	12 weeks (36 sessions)	Healthy trained kickboxers	Physical and mental training group: warm up, strength exercices, plyometric drills + same imagined exercises, cool down (36 training sessions occurred over 12 consecutive weeks, with a maximum of 3 training sessions per week)	Yes; SIAM	Physical-training group: warm up, strength exercices, plyometric drills, neutral cognitive task, cool down (36 training sessions occurred over 12 consecutive weeks, with a maximum of 3 training sessions per week) Control group: no mental or physical training	Bench press and Half squat strength (kg)
Smith & al	2003	Finger (5th)	29.33 years (\pm 8.72) E41	4 weeks (8 sessions)	Healthy subjects	Mental practice group: performed 20 imaginary MVCs with the right fifth digit against the load cell.	Yes; MIQ	Physical practice group: performed 20 MVCs with the right fifth digit against the load cell. Control group: no intervention	Abduction strength
Stenekes & al	2009	Hand	MI group : 36.1 (\pm 11.3) yo; Control group: 31.1 (\pm 10) ; 18 M & 7 F; 25	12 weeks (=336 sessions)	Surgical flexor tendon repair (complete sharp transection of at least a flexor digitorum superficialis or flexor digitorum profundus tendon), 6 weeks immobilization	Motor imagery group: regular treatment (same as control group) + perform active flexion and extension movements mentally during the immobilization period	Yes; VVIQ	Control group: during the first 4 weeks postoperatively, only passive flexion of the finger joints was allowed, while in the following 2 weeks, place-hold exercises were also practiced: exercises in which a subject flexes the fingers passively with the help of the other hand	Active total motion (goniometer), grip strength and pinch strength (digital dynamometer and pinchmeter)

Author/Study	Year	Body part	Population (age, sex, n)	Study duration	Population/Context	Motor imagery intervention	Evaluation of the ability	Control	Outcomes
Vergeer & al	2006	Hip	40,8 (± 9,8) yo; 25 M & 22 F; 47	4 weeks (11 sessions)	Healthy subjects	Movement imagery group : participants imagined moving the limb they were stretching	Yes; VVIQ	Stretching imagery group: participants imagined the physiological processes involved in stretching the muscle. Control group: participants did not engage in mental imagery.	Active and passive range of motion around the hip
Williams & al	2004	Hip	21,01 (± 2,09) yo; M & F; 24	28 days (15 sessions)	Healthy subjects	Proprioceptive neuromuscular facilitation (PNF) coupled with an internal mental imagery technique (PNFI) : mentally image, specifically, feel themselves producing the observed range-of-movement	Yes; RVI	PNF group: flexibility program. Control group: no intervention.	Hip flexion (ROM)
Yamada & al	2009	Shoulder	54.8 (+/- 10.5) ; not reported; 40	4 weeks (x sessions)	Frozen shoulder (periarthritis/ joint disorder)	Mental rotation intervention: identification of the side while seeing rotated views (at various angles) of the hand/limb+ standard rehabilitation	No	Standard rehabilitation: joint range training, stretching, relaxation	Shoulder range of motion : flexion, abduction and external rotation
Yao & al	2013	Elbow	18 - 35 yo; M & F; 18	6 weeks (30 sessions)	Healthy subjects	Internal motor imagery (IMI): participants visualized and feel as if they were physically executing a maximal elbow-flexion contraction External motor imagery (EMI): participants viewed (in their mind) themselves performing the elbow flexion task from a third-person perspective (15min/day for 5 days/week).	No	No-practice CTRL group	Right arm elbow flexion force (force tander)
Yue & al	1992	Hand	21-29 yo; M & F; 30	4 weeks (20 sessions)	Healthy subjects	Imagining group: imagined MVC of the fifth digit (5 sessions/week)	No	Contraction group: MVC pf the fifth digit. Control group: no intervention.	Abduction strength, flexion strength (force transducer)

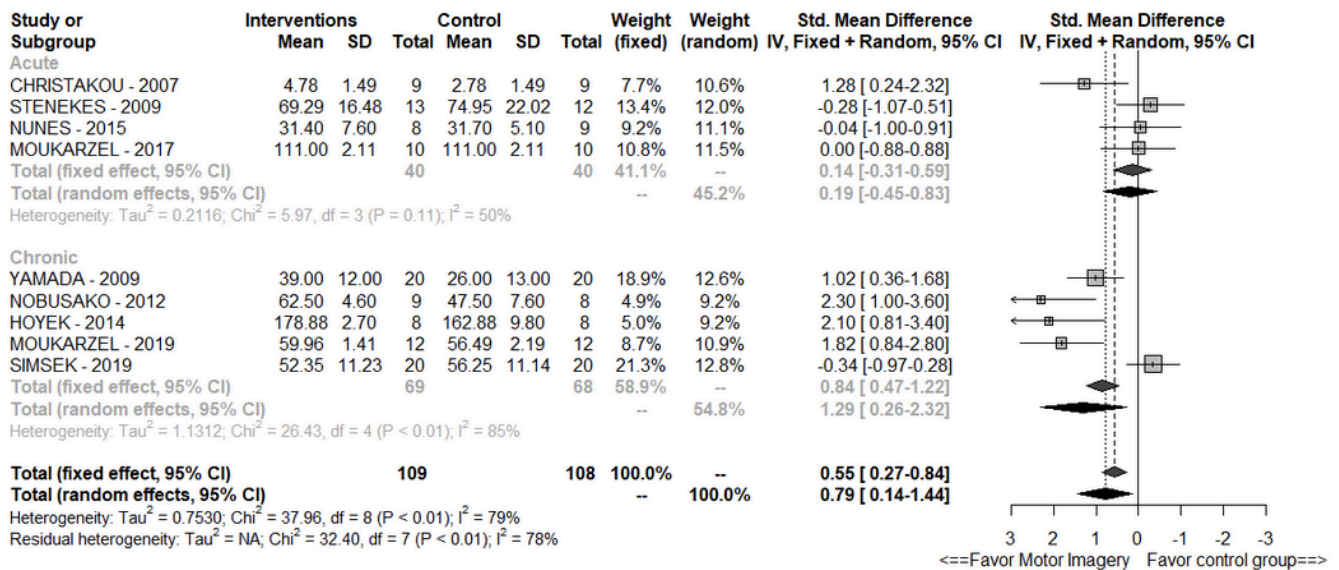
Appendices

Appendix 1: Sensitivity analysis on pain (A) and range of motion (B), depending on acute or chronic condition

A

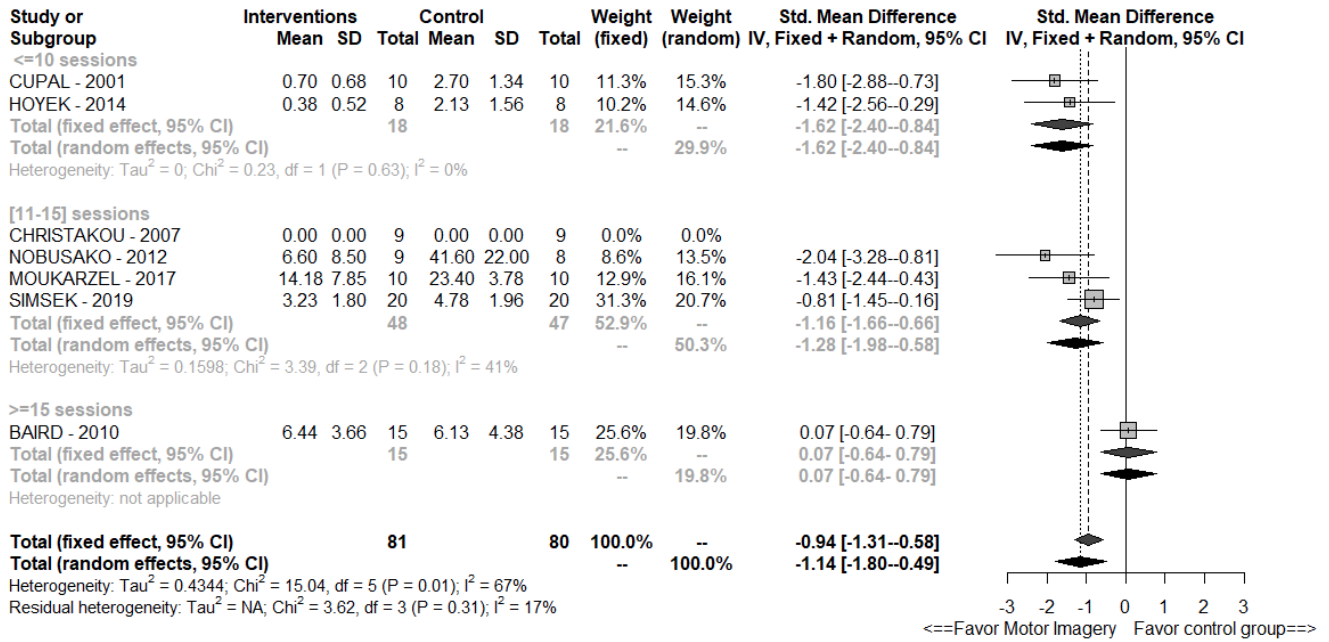


B

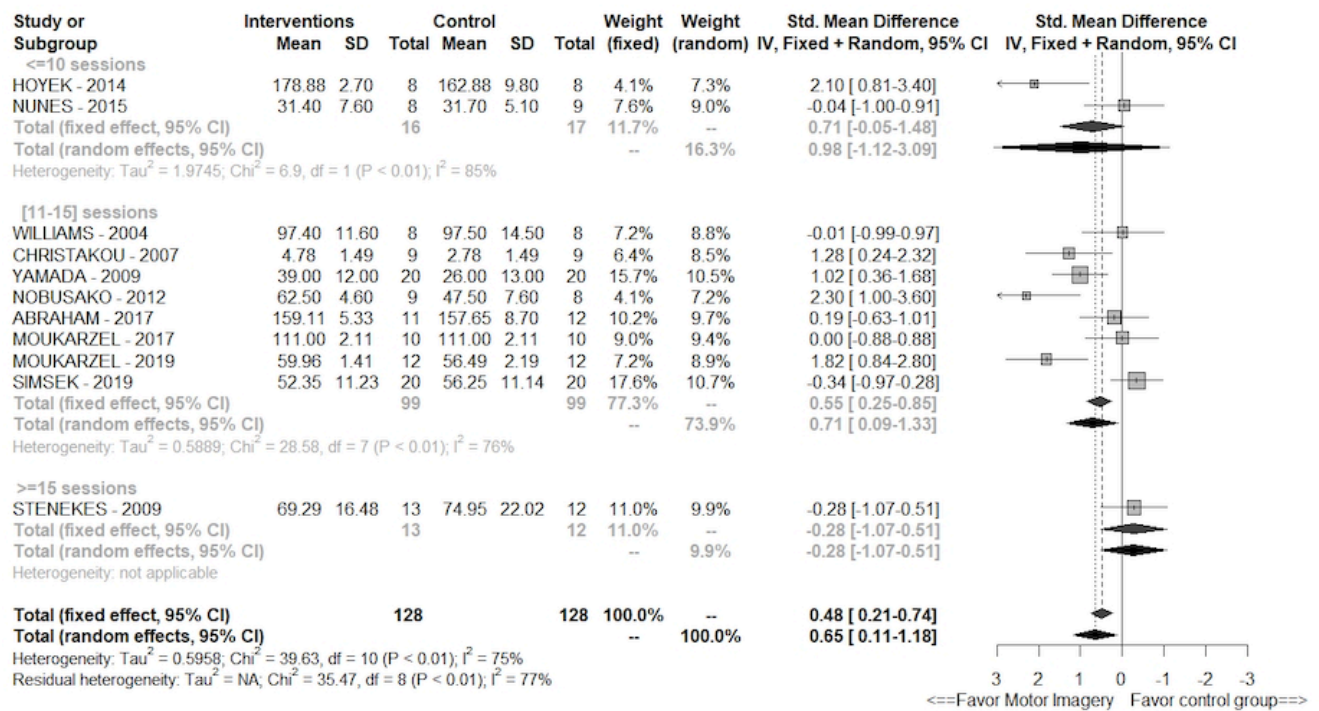


Appendix 2: Sensitivity analysis on pain (A), range of motion (B) and strength (C), depending on the number of MI sessions.

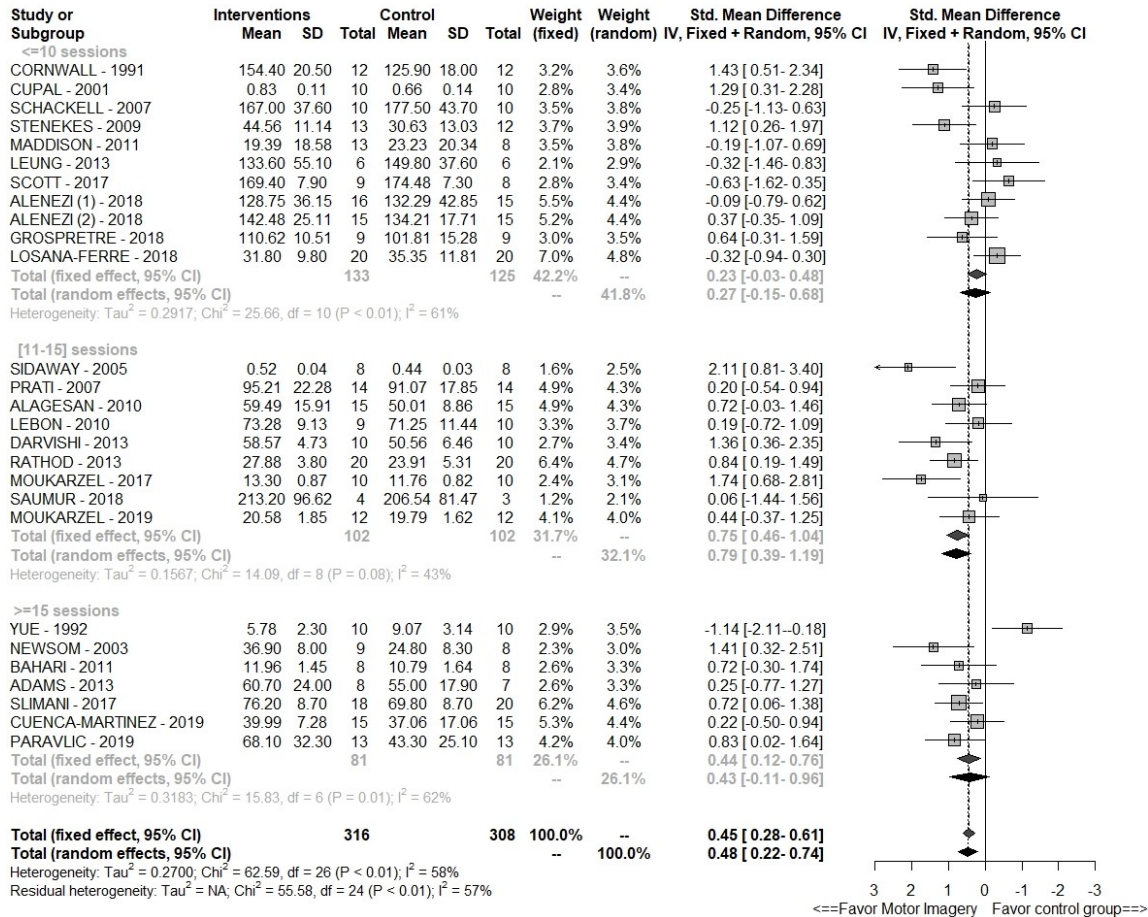
A



B

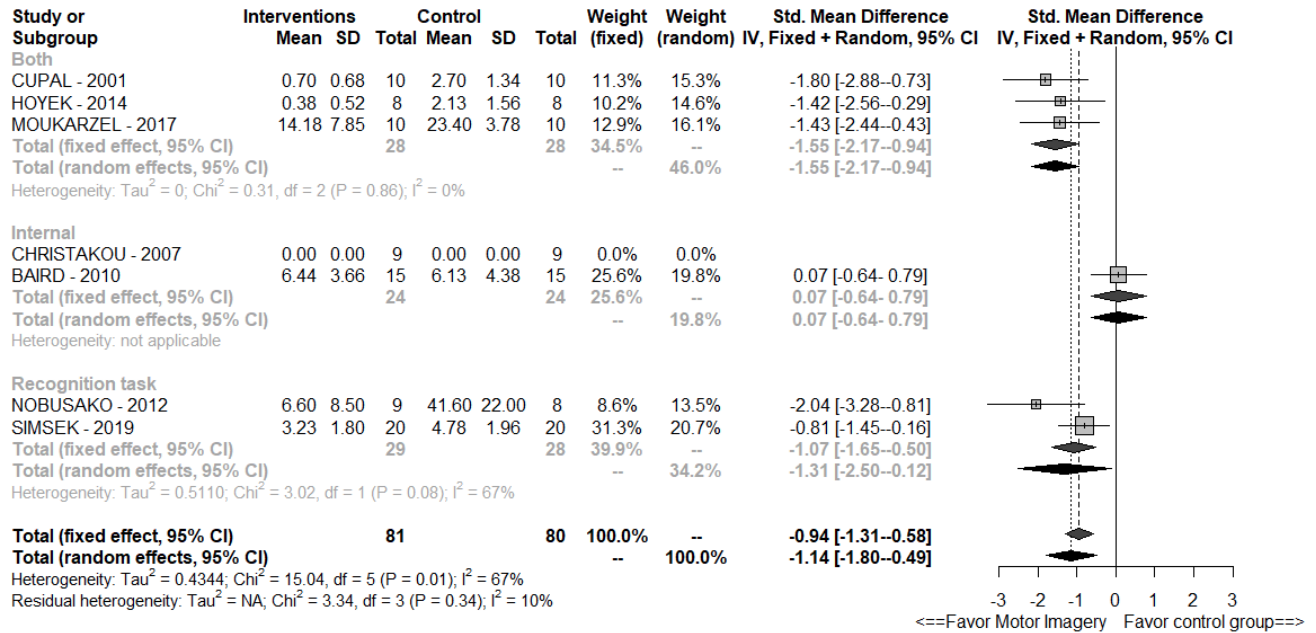


C

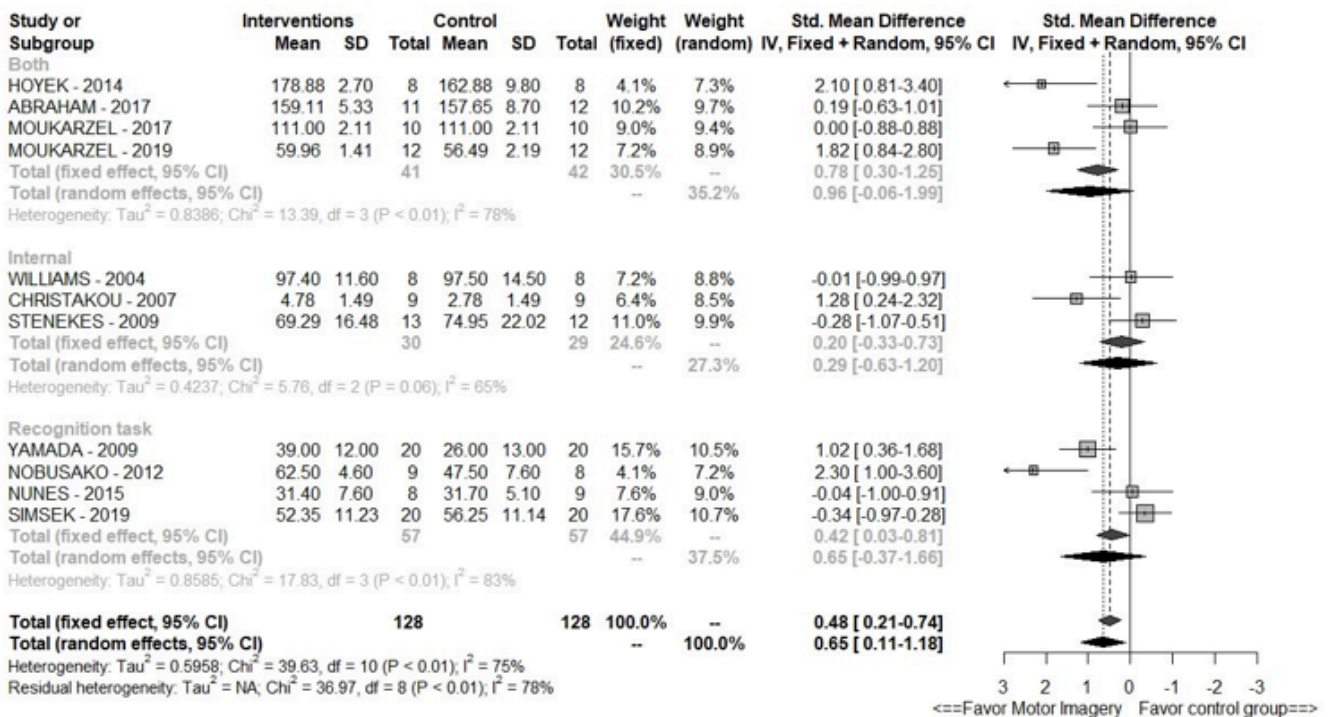


Appendix 3: Sensitivity analysis on pain (A), range of motion (B) and strength (C), depending on the MI type.

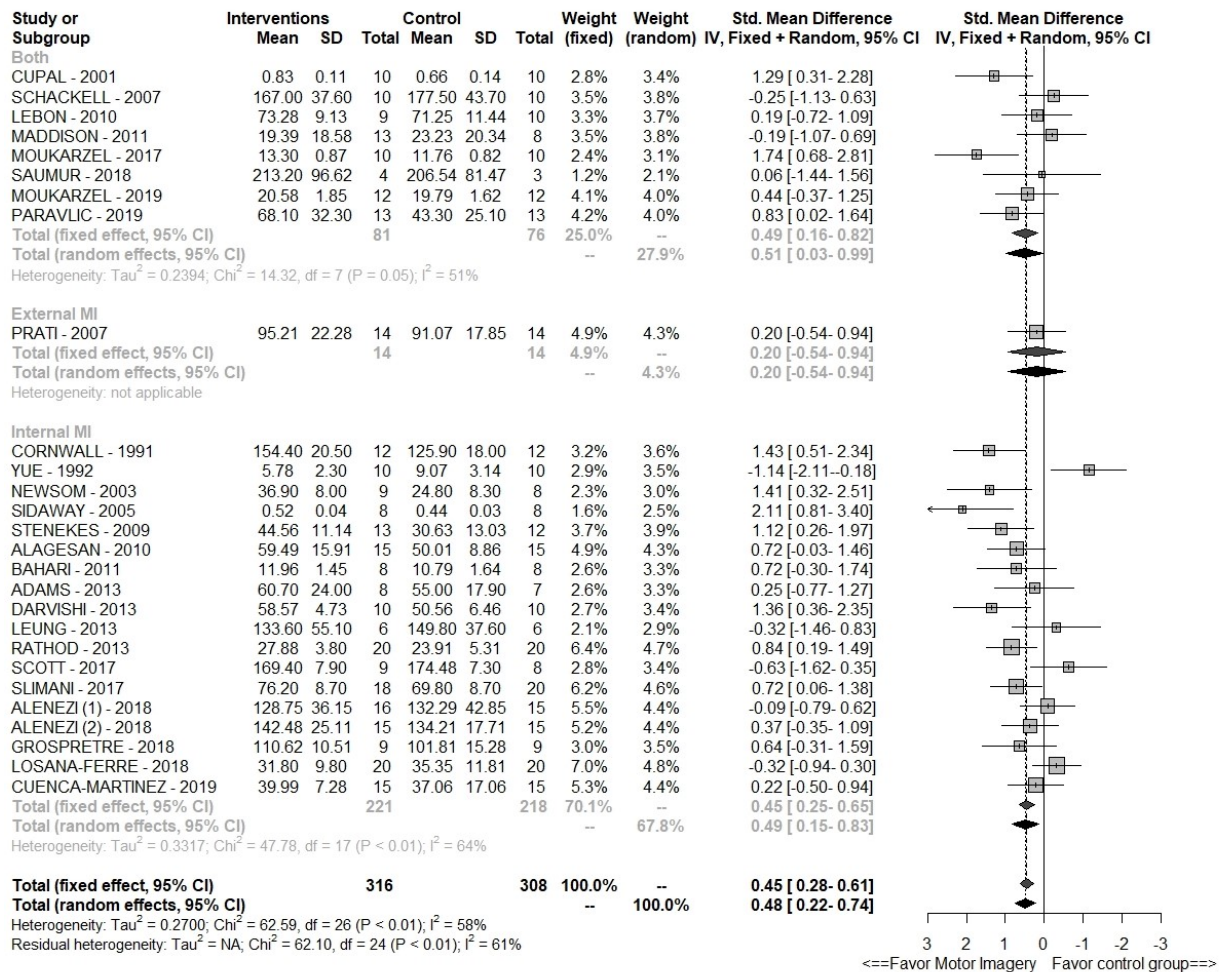
A



B

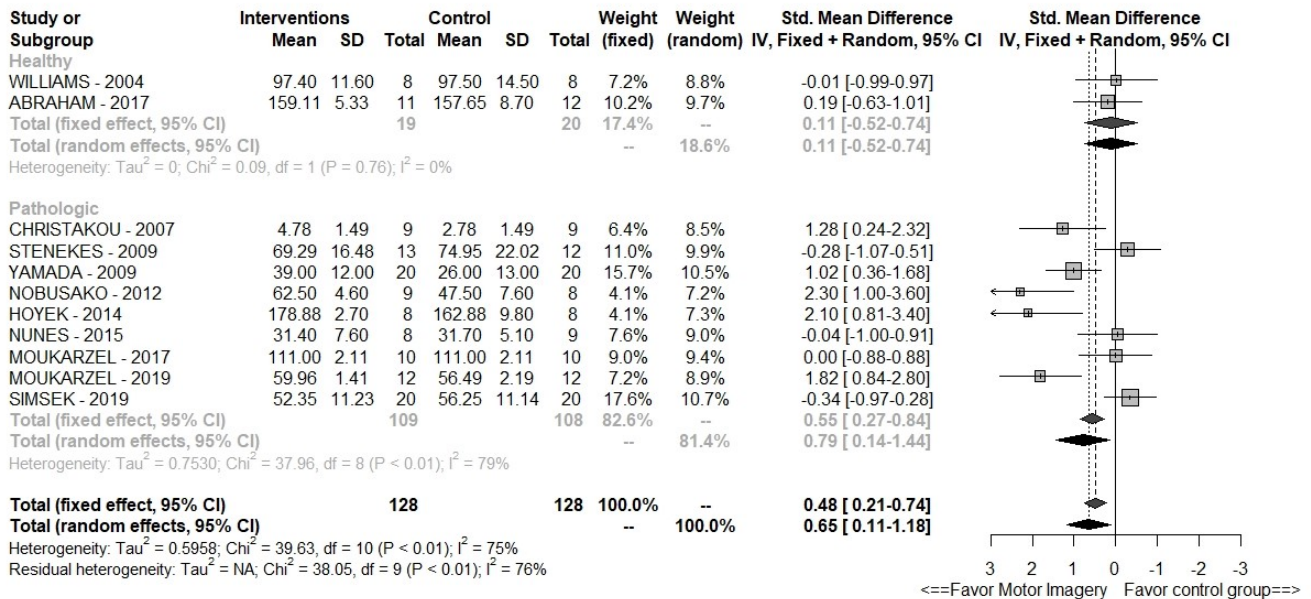


C

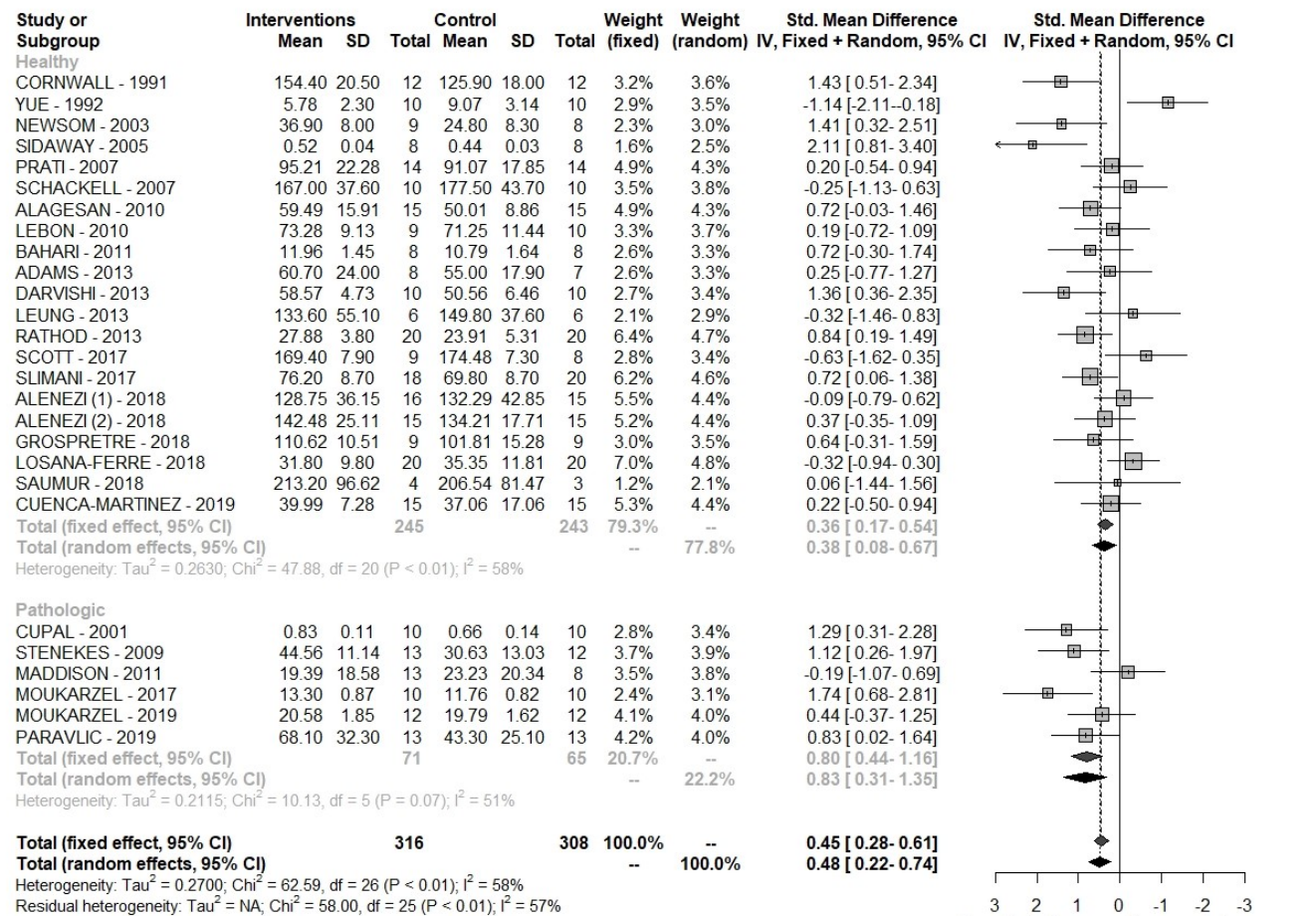


Appendix 4: Sensitivity analysis on range of motion (A) and strength (B), comparing pathological subjects and healthy participants

A



B



6) Serment d'Hippocrate

En présence des Maîtres de cette école, de mes chers condisciples et devant l'effigie d'Hippocrate, je promets et je jure, au nom de l'Être suprême, d'être fidèle aux lois de l'honneur et de la probité dans l'exercice de la médecine.

Je donnerai mes soins gratuits à l'indigent et n'exigerai jamais un salaire au-dessus de mon travail.

Admise dans l'intérieur des maisons, mes yeux ne verront pas ce qui s'y passe, ma langue taira les secrets qui me seront confiés, et mon état ne servira pas à corrompre les mœurs, ni à favoriser le crime.

Respectueuse et reconnaissante envers mes Maîtres, je rendrai à leurs enfants l'instruction que j'ai reçue de leurs pères.

Que les hommes m'accordent leur estime si je suis fidèle à mes promesses. Que je sois couverte d'opprobre et méprisée de mes confrères si j'y manque.

RESUME

Objectifs : L'imagerie motrice (IM) consiste à visualiser mentalement une action sans aucune exécution motrice. Que ce soit sous sa forme explicite ou implicite, l'IM implique l'activation des mêmes réseaux corticaux que l'exécution motrice. L'IM est de plus en plus utilisée dans divers contextes - rééducation locomotrice, entraînement physique ou maladies neurologiques. Cette revue systématique vise à étudier les effets de l'IM dans des conditions non neurologiques, sur la douleur, les amplitudes articulaires et la force motrice, en plus des pratiques habituelles. De plus, nous avons cherché à évaluer l'influence de différentes modalités de pratique d'IM sur l'amélioration de ces trois critères de jugement.

Méthodes : 8 bases de données et la littérature grise ont été interrogées jusqu'en mars 2020. 2 évaluateurs indépendants ont examiné les résultats de la recherche pour n'inclure que les essais contrôlés randomisés. Les données concernant la douleur, les amplitudes articulaires et la force musculaire ont été récupérées. La qualité méthodologique a été évaluée à l'aide de l'outil "Risk of bias 2" de la Cochrane. Des méta-analyses ont été réalisées avec un modèle à effets aléatoires après avoir testé l'hétérogénéité.

Résultats : 46 études ont répondu aux critères requis et 41 ont été incluses dans l'analyse quantitative, dont 470 sujets dans le groupe IM et 455 dans le groupe témoin. Il existe une différence de moyenne standardisée significative entre le groupe IM et le groupe contrôle en ce qui concerne la réduction de la douleur (SMD -1.14, 95 % IC, -1.80 à -0.48 ; $P < 0,01$), le gain de force (SMD 0.48, 95 % IC, 0.22 à 0.74 ; $P < 0.01$) et l'amélioration des amplitudes articulaires (SMD 0.65, 95 % IC, 0.11 à 1.18 ; $P < 0.01$).

Conclusion : L'IM réduit significativement la douleur avec une taille d'effet importante, sans atteindre la différence minimale cliniquement pertinente. Elle favorise également le gain de force et aide à la récupération des amplitudes articulaires avec une taille d'effet modérée.

Mots-clés : Imagerie mentale, imagerie motrice, rééducation locomotrice, troubles musculo-squelettiques, entraînement physique.