Osteoarthritis and Cartilage 27 (2019) 196–218

Osteoarthritis and Cartilage

Review

Sleep interventions for osteoarthritis and spinal pain: a systematic review and meta-analysis of randomized controlled trials

K.K.N. Ho † *, P.H. Ferreira †, M.B. Pinheiro †, D. Aquino Silva ‡, C.B. Miller §, R. Grunstein §, M. Simic †

† *The University of Sydney, Musculoskeletal Research Group, Faculty of Health Sciences, 75 East St, Lidcombe, Sydney, 2141 NSW, Australia*
‡ *Universidade Federal de Minas Gerais, Departamento de Fisioterapia, Av. Pres. Antônio Carlos, 6627 Pampulha, Belo Horizonte, MG, Brazil*
§ *CIRUS, Centre for Sleep and Chronobiology, Woolcock Institute of Medical Research, University of Sydney and Sydney Health Partners, 431 Glebe Point Road, Sydney, 2037 NSW, Australia*

ARTICLE INFO

Article history:
Received 13 February 2018
Accepted 24 September 2018

Keywords:
Osteoarthritis
Spinal
Sleep
Pain
Systematic review

SUMMARY

Objectives: To determine if sleep interventions improve pain and sleep in people with osteoarthritis (OA) and/or spinal pain compared to control/placebo.
Design: Medline, Embase, AMED, PsycINFO, CENTRAL, CINAHL and PEDro were searched from their inception date to July 2017. Keywords relating to "sleep", "OA", "spinal pain", and "randomized controlled trial (RCT)" were combined. Included RCTs investigated the use of sleep interventions for people with OA and/or spinal pain, and measured at least one sleep and health related outcome. Meta-analyses were performed to pool mean differences for pain and sleep quality. PROSPERO: CRD42016036315.
Results: Of 1445 unique records, 24 studies were included. Sixteen studies included participants with spinal pain, seven with OA, and one included a mixed population. Sleep interventions included established sleep interventions (ESI) [cognitive behavioural therapy (CBT) and pharmacological interventions], and a range of others. Intervention periods ranged from 4 to 10 weeks. Thirteen studies were of moderate to high quality (PEDro $\geq$ 6/10). Due to high heterogeneity between studies we also performed sub-group and sensitivity analyses. ESI decreased Insomnia Severity Index (ISI) for people with low back pain (LBP) (pooled mean difference: −6.78/28, 95% confidence interval (95% CI): [−9.47, −4.09], $I^2 = 40\%$) and OA (−2.41, [−4.19, −0.63], 0%). However ESI decreased pain for people with LBP (pooled mean difference: visual analogue scale (VAS) −12.77/100, 95% CI: [−17.57, −7.97], $I^2 = 0\%$), but not OA (−2.32, [−7.18, 2.54], 27%).
Conclusion: ESI appeared to improve sleep and pain for people with LBP, and sleep for people with OA. However more vigorous studies need to be conducted.

Introduction

Osteoarthritis (OA), low back pain (LBP), and neck pain (collectively as "spinal pain") are the highest contributors to global disability, with LBP ranking first, neck pain fourth, and OA thirteenth[1]. These conditions share pain mechanisms such as central sensitization[2,3] and abnormal endogenous pain modulation which contribute to their chronicity and co-occurrence[4]. There is evidence of central sensitization in the form of cortical changes in the thalamus for people with OA[5], and in the primary somatosensory cortex for people with LBP[6,7]. People with OA and people with LBP also have widespread hyperalgesia, demonstrated by quantitative sensory tests such as pain pressure thresholds and temporal summation[6,8]. Leading international clinical guidelines for OA and LBP recommend diagnoses based on clinical presentation and a multimodal management approach to address comorbidities which may contribute to pain[9–11]. Insomnia is an important comorbidity to address, being associated with increased frequency of pain over eleven years in

* Address correspondence and reprint requests to: K.K.N. Ho, The University of Sydney, Musculoskeletal Research Group, Faculty of Health Sciences, 75 East St, Lidcombe, Sydney, 2141 NSW, Australia. Tel: 61-2-9351-9010.
E-mail addresses: kevin.ho@sydney.edu.au (K.K.N. Ho), paulo.ferreira@sydney.edu.au (P.H. Ferreira), marina.pinheiro@sydney.edu.au (M.B. Pinheiro), danielle_aquino_silva@hotmail.com (D. Aquino Silva), chris.miller@bighealth.com (C.B. Miller), ron.grunstein@gmail.com (R. Grunstein), milena.simic@sydney.edu.au (M. Simic).

https://doi.org/10.1016/j.joca.2018.09.014

people with spinal pain[12], and greater intensity of pain in people with OA[13]. Insomnia symptoms are highly prevalent in these conditions, with 71% of people with OA[14], 59% of LBP[15], and 41% of neck pain[16] either diagnosed with insomnia or reporting significant insomnia symptoms. These symptoms include poor sleep quality, non-restorative sleep, early awakenings, and difficulty initiating and maintaining sleep[17]. Yet insomnia is a modifiable comorbidity, and its management may improve health outcomes of these patients.

Insomnia disorder[18] is no longer viewed as a consequence of pain or depression but as a parallel condition which requires specific management[18,19]. Many people experience temporary insomnia symptoms due to instances such as major life events, work commitments, or pain[19]. For people with chronic OA or spinal pain, these persistent symptoms of poor sleep habits, irregular sleep scheduling, and fear of not sleeping, can develop into chronic insomnia which does not necessarily resolve from the reduction of pain alone[19]. Chronic insomnia further complicates management for people with OA and spinal pain, being associated with more severe pain presentation[15,20], presence of depression[21,22], and poorer physical function[23,24]. This is likely due to the bidirectional relationship between sleep and pain[25], meaning that poorer sleep may lead to worse pain, and worse pain may lead to poorer sleep. The sleep–pain relationship is presumed to be multifactorial[26], with basal inflammation and altered central pain modulation proposed as mechanistic factors between insomnia and OA pain[13,27,28]. Physical function and mood may also mediate this sleep–pain relationship[13]. While the processes behind this relationship are not fully understood, it is likely that health outcomes can improve for people with OA and spinal pain through the management of insomnia symptoms.

Insomnia can be effectively treated with established sleep interventions (ESI), namely cognitive behavioural therapy (CBT) and pharmacological interventions[29]. CBT is the first line intervention for insomnia[29], but if unsuccessful may be combined with short term use of pharmacological interventions[29,30], as prolonged use of pharmacological interventions might result in tolerance and dependence issues[31]. There have been a few randomized controlled trials (RCTs) evaluating the use of CBT for sleep quality in people with chronic pain. These reported significant improvements in sleep quality, but varied results for pain and physical function[27,32–37]. Two systematic reviews[38,39] have examined the use of sleep interventions for people with chronic pain, reporting moderate improvements in sleep quality and small reductions in pain. However these reviews were limited to non-pharmacological sleep interventions, included participants with widespread pain conditions (e.g., cancer and fibromyalgia) which differ to the localized nature of OA and spinal pain, nor focused on OA or spinal pain. Therefore, the efficacy of sleep interventions OA and spinal pain, the most prevalent conditions which share common pain mechanisms, treatment approaches and insomnia comorbidity, have not been summarized. Furthermore, several RCTs examining sleep interventions for OA and spinal pain have recently been published[32,40–45], warranting a more current and specific review.

The aim of this systematic review and meta-analyses was to determine the efficacy of sleep interventions in improving pain and sleep for people with OA and/or spinal pain, compared to control/placebo. The secondary aim was to determine the efficacy of sleep interventions on other health related outcomes, including physical function, and health related quality of life.

Methods

Data sources and searches

We searched the following electronic databases: Medline, Embase, AMED, PsycINFO, CENTRAL, CINAHL and PEDro. Searches were from their inception date to April 2016 and an updated search was performed in July 2017. The search strategy comprised of the key terms such as: “sleep”, “OA”, “spinal pain”, and “RCT” and limited to human studies (Appendix 1). Citation tracking was performed for included studies and relevant reviews. This review was registered with the International Prospective Register of Systematic Reviews (CRD42016036315) and written in accordance to the 2015 PRISMA Statement[46].

Inclusion and exclusion criteria

Eligible studies were RCTs published in peer reviewed journals which investigated the use of sleep interventions for participants with OA or spinal pain, by evaluating at least one other health related outcome and one sleep outcome. To be comprehensive for which types of sleep interventions were effective or non-effective for people with OA, LBP or neck pain, we used a broad definition for sleep interventions and planned for subgroup analyses. We excluded other publication types (e.g., guidelines, reviews, and conference abstracts). There were no restrictions on participant age, gender, race, or ethnicity. There were no restrictions of language or geographic location of studies. Non-English studies were translated (German, Korean and Russian).

Population

We defined OA as a chronic disease of a whole joint associated with symptoms of pain. Likewise we defined spinal pain as non-specific cervical, thoracic, lumbar pain, or a combination of these. We also accepted the study's definition of OA and spinal pain. We included participants with spinal pain in acute, sub-acute, and chronic stages or OA in any joint. Studies investigating both OA and spinal pain were included. Studies investigating general musculoskeletal pain were included if data for OA or spinal pain were reported separately. We excluded studies investigating the following conditions: serious spinal pathologies (e.g., fracture, spinal cord injury, spinal stenosis, and nerve root compromise), cancer, systematic inflammatory conditions (e.g., rheumatoid arthritis), any spinal surgery, joint replacement surgery, other joint surgery within the past 6 months (e.g., arthroscopies), and fibromyalgia. Insomnia diagnosis was not required for inclusion, however we excluded studies investigating people with sleep movement or breathing disorders (e.g., sleep apnea and restless leg syndrome) as these present differently to insomnia.

Sleep and comparison interventions

Sleep interventions were defined as interventions which aim to directly improve sleep related outcomes. We only included studies that had this definition within the article title, abstract, or methods. Both non-pharmacological and pharmacological interventions were included. Studies with multimodal sleep interventions or sleep interventions as an adjunct were also included. No restrictions were placed on the comparison group and could include control (no intervention, waiting list), placebo, or any intervention.

Outcomes

Included studies had to evaluate at least one health related outcome and one sleep related outcome. Health related outcomes included but were not limited to: pain, physical function, and health related quality of life. Sleep outcomes included any measure of sleep efficiency, quality, or insomnia such as: % sleep efficiency ([total sleep duration]/[total time spent in bed])[47], Insomnia Severity Index (ISI)[48], and Pittsburgh Sleep Quality Index (PSQI)[49].

Study inclusion and data extraction

Titles and abstracts of potentially eligible articles from the search yield were screened independently by two reviewers (KH and DAS), whom then screened the full text of potentially eligible articles. Any disagreements were resolved with a third reviewer (MS). Data from included studies were extracted into spreadsheets independently by two reviewers (KH and DAS) and scrutinized for errors. Reviewers piloted study screening ($n = 20$) and extraction ($n = 5$) protocols and refined it accordingly. The following data was extracted: recruitment methodology and criteria, participant demographics, sample size and follow-up rates, sleep outcomes, pain outcomes, other heath related outcomes, adherence and credibility outcomes, statistical methodology and adverse events. For participant outcomes, mean estimates were extracted in the following hierarchy: final values, change scores, mean differences. Baseline, post-intervention, and follow-up data were extracted where possible. We contacted nine authors for further information regarding participant demographics, where four authors provided data.

Methodological quality assessment

Methodological quality of eligible studies was evaluated using the PEDro scale[50]. Quality scores of studies available from the PEDro database were extracted. For all other studies PEDro scores were independently evaluated by two reviewers (KH and DAS), with any disagreements resolved with a third reviewer (MS).

Data synthesis and analysis

A narrative synthesis of the findings from included studies was performed, structured around population characteristics, intervention content, and outcomes. We performed meta-analyses on non-standardized mean differences to determine the effect of the sleep interventions on pain, sleep, physical function, and health related quality of life outcomes. The scores from different instruments were converted to a scale of 0–100 and non-standardized mean differences were calculated. Heterogeneity was assessed using Chi-squared Tests and I-squared statistics. If substantial heterogeneity was found ($I^2 > 50\%$), we performed a random-effects meta-analysis and calculated 95% confidence intervals (95% CIs) and two-sided P values for each outcome. Our main analyses were the comparisons between sleep interventions vs control/placebo. We planned to conduct sensitivity analyses based on study quality (PEDro score ≥ 6)[50], comparator intervention, and where possible, subgroup analyses by the following order: sleep intervention type (e.g., ESI), condition, stage of condition and joint(s) affected. If studies had more than one comparison group, the choice of comparison group followed the hierarchy: placebo, control, and others. Analyses were conducted with Review Manager Version 5.3.5.

Results

Included studies

The search strategy identified 1445 unique articles (Fig. 1). After screening, 24 RCTs were included with 23 RCTs being included in the meta-analyses. Meta-analyses included 1551 participants (1123 female) with mean age of 53 years (range = 33–73). Overall characteristics of included studies[27,32–37,40–45,51–61] were detailed in Table I, and additional study characteristics were listed in Appendix 2. Eight studies collected follow-up data, ranging from 1 to 18 months post-intervention. Within our included studies there were two cases of duplicated studies reporting results on the same cohort, with the latest publication reporting longitudinal data[45,52] on their respective RCTs[33,55]. Data values from the most recent publication were analysed.

Participants

Studies included participants with chronic non-specific LBP[41,42,51,53,54,56] ($n = 6$), chronic non-specific neck pain[44,52,55,58–60] ($n = 6$), any spinal pain[34–36,61] ($n = 4$), knee OA[32,40,43,57] ($n = 4$), general OA[27,33,45] ($n = 3$), and a combination of people with spinal pain and/or OA[37] ($n = 1$). All studies classified chronic LBP as pain lasting longer than at least 3–6 months. Neck pain diagnosis criteria included assessment of neck range of motion and muscle tenderness[52,55,59] ($n = 3$). Diagnosis of OA was based on radiographic criteria[27,32,43,57] ($n = 4$), or clinical criteria[33,37,40,45] ($n = 4$). Eleven studies[27,32–37,41,45,57,60] reported inclusion criteria for sleep symptoms. These included the Diagnostic and Statistical Manual of mental disorders Fifth Edition[19] (DSM-5) definition of insomnia[27,32,33,35–37,41,45] ($n = 8$); any sleep complaints[34] ($n = 1$), PSQI >5[57] ($n = 1$), and delayed melatonin onset[60] ($n = 1$).

Sleep and comparison interventions

Sleep interventions and intervention protocols varied across included studies. ESI included CBT[27,32–37,45] ($n = 8$), melatonin[42,60] ($n = 2$), and eszopiclone[41] ($n = 1$). Other sleep interventions included pillows[43,52,55,58,59] ($n = 5$), exercise[40,44,53] ($n = 3$), massage[54,56] ($n = 2$), singing bowls[61] ($n = 1$), acupuncture[57] ($n = 1$), and mattresses[51] ($n = 1$). Nine studies combined a sleep intervention in addition to a pain intervention: CBT for insomnia with CBT for pain[33,35,37,45] ($n = 4$), a sleep pharmacological intervention with a pain pharmacological intervention[41,42] ($n = 2$), pillow with physiotherapy intervention[52,55] ($n = 2$), and acupuncture for sleep with acupuncture for pain[57] ($n = 1$). All interventions except pillows, mattresses and pharmacological interventions were delivered face-to-face in individual or group settings. Intervention periods ranged from 2 to 12 weeks, and most face-to-face interventions occurred weekly. All CBT for insomnia was face-to-face and had some variations in content, but all focused on at least two of the recommended components: sleep restriction, stimulus control, and cognitive restructuring[62]. There was no sleep intervention specifically tailored to certain age groups.

Comparison groups and adverse events

There were a variety of comparators: sham/behavioural placebo[32,41,42,57,60,61] ($n = 6$), education/wait list control[27,33–37,40,43,45,52,54–56] ($n = 13$), or pain interventions[33,35,44,45,51,53,57–59] ($n = 9$). Investigations into adverse events were reported in seven studies[32,40,41,53,57,60]. There were no reports of adverse events associated with CBT[32] ($n = 1$) or exercise[40,44,53] ($n = 3$), while headaches were associated with eszopiclone[41] (0.06% intervention, 0.04% placebo), melatonin[60] (0.03% intervention), and increased pain was reported in one study of acupuncture (0.04%)[57].

Risk of bias within studies

Study quality was moderate with a mean PEDro score of 6.3/10 (range 3–9) (Table II). Thirteen studies were of moderate to high study quality (PEDro $\geq$ 6/10). All studies had randomization, but only ten had concealed allocation. Given that most sleep interventions were face-to-face, only 13 studies included blinding either in the form of subjects ($n = 10$), therapists ($n = 2$), and

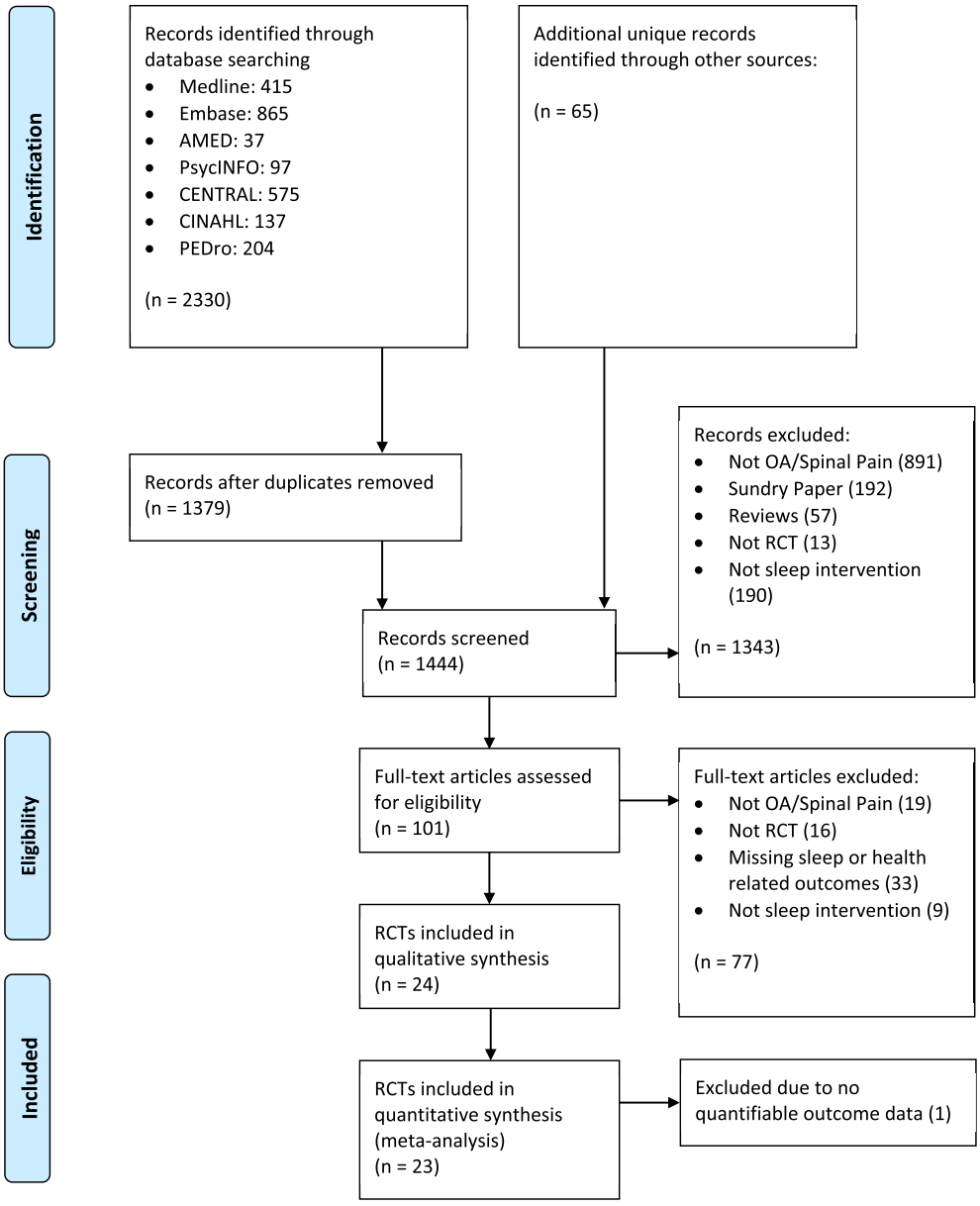


Fig. 1. Selection process for RCTs.

assessors (n = 10). Average follow-up rate was 91.2% at post-intervention. One study did not report quantitative data between groups for pain outcomes[60] and one for sleep outcomes[42].

Synthesis of results

All overall pooled post-intervention results including all sleep interventions, pain conditions and comparator groups demonstrated high heterogeneity, hence subgroup and sensitivity analyses were performed (Table III, Figs. 2 and 3). Studies[33,35,45,57] with three or more comparison arms had data included from their respective comparison groups for sensitivity analyses. Studies involving participants with more than one condition[34–37] were classified as one subgroup if it had majority (>60%). Post-hoc, we stratified analyses based on ESI[29] and performed sensitivity analyses of studies which had adequate sleep problems at baseline, as this was uncertain in many non-ESI studies. Studies with confirmed sleep problems at baseline either had the DSM insomnia as inclusion criteria, or sample majority within the PSQI/ISI thresholds[48,49] (within 2 standard deviations).

These subgroup analyses achieved satisfactory homogeneity for most outcomes and consistent findings when compared to the pooling of all sleep interventions (Table III, Appendix 4). Follow-up data were analysed in accordance of two groupings (1–9 months, and 10–18 months) due to high variability in reported time points, using the longest follow-up value available. Inspection of funnel plots revealed no evidence of publication bias (Appendix 3). Only one study[45] reported 10–18 months follow-up of an ESI.

Question 1 Do sleep interventions improve pain compared to control/placebo?

The visual analogue scale (VAS) at rest was the most common pain outcome[32,33,36,37,41,42,44,45,51–56,58,59,61] (n = 17, Appendix 2). For people with LBP, ESI improved pain at post-intervention

Table I
Characteristics of 24 studies investigating sleep and pain

Author, Year	Condition	Condition criteria	Sleep criteria	No. (% Female)	Age (SD)	Intervention arms	Treatment content	Treatment dosage/Duration
Bergholdt, 2008	Chronic LBP	Age: 18–60 years Duration: >6 months	No	141 (65)	42.0 (7.2)	Waterbed mattress	Water mattress with 4 horizontal layers of fibres.	All interventions used nightly, for 4 weeks
						Body contour foam mattress	Mattress with temperature sensitive pressure relieving material that moulds to the person.	
						Firm Mattress	Foam core mattress surrounded by 3 layers of cotton.	
Eadie, 2013	Chronic LBP	Age: 18–70 Duration >3 month or >3 episodes in 12 months. European Guidelines for the management of chronic non-specific LBP 2006	No	60 (62)	45 (13.4)	Walking program	Graded activity approached based on American College of Sports Medicine guidelines. Weekly review with CBT trained physiotherapist.	Individual sessions 1×/week for 8 weeks.
						Supervised exercise class	"Back to Fitness" program endorsed by UK National Institute of Health and Clinical Excellence guidelines, with CBT trained physiotherapist.	Group classes 1×/week for 8 weeks.
						Usual physiotherapy (control)	Individualized education/advice, exercise therapy, and manipulative therapy at the discretion of the treating CBT trained physiotherapist based on usual practice.	Sessions as determined by physiotherapist, for 8 weeks.
Field, 2007	Chronic LBP	Duration >6 months	No	30 (47)	41 (NR)	Massage therapy	Massage to the back, legs, neck and abdomen.	30 min sessions, 2×/week, for 5 weeks.
						Relaxation therapy (Control)	Progressive relaxation home exercises including tensing and relaxing large muscle groups starting with the feet and progressing to the calves, thighs, hands, arms, back and face.	Initial session then follow up calls 1×/week, for 5 weeks.
Goforth, 2014	Chronic LBP	Age: 24/64 VAS >40/100 Duration >3/12	DSM-IV-TR for Insomnia† ISI >14	58 (63)	42.5 (11.9)	Eszopiclone and Naproxen	3 mg Eszopiclone + 500 mg Naproxen, taken 30 min before sleep.	2 tablets nightly, for 4 weeks
						Placebo and Naproxen	Placebo + 500 mg Naproxen, taken 30 min before sleep.	2 tablets nightly, for 4 weeks.
Hernandez, 2009	Chronic LBP	Duration >6 months	No	24 (54)	39.6 (15.2)	Massage therapy	Massage to the back, legs, neck and abdomen.	30 min sessions, 2×/week, for 5 weeks.
						Relaxation therapy (Control)	Progressive relaxation home exercises including tensing and relaxing large muscle groups starting with the feet and progressing to the calves, thighs, hands, arms, back and face.	Initial session then follow up calls 1×/week, for 5 weeks.
Kurganova, 2015	Chronic LBP	VAS >3/10 Duration >12 weeks	No	60 (77)	53 (6.6)	Melaxin + APTPA	Melaxen 1 tablet (3 mg of melatonin), 30–40 min before sleep.	Melaxin: 1×/day, for 3 months.
						APTPA only	APTPA 1 tablet (500 mg of glucosamine hydrochloride and 500 mg of chondroitin sulphate)	APTPA: 2×/day for 1 month, then 1 tablet 1×/day for 2 months.
Bernateck, 2007	Chronic cervicobrachialgia	International Classification of Diseases 10	No	149 (82)	51.4 (6.7)	Physiotherapy	Thermal modalities massage and active exercise.	35 min, ≥1/day, for 4 weeks.
						Physiotherapy + Pillow	Physiotherapy as above. 50 × 32 × 15 cm polyurethane pillow, used daily. Participants educated by a physiotherapist on use.	As above and pillows nightly.
Gutenbrunner, 1999	Chronic cervicobrachialgia	International Classification of Diseases 10	No	149 (82)	51.4 (6.7)	Physiotherapy	Thermal modalities massage and active exercise.	35 min, ≥1/day, for 4 weeks.
						Physiotherapy + Pillow	Physiotherapy as above. 50 × 32 × 15 cm polyurethane pillow, used daily. Participants educated by a physiotherapist on use.	As above and pillows nightly.

Jochem, 1997	Neck pain	Age: 40–70 years Sleep duration >6 h (For pillow use)	No	20 (55)	51.9 (8.6)	"The pillow"	Polyester cushion with soft upper layer and hard lower layer. Curved slot for head.	Pillows used nightly for 2 weeks
						Standard pillow (Control)	Smooth rectangular pillow with feather or synthetic filling.	
Lavin, 1997	Neck pain	Mechanical neck pain confirmed by physical examination	No	41 (51)	48 (NR)	Water pillow	Soft polyester fibre over 3.8 cm water base.	Pillows used nightly, for 2 weeks
						Roll pillow	Polyester fibre filled roll pillow, 43 cm × 17.8 cm.	
						Standard pillow	Client's current pillow, usually standard down or foam pillow.	
Lee, 2016	Neck pain	VAS >4/10	No	50 (24)	47 (13.3)	Functional pillow	Combination of cotton, polyester and memory foam layers. 65 cm × 35 cm × 18 cm	Pillows used nightly, up to 4 weeks or discharge
						Standard pillow	Cotton pillow. 40 cm × 60 cm × 15 cm	
Van Wieringen, 2001	Chronic whiplash associated disorder	Age >18 Involved in rear-end car collision >6 months ago.	Delayed dim-light melatonin onset.	81 (73)	33.4 (10.7)	Melatonin	Oral exogenous melatonin 5 mg, mixed with crystalline cellulose in a tablet	1 Tablet, nightly, 5 h before Dim Light Melatonin Onset, for 4 weeks
						Placebo	Identical looking tablet	
Currie, 2000	Chronic pain: LBP 72% Neck pain 20% Lower limbs 5% Pelvic 3%	Age: <60	Any sleep complaint	60 (55)	45 (8.0)	CBT insomnia	Sleep diary review, education, behaviour therapy, relaxation training, cognitive component thoughts and attitudes and sleep hygiene.	2 h group sessions, 1×/week for 7 weeks.
						Wait list control	Sleep diary review only.	10 min individual phone calls, 1×/week for 7 weeks.
Jungquist, 2010	Spinal pain 64% LBP 32% Neck pain 4% Thoracic pain	Age: > 25 Duration >6 months	Similar to DSM-5 criteria, but duration >6 months*	28 (78)	48.7 (10.7)	CBTI	CBT insomnia: Sleep restriction therapy, stimulus control instructions, sleep hygiene instructions, and one session of cognitive therapy.	Both interventions were individualised 45–90 min sessions, 1×/week for 8 weeks
						Control	Sleep/Pain Diary weekly review. Interrogative rather than therapeutic.	
Pigeon, 2012	Spinal Pain	Non-malignant pain originating in the spine, shoulders, hips or limbs. Duration >6 months	Similar to DSM-5 criteria, but duration >6 months*	21 (33)	50.7 (8.3)	CBT insomnia and pain	Combination of the two CBT therapies below	Individual sessions 1×/week, for 10 weeks.
						CBT insomnia	Sleep education, sleep restriction therapy, stimulus control therapy, sleep hygiene, sleep-specific cognitive therapy, relaxation training, and relapse prevention.	
						CBT pain	Pain psychophysiology education, relaxation training, pacing, pain-specific cognitive therapy, activity planning, problem-solving, communication skills, flare-up planning and relapse prevention. Daily Sleep Diaries.	
						Wait List Control:	Daily Sleep Diaries only	
Tang, 2012	85% Spinal pain, 35% OA, 30% Both	Age: 18–65 Brief Pain Inventory-Present Pain Intensity> 4 Duration >6 months	DSM-IV-TR for insomnia† ISI >15/28	20 (90)	48.5 (8.6)	CBT pain and insomnia	Insomnia treatment included sleep psychoeducation, stimulus control therapy, sleep restriction therapy, cognitive therapy. Pain treatment included individual formulation, goal setting and behavioural activation, reducing pain catastrophising and safety-seeking behaviour, reversing mental defeat.	Individual 2 h sessions 1×/week, for 4 weeks
						Symptom monitoring	Reviewed pain and sleep diary	

(*continued on next page*)

Table 1 (*continued*)

Author, Year	Condition	Condition criteria	Sleep criteria	No. (% Female)	Age (SD)	Intervention arms	Treatment content	Treatment dosage/Duration
Wepner, 2008	Spinal pain	Age: 20–60 years Pain from back or neck >3 months.	No	84 (63)	47.06 (9.3)	Singing bowls	Crystal singing bowels were struck to produce harmonic vibrations and sound and moved around the proximity patient's pain.	6 sessions over 4 weeks
						Placebo	As above, but the bowls were not struck.	
Cheung, 2014	Knee OA	Age: 65–90 Duration >6 months American College of Rheumatology classification criteria for knee OA.	No	36 (100)	72 (5.2)	Yoga	Hatha yoga designed specifically for knee OA, with components of poses, breathing and meditation. Instructed to do 30 min home exercise program to be done 4×/week. Performed by certified yoga teachers with >10 years of experience.	60 min/session, 1×/week, for 8 weeks
						Wait-list control	Instructed to carry on usual care.	8 weeks.
Huang, 2010	Knee OA	Age >55 Kellgren and Lawrence Grade 2–4 Self-report knee pain >50% of the time	PSQI >5	24 (NR)	NR	TSsP TPsS TSTP sSsP	True sleep acupuncture + Sham pain acupuncture True pain acupuncture + sham sleep acupuncture True sleep acupuncture + True pain acupuncture Sham sleep acupuncture + Sham pain acupuncture Acupuncture needles selection based on Traditional Chinese Medicine theory	30 min sessions, 2×/week for 4 weeks, then 1×/week for 4 weeks, (8 weeks total)
Lu, 2017	Knee OA	Age: 60–70 American College of Rheumatology classification criteria for knee OA. Kellgren/Lawrence Grade ≥1	No	46 (100)	64.5 (3.4)	Tai Ji Quan	Training protocol followed an easy-to-difficult progression, with standing exercises focussing on posture, balance, weight bearing, and closed chain knee flexion and extension exercises. Exercises were integrated with rhythmic breathing and classes were led by two Tai Ji Quan specialists.	60 min/session, 3×/week, for 24 weeks
						Control	Wellness education lectures specific to knee OA and performed by multidisciplinary staff. Monitored by 10–15 min weekly check-in phone calls.	60 min/session, 2×/week, for 24 weeks
McCurry, 2014	OA	Age >60 Grade II to IV pain on the Graded Chronic Pain Scale	DSM-IV-TR for insomnia†	367 (78)	73 (8.2)	CBT pain and insomnia	Pain CBT as below and standard CBT for insomnia (sleep hygiene education, stimulus control, sleep restriction, and daily sleep monitoring).	All interventions were 90 min group sessions 1×/week, for 6 weeks,
						CBT pain	Pain education, physical activation, goal setting, relaxation, activity pacing, guided imagery, cognitive restructuring.	
						Education only control	Educational content related to pain and sleep management. Classes facilitated in nondirective, self-help format.	
Smith, 2015	Knee OA	American College of Rheumatology criteria for classification of knee OA Kellgren/Lawrence Grade ≥1	DSM-IV-TR for Insomnia†	100 (79)	59.4 (9.5)	CBT insomnia:	Sleep restriction therapy, stimulus control therapy, cognitive therapy for insomnia, sleep hygiene education.	Individual 45 min sessions 1×/week, for 8 weeks,
						Behavioural desensitization (Placebo)	Presented as a means of eliminating the conditioned arousal through imagery.	
Vitello, 2009	OA	Age: >55 OA: Physician-diagnosed osteoarthritis confirmed by a radiograph or magnetic	Similar to DSM-5 criteria, but duration >6 months*	51 (88)	67.85 (8.3)	CBT insomnia	Stimulus control, sleep restriction, cognitive restructuring, relaxation training, sleep-hygiene education	2 h group sessions 1×/week, for 8 weeks
						Stress management and wellbeing	Designed as an attention control but did have several components that had modest effect on chronic pain.	

		resonance imaging study				
Vitello, 2013	OA	Age >60 Grade II to IV pain on the Graded Chronic Pain Scale	DSM-IV-TR for insomnia†	367 (78)	73 (8.2)	CBT pain and insomnia	Pain CBT as below, and standard CBT for insomnia (sleep hygiene education, stimulus control, sleep restriction, and daily sleep monitoring).	All interventions were 90 min group sessions 1×/week, for 6 weeks.
						CBT pain	Pain education, physical activation, goal setting, relaxation, activity pacing, guided imagery, cognitive restructuring.	
						Education only control	Educational content related to pain and sleep management. Classes facilitated in nondirective, self-help format.	

CBT = Cognitive Behavioural Therapy; DSM-V = Diagnostic and Statistical Manual of mental disorders Fifth Edition; DSM-IV-TR = Diagnostic and Statistical Manual of mental disorders Fourth Edition Text Revision; LBP = Low Back Pain; OA = Osteoarthritis; VAS = Visual Analogue Scale.

* Satisfies DSM-5 criteria: difficulty falling asleep for at least 3 nights each week for 3 months or more. Diagnosis is based on exclusion of other sleep disorders (e.g., restless leg syndrome and sleep apnea) as well as any other major psychological disorders (e.g., severe depression).

† DSM-IV-TR differs from DSM-5 with symptom during duration being only 1 month or more.

(−12.77/100, 95% CI: [−17.57, −7.97], I^2 = 0%, n = 200, 4 studies[34,36,41,42]), and one study[34] reported follow-up data which showed improvement at 3 months. For people with OA, ESI did not improve pain at post-intervention (−2.32 [−7.18, 2.54], 27%, n = 377, 3 studies[27,32,33]), or at 1–9 months follow-up (−0.27, [−6.59, 6.05], 0%, n = 297, 2 studies[32,33]). For people with neck pain there were no RCTs evaluating an ESI. Exercise[40,43,53] did not improve pain at post-intervention.

Question 2 Do sleep interventions improve sleep compared to control/placebo?

The most prevalent sleep outcomes were diary reported sleep efficiency[27,32–37,41,43,45] (n = 10, mean = 74.9, range = 0–100%, higher scores better), ISI[32,33,35–37,41,45,53] (n = 8, mean = 16.4, range = 0–28, lower scores better), PSQI[34,40,42–44,53,57] (n = 7, mean = 10.2, range = 0–21, lower scores better), and sleep disturbance scale[63]. Meta-analyses of sleep outcomes are presented in Table III.

Sleep efficiency. For people with LBP, ESI improved diary reported sleep efficiency at post-intervention (12.78/100, 95% CI: [8.32, 17.42], I^2 = 15%, n = 140, 3 studies[34,36,41]), and one study[34] reported follow-up data which showed improvement at 3 months. For people with OA, ESI (only CBT identified) improved sleep efficiency post-intervention (3.92, [1.27, 6.56], 33%, n = 362, 3 studies[27,32,33]), but not at 1–9 months follow-up (2.84, [−0.04, 5.72], 0%, n = 297, 2 studies[32,33]).

Insomnia Severity Index. For people with LBP, ESI improved ISI at post-intervention (−6.78/28, 95% CI: [−9.47, −4.09], I^2 = 40%, n = 86, 2 studies[36,41]), but no studies had follow-up data. For people with OA, ESI (only CBT identified) improved sleep efficiency for people with OA at post-intervention (−2.41, [−4.19, −0.63], 0%, n = 336, 2 studies[32,33]). There was one study which reported 1–9 month follow-up[33] and one which reported 10–18 month follow-up[45], and both showed no change in ISI.

Pittsburgh Sleep Quality Index. When all sleep interventions and conditions were pooled, PSQI significantly improved at post-intervention by −2.13/21 (95% CI: [−3.75, −0.51], I^2 = 56%, n = 154, 4 studies[34,40,43,57]). There was one RCT[34] which used an ESI and in the overall pooling (Fig. 2), this was the only study which demonstrated a significant effect for PSQI. Exercise did not improve PSQI at post-intervention for people with OA or LBP.

Question 3 Do sleep interventions improve other health related outcomes compared to control/placebo?

For people with LBP, ESI improved depression at post-intervention (−4.93/100, 95% CI: [−7.89, −1.98], I^2 = 10%, n = 140, 3 studies[34,36,41]), however one study[34] reported follow-up data and showed no improvement. ESI did not improve physical function for people with either OA or LBP. For the outcomes of mental quality of life[40,43,53,61], physical quality of life[40,43,53,61] and anxiety[37,53,54,56] the overall pooling of sleep interventions and conditions revealed no significant change and the pooling of ESI could not be performed. Hence these analyses are represented in Appendix 4.

Other subgroup analyses

Sensitivity analyses where the comparison group only included interventions not aimed at sleep (i.e., pain interventions), identified that ESI were not better at improving any outcome compared to pain interventions alone when pain conditions were pooled together (Table III). Pillows[44,52,58,59] did not improve pain at post-intervention when compared to another pain intervention/pillow.

Table II
PEDro criteria for included studies

	Bergholdt, 2008	Bernateck, 2007*	Cheung, 2014*	Currie, 2000*	Eadie, 2013*	Field, 2007*	Goforth, 2014	Gutenbrunner, 1999	Hernandez-reif, 2009*	Huang, 2010	Jochem, 1997*	Jungquist, 2010	Kurganova, 2015	Lavin, 1997*	Lee, 2016	Lu, 2017*	McCurry, 2014	Pigeon, 2012	Smith, 2015	Tang, 2012*	Van Wieringen, 2001	Vitiello, 2009*	Vitiello, 2013	Wepner, 2008
Eligibility criteria (not scored)	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Randomized allocation	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Concealed Allocation	1	0	1	0	1	0	1	0	1	0	0	1	0	0	0	0	0	0	1	0	1	1	0	1
Comparable at baseline	1	1	1	1	1	1	1	1	0	0	1	1	1	0	1	1	1	0	1	1	1	1	1	0
Blinded subjects	0	0	0	0	0	0	1	0	1	1	0	1	0	0	0	0	1	0	1	0	1	1	1	1
Blinded therapists	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Blinded assessors	1	0	1	0	1	0	1	0	0	0	0	1	0	0	1	1	1	1	1	0	1	0	1	0
Adequate follow-up	0	1	1	0	0	0	0	1	0	1	1	0	1	0	1	1	0	0	1	0	1	1	1	1
Intention to treat analysis	1	0	1	1	1	0	1	0	0	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1
Between group comparisons	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Point estimates and variability	1	0	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1
Total Score (0-10)	7	4	8	5	7	3	9	4	5	6	5	8	6	3	7	7	7	5	9	5	9	7	8	7

Total Score: Red = Poor quality, Yellow = Moderate Quality, Green = High Quality
*PEDro Score provided from the PEDro database.

Sensitivity analyses of studies which had confirmed baseline sleep problems did not significantly change the results. Subgroup analyses stratified by condition and including all sleep interventions yielded inconsistent and heterogeneous results for all outcomes (Appendix 4).

Discussion

Overall summary of findings

Overall pooling of all sleep interventions and pain conditions led to inconsistent findings due to high variability in the efficacy of sleep interventions and inclusion of people without insomnia symptoms. Our main findings were therefore based on subgroup analyses of a few studies. For people with LBP, ESI improved pain, sleep efficiency, ISI, PSQI and depression. For people with OA, CBT improved sleep efficiency and ISI, however no effects on pain were identified. For people with neck pain, there were no RCTs which evaluated ESI.

Did pain and sleep improve with an intervention for sleep?

For people with OA or LBP, sleep interventions can moderately improve multiple dimensions of sleep. To determine whether these effects are clinically worthwhile, we considered the minimal clinical important difference (MCID). For people with chronic LBP, the MCID for pain is 15/100 for physiotherapy treatment, and 20/100 for nonsteroidal anti-inflammatory drugs[64]. The largest improvement in pain for people with LBP were the subgroups CBT (8.49) and pharmacological interventions (15.22), which fall short of the MCIDs determined by their non-pharmacological or pharmacological counterparts. For people with insomnia, the MCID for ISI is 6–7 points[48,65] and 10% for sleep efficiency[66] for ESI. MCIDs for ISI were met with ESI for people with LBP (6.78), and CBT for people with OA (6.35). MCIDs for sleep efficiency were met with ESI for people with LBP (12.87), but not with CBT for people with OA (3.92). Improvements in ISI (2.46) and sleep efficiency (5.50) were maintained up to 9 months with ESI for people with LBP or OA, and though these are below the MCIDs, it is still considerable as most interventions occurred for 6–8 weeks, and OA pain worsens over time[67].

Study strengths and limitations

Overall quality of the studies were of moderate to high quality, however some studies had poor blinding and small sample sizes. Most sleep intervention methodologies were clearly reported and interventions of the same type (e.g., CBT) had similar protocols. Inclusion criteria for people with OA and spinal pain were fairly robust, however only nine studies (39%) had confirmed sleep problems, and these evaluated an ESI. This created uncertainty regarding the efficacy of other interventions such as pillows and exercise, as participants may not have had adequate baseline levels of insomnia symptoms amendable to change. Our stratified analyses by ESI had the most certainty, as most of these RCTs had confirmed sleep problems and reported similar sleep outcomes. However in some of these higher quality RCTs, validity was still compromised particularly for the knee OA studies due to 1) the control having effective behavioral components for pain[27], or 2) inadequate time for the insomnia component due to combination

Table III
Meta-analyses: Pain, sleep and other health outcomes

		No of studies (Ref)	Intervention	Comparison (Control/ Placebo)	Overall effect (95% CI)	I^2	Sensitivity analyses (Mean difference, 95% CI, *I* squared, participants per group, number of RCTs)		
							Comparator: Pain interventions	Adequate baseline sleep problems	Comparator: Control/ Placebo/Any pain
Pain† (0–100)									
Overall (All interventions and conditions)	Post	16[27,32–37,40–43,52,54,56,57,61]	477	463	−6.92 [−11.87, −1.98]*	72%	−5.58 [−9.09, −2.07]*, 0%, 238 vs 250, 8[33,35,44,51,53,57–59]	−3.75 [−11.44, 3.95], 75%, 278 vs 269, 8[27,32–37,41]	−6.22 [−10.24, −2.21]*, 67%, 590 vs 585, 21[27,32–37,40–44,51–54,56–59,61]
	1–9 Mth	5[32–34,52,57]	254	264	−6.42 [−9.62, −3.23]*	24%,	−0.89 [−8.32, 6.55], 0%, 130 vs 134, 3[33,53,57]	−4.00 [−9.03, 1.03], 46%, 172 vs 185, 3[32–34]	−6.00 [−9.16, −2.84]*, 37%, 270 vs 281, 6[32–34,52,53,57]
	10–18 Mth	2[45,52]	177	178	−8.59 [−12.00, −5.18]*	0%	n/a (None)	n/a (One RCT)[45]	n/a (Same)
ESI (All conditions)	Post	9[27,32–37,41,42]	309	298	−5.07 [−12.24, 2.09]	77%	−1.94 [−8.79, 4.92], 0%, 119 vs 122, 2[33,35]	−3.75 [−11.44, 3.95], 75%, 278 vs 269, 8[27,32–37,41]	n/a (Same)
	1–9 Mth (CBT only)	3[32–34]	172	185	−4.00 [−9.03, 1.03]	46%	n/a (One RCT)[33]	n/a (Same)	n/a (Same)
ESI (LBP)	Post	4[34,36,41,42]	114	86	−12.77 [−17.57, −7.97]*	0%	n/a (None)	−12.14 [−18.71, −5.57]*, 21%, 83 vs 57, 3[34,36,41]	n/a (Same)
ESI (OA) (Only CBT)	Post	3[32–34]	179	198	−2.32 [−7.18, 2.54]	27%	n/a (One RCT)[33]	n/a (Same)	n/a (Same)
	1–9 Mth	2[32,33]	140	157	−0.27 [−6.59, 6.05]	0%	n/a (One RCT)[33]	n/a (Same)	n/a (Same)
CBT	Post	7[27,32–37]	246	249	−1.26 [−8.49, 5.97]	68%	−1.94 [−8.79, 4.91], 0%, 119 vs 122, 2[33,35]	n/a (Same)	n/a (Same)
CBT (LBP)	Post	2[34,36]	51	37	−8.49 [−16.46, −0.53]*	0%	n/a (None)	n/a (Same)	n/a (Same)
Pharmacological interventions (LBP)	Post	2[41,42]	63	49	−15.22 [−21.23, −9.20]*	0%	n/a (None)	n/a (One RCT)[41]	n/a (Same)
Massage (LBP)	Post	2[54,56]	27	27	−12.66 [−24.55, −0.77]*	0%	n/a (None)	n/a (None)	n/a (Same)
Pillows (Neck)	Post	n/a	n/a	n/a	n/a	n/a	−1.48 [−4.41, 1.45], 0%, 132 vs 127, 4[44,52,58,59]	n/a (None)	n/a (None)
Exercise (OA and LBP)	Post	2[40,43]	41	41	−24.96 [−53.68, 3.77]	79%	n/a (One RCT)[53]	n/a (None)	−12.77 [−37.19, 11.66], 83%, 57 vs 58, 3[40,43,53]
Exercise (OA)	Post	2[40,43]	41	41	−24.96 [−53.68, 3.77]	79%	n/a (None)	n/a (None)	n/a (Same)
ISI† (0–28)									
Overall	Post	6[32,33,35–37,41]	235	217	−6.12 [−9.23, −3.01]*	80%	−3.04 [−8.46, 2.37], 89%, 135 vs 138, 3[33,35,53]	- n/a (Same)	−5.09 [−8.22, −1.96]*, 82%, 251 vs 234, 7[32,33,35–37,41,53]
	1–9 Mth	2[32,33]	142	160	−2.46 [−4.19, −0.72]*	0%	−0.63 [−3.25, 2.00], 53%, 123 vs 124, 2[33,53]	n/a (Same)	−1.48 [−3.70, 0.75], 58%, 157 vs 173, 3[32,33,53]
ESI (All conditions)	Post	6[24,25,27,28,33,54]	235	217	−6.12 [−9.23, −3.01]*	80%	−5.17 [−11.41, 1.07], 91%, 119 vs 121, 2[ref]	n/a (Same)	n/a (Same)
	1–9 Mth	2[32,33]	142	160	−2.46 [−4.19, −0.72]*	0%	n/a (One RCT)[33]	n/a (Same)	n/a (Same)
ESI (LBP)	Post	2[36,41]	52	34	−6.78 [−9.47, −4.09]*	40%	n/a (None)	n/a (Same)	n/a (Same)
ESI (OA) (Only CBT)	Post	2[32,33]	167	169	−2.41 [−4.19, −0.63]*	0%	n/a (One RCT)[33]	n/a (Same)	n/a (Same)
CBT	Post	5[32,33,35–37]	202	192	−6.35 [-10.17, −2.53]*	84%	−5.17 [−11.41, 1.07], 91%, 119 vs 121, 2[33,35]	n/a (Same)	n/a (Same)
Pharmacological interventions	Post	1[41]	33	35	−5.37 [−8.81, −1.93]*	n/a	n/a (Same)	n/a (Same)	n/a (Same)
Exercise	Post	1[53]	16	17	1.68 [−2.41, 5.77]	n/a	n/a (Same)	n/a (None)	n/a (Same)
PSQI† (0–21)									
Overall	Post	4[34,40,43,57]	79	75	−2.13 [−3.75, −0.51]*	56%	−0.09 [−0.50, 0.33], 0%, 45 vs 44, 3[44,53,57]	n/a (One RCT)[34]	−1.53 [−2.85, −0.20]*, 52%, 181 vs 113, 6[34,40,43,44,53,57]
	1–9 Mth	n/a (One RCT)[34]	n/a	n/a	n/a	n/a	n/a (One RCT)[53]	n/a (One RCT)[34]	−3.49 [−7.90, 0.92], 85%, 47 vs 41, 2[34,53]

(*continued on next page*)

Table III (*continued*)

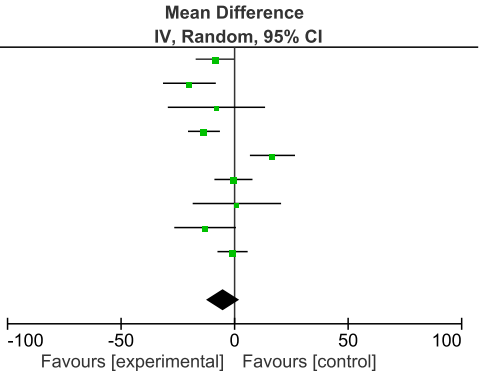
		No of studies (Ref)	Intervention	Comparison (Control/ Placebo)	Overall effect (95% CI)	I^2	Sensitivity analyses (Mean difference, 95% CI, *I* squared, participants per group, number of RCTs)		
							Comparator: Pain interventions	Adequate baseline sleep problems	Comparator: Control/ Placebo/Any pain
ESI (LBP) (Only CBT)	Post	1[34]	32	28	−3.90 [−5.65, −2.15]*	n/a	n/a (Same)	n/a (Same)	n/a (Same)
Exercise (OA and LBP)	Post	2[40,43]	41	41	−1.08 [−2.32, 0.17]	0%	n/a (One RCT)[53]	n/a (None)	−0.80 [−1.92, 0.33], 0%, 57 vs 56, 3[40,43,53]
Exercise (OA)	Post	2[40,43]	41	41	−1.08 [−2.32, 0.17]	0%	n/a (None)	n/a (None)	n/a (Same)
Sleep efficiency‡ (0–100)									
Overall	Post	9[27,32–37,41,43]	291	287	9.55 [5.41, 13.69]*	70%	2.45 [−4.59, 9.50], 52%, 102 vs 106, 2[33,35]	9.78 [5.16, 14.39]*, 75%, 266 vs 264, 8[27,32–37,41]	n/a (Same)
	1–9 Mth	3[32–34]	161	173	5.50 [0.20, 10.80]*	72%	n/a (One RCT)[33]	n/a (Same)	n/a (Same)
ESI (OA and LBP)	Post	8[27,32–37,41]	268	264	9.78 [5.16, 14.39]*	74%	2.45 [−4.59, 9.50], 52%, 102 vs 106, 2[33,35]	n/a (Same)	n/a (Same)
	1–9 Mth	3[32–34]	161	173	5.50 [0.20, 10.80]*	72%	n/a (One RCT)[33]	n/a (Same)	n/a (Same)
ESI (LBP)	Post	3[34,36,41]	83	57	12.87 [8.32, 17.42]*	15%	n/a (None)	n/a (Same)	n/a (Same)
ESI (OA) (Only CBT)	Post	3[27,32,33]	169	193	3.92 [1.27, 6.56]*	33%	n/a (One RCT)[33]	n/a (Same)	n/a (Same)
	1–9 Mth	2[32,33]	129	145	2.84 [−0.04, 5.72]	0%	n/a (One RCT)[33]	n/a (Same)	n/a (Same)
CBT (OA and LBP)	Post	7[27,32–37]	236	244	10.03 [4.74, 15.32]*	77%	2.45 [−4.59, 9.50], 52%, 102 vs 106, 2[33–35]	n/a (Same)	n/a (Same)
Pharmacological interventions (LBP)	Post	1[41]	32	20	9.20 [2.52, 15.88]*	n/a	n/a (Same)	n/a (Same)	n/a (Same)
Exercise	Post	1[43]	23	23	8.68 [1.07, 16.29]*	n/a	n/a (Same)	n/a (None)	n/a (Same)
Sleep disturbance scale‡ (0–100)									
Massage (LBP)	Post	2[54,56]	27	27	−2.81 [−13.30, 7.68]	0%	n/a (None)	n/a (None)	n/a (Same)
Physical function‡ (0–100)									
Overall	Post	5[33,40,41,43,61]	203	201	7.71 [4.50, 10.92]*	28%	0.71 [−5.04, 6.42], 0%, 192 vs 2016, 4[33,44,51,53]	2.83 [−4.33, 10.00], 0%, 144 vs 142, 2[33,41]	6.33 [3.42, 9.30]*, 42%, 283 vs 290, 8[33,40,41,43,44,51,53,61]
	1–9 Mth	n/a (One RCT)[33]	n/a	n/a	n/a	n/a	2.79 [−4.75, 10.33], 0%, 123 vs 128, 2[33,53]	n/a (One RCT)[33]	2.38 [−4.50, 9.25], 0%, 123 vs 137, 2[33,53]
ESI (All conditions)	Post	2[33,41]	144	142	2.83 [−4.33, 10.00]	0%	n/a (One RCT)[33]	n/a (Same)	n/a (Same)
Exercise (All conditions)	Post	2[40,43]	41	41	9.83 [6.08, 13.54]*	0%	n/a (One RCT)[53]	n/a (None)	5.13 [−3.58, 13.83], 76%, 57 vs 58, 3[40,43,53]
Pillows (Neck)	Post	n/a	n/a	n/a	n/a	n/a	1.27 [−1.21, 3.74], 0%, 64 vs 72, 2[44,51]	n/a (None)	1.27 [−1.21, 3.74], 0%, 64 vs 72, 2[44,51]
Depression† (0–100)									
Overall (All interventions, LBP and Neck)	Post	7[34–37,41,54,56]	126	98	−7.82 [−17.16, 1.52]	94%	−2.25 [−16.25, 11.74], 72%, 22 vs 22, 2[35,53]	−10.75 [−21.88, 0.38], 95%, 99 vs 71, 5[34–37,41]	−6.32 [−15.23, 2.58], 94%, 142 vs 115, 8[34–37,41,53,54,56]
ESI (Overall)	Post	5[34–37,41]	99	71	−10.75 [−21.88, 0.38]	95%	n/a (One RCT)[35]	n/a (Same)	n/a (Same)
ESI (LBP)	Post	3[34,36,41]	83	57	−4.93 [−7.89, −1.98]*	10%	n/a (None)	n/a (Same)	n/a (Same)
CBT (OA and LBP)	Post	4[34–37]	67	51	−11.70 [−25.86, 2.46]	96%	n/a (One RCT)[35]	n/a (Same)	n/a (Same)
Pharmacological interventions (LBP)	Post	1[41]	32	20	−7.18 [−12.07, −2.29]	n/a	n/a (Same)	n/a (Same)	n/a (Same)
Massage (LBP)	Post	2[54,56]	27	27	−0.57 [−6.67, 5.53]	0%	n/a (None)	n/a (None)	n/a (Same)

ESI = Established Sleep Interventions, CBT = Cognitive Behavioural Therapy, LBP = Low Back Pain, OA = Osteoarthritis, Mth: Months, CI = Confidence Interval.
n/a (Same) = Same included studies and result.
n/a (None) = Meta-analysis could not be performed due to no RCTs satisfying the criteria.
n/a (One RCT) = Meta-analysis could not be performed due to only one RCT.
* Denotes statistical significance.
† Lower scores are better.
‡ Higher scores are better.

A. Forest plot: Established Sleep Interventions for Pain at Post-Intervention.
Scale: 0-100, lower better.

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Currie, 2000	48.57	16.67	32	57.14	17.14	28	12.8%	-8.57 [-17.15, 0.01]
Goforth, 2014	31.69	17.92	32	51.6	22.44	20	11.1%	-19.91 [-31.54, -8.28]
Jungquist, 2010	38	29	19	46	26	9	6.5%	-8.00 [-29.41, 13.41]
Kuraganova, 2015	9	11.2	31	22.5	16	29	13.6%	-13.50 [-20.53, -6.47]
Pigeon, 2012	52.38	10.95	6	35.71	4.76	4	12.0%	16.67 [6.74, 26.60]
Smith, 2015	39.81	21.46	43	40.32	19.07	48	12.9%	-0.51 [-8.89, 7.87]
Tang 2012	60	19	10	59	25	10	7.3%	1.00 [-18.46, 20.46]
Vitiello, 2009	33.9	24.3	23	46.9	25	28	10.0%	-13.00 [-26.58, 0.58]
Vitiello, 2013	39.9	28.97	113	40.8	22.32	122	13.8%	-0.90 [-7.55, 5.75]
Total (95% CI)			**309**			**298**	**100.0%**	**-5.07 [-12.24, 2.09]**

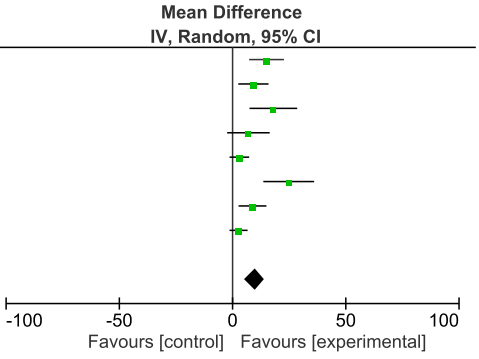
Heterogeneity: Tau² = 85.27; Chi² = 35.23, df = 8 (P < 0.0001); I² = 77%
Test for overall effect: Z = 1.39 (P = 0.16)



B. Forest plot: Established Sleep Interventions for Sleep Efficiency at Post-Intervention.
Scale: 0-100, higher better.

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Currie, 2000	85	11	32	70	18	28	12.2%	15.00 [7.32, 22.68]
Goforth, 2014	88.41	6.68	32	79.21	14.3	20	13.3%	9.20 [2.52, 15.88]
Jungquist, 2010	94	3	19	76	16	9	9.4%	18.00 [7.46, 28.54]
Pigeon, 2012	91.5	4.65	6	84.5	8.8	4	10.4%	7.00 [-2.39, 16.39]
Smith, 2015	86	12	50	83	10	50	15.8%	3.00 [-1.33, 7.33]
Tang 2012	92.1	8.1	10	67.3	16.2	10	8.8%	24.80 [13.57, 36.03]
Vitiello, 2009	84	8.1	23	75.2	14	28	13.9%	8.80 [2.65, 14.95]
Vitiello, 2013	83.66	17.87	96	81.02	9.68	115	16.2%	2.64 [-1.35, 6.63]
Total (95% CI)			**268**			**264**	**100.0%**	**9.78 [5.16, 14.39]**

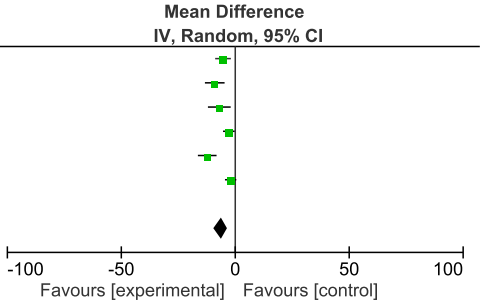
Heterogeneity: Tau² = 30.12; Chi² = 26.62, df = 7 (P = 0.0004); I² = 74%
Test for overall effect: Z = 4.15 (P < 0.0001)



C. Forest plot: Established Sleep Interventions for Insomnia Severity Index at Post-Intervention.
Scale: 0-28, lower better.

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Goforth, 2014	8.38	6.42	33	13.75	6.78	25	17.1%	-5.37 [-8.81, -1.93]
Jungquist, 2010	4	4	19	13	6	9	15.3%	-9.00 [-13.31, -4.69]
Pigeon, 2012	6	4.65	6	13	3.4	4	13.9%	-7.00 [-11.99, -2.01]
Smith, 2015	8.87	5.54	45	11.68	6.92	47	18.9%	-2.81 [-5.37, -0.25]
Tang 2012	5.9	6.3	10	18.2	2	10	15.7%	-12.30 [-16.40, -8.20]
Vitiello, 2013	8.5	9.6	122	10.53	10.21	122	19.0%	-2.03 [-4.52, 0.46]
Total (95% CI)			**235**			**217**	**100.0%**	**-6.12 [-9.23, -3.01]**

Heterogeneity: Tau² = 11.62; Chi² = 24.44, df = 5 (P = 0.0002); I² = 80%
Test for overall effect: Z = 3.86 (P = 0.0001)



D. Forest plot: All Sleep Interventions for Pittsburgh Sleep Quality Index at Post-Intervention.
Scale: 0-21, lower better.

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Cheung, 2014	5	2.21	18	6.1	2.21	18	24.0%	-1.10 [-2.54, 0.34]
Currie, 2000	8.8	3.5	32	12.7	3.4	28	21.2%	-3.90 [-5.65, -2.15]
Eadie, 2013	-1.06	3.73	16	-1.54	4.06	17	14.3%	0.48 [-2.18, 3.14]
Huang, 2010	7.3	2.8	6	10	4.2	6	8.1%	-2.70 [-6.74, 1.34]
Lee, 2017	9.91	3.52	23	10.67	4.13	21	16.8%	-0.76 [-3.04, 1.52]
Lu, 2017	-1.48	1.83	23	-0.47	5.74	23	15.5%	-1.01 [-3.47, 1.45]
Total (95% CI)			**118**			**113**	**100.0%**	**-1.53 [-2.85, -0.20]**

Heterogeneity: Tau² = 1.35; Chi² = 10.49, df = 5 (P = 0.06); I² = 52%
Test for overall effect: Z = 2.26 (P = 0.02)

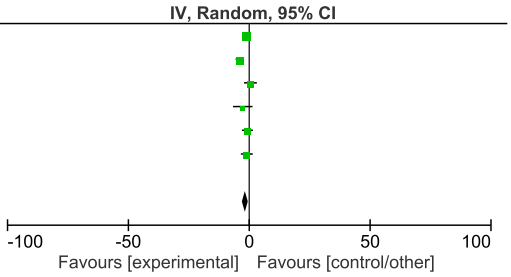
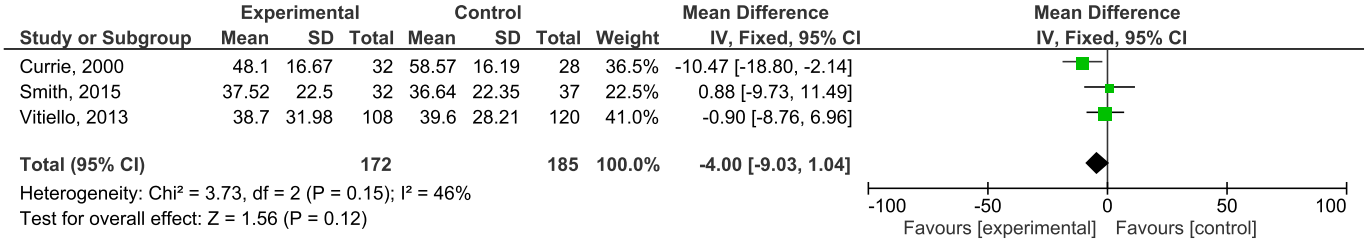
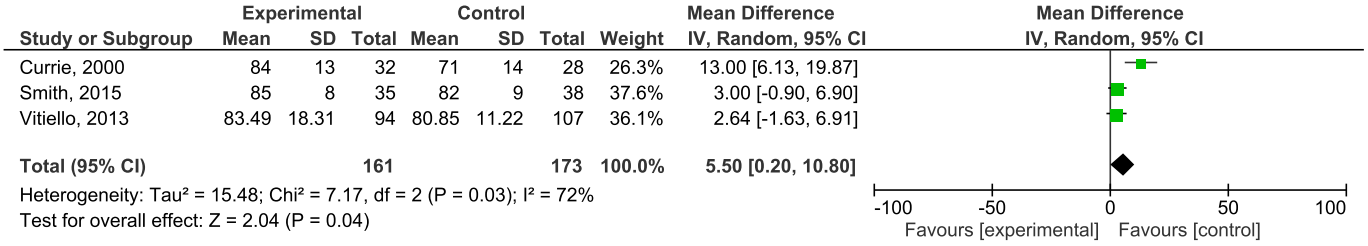


Fig. 2. Forest plot: sleep interventions for pain and sleep at post-intervention.

A. Forest plot: Established Sleep Interventions for Pain at 1-9 Months. Scale 0-100, lower better



B. Forest plot: Established Sleep Interventions for Sleep Efficiency at 1-9 Months. Scale 0-100, higher better



C. Forest plot: Established Sleep Interventions for Insomnia Severity Index at 1-9 Months. Scale 0-28, lower better.

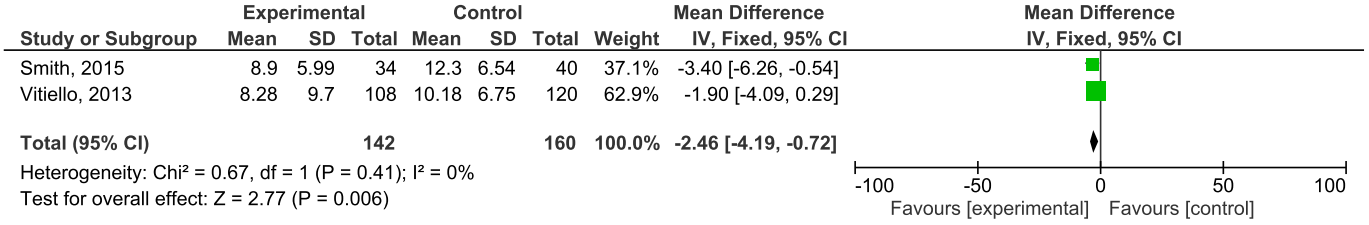


Fig. 3. Forest plot: sleep interventions for pain and sleep at 1–9 months.

insomnia and pain treatment[33], or 3) interventionist bias[32]. These may be possible reasons why ESI did not improve pain for people with OA, and why CBT for insomnia was not superior to pain interventions (i.e., CBT for pain) in the sensitivity analyses.

Strengths of our review include the comprehensive conduct of subgroup analyses for evaluated conditions and interventions, the inclusion of all available sleep interventions, and evaluation of secondary health outcomes. We evaluated multiple dimensions of sleep (sleep efficiency, ISI and PSQI). While VAS pain at rest was the most commonly report outcome and analysed, it is not the most robust assessment as it may miss aspects of in pain in regards to activity or severity. It is possible that participants may had similar levels of pain intensity but improved in physical activity or self-efficacy. Although our review evaluated other health outcomes besides pain and sleep, our search strategy was not specific for these outcomes. Therefore studies which may have measured these outcomes but not sleep outcomes would have been excluded from this review. Furthermore, our sensitivity and subgroup analyses resulted with small numbers of studies and sample sizes and should be interpreted with caution. It is also worth noting that some of the analyses used a random effects model due to high heterogeneity (pooling of OA and LBP) which represents an average effect of interventions[68]. Lastly, due to the scarcity of available data, our review does not analyse whether sleep interventions improve pain as a consequence of improving sleep, or vice versa and does not fall in the scope of the review. However, some secondary analysis studies[69,70] of identified RCTs from our review[32,33] suggest that a minimum of 30% improvement in sleep is needed with CBT for significant improvements in pain among people with knee OA at follow-up.

Clinical implications and future directions

Given the prevalence of comorbid insomnia with OA and LBP, and amenability to treatment, clinicians managing people with

OA or LBP should screen for insomnia symptoms and refer for management[11,17]. Various guidelines for OA[71,72] or LBP[73] highly recommend primary health professionals to screen for comorbidities, but are less clear on follow-up actions once identified. Our results suggest that ESI may be used to provide worthwhile insomnia improvements if not also worthwhile pain improvements (LBP). With the widespread problem of insomnia overwhelming numbers of sleep specialists, the most feasible course may be to refer to primary care professions (general practitioners, pharmacists) experienced in insomnia management or e-Health. The use of effective online CBT programs for insomnia[74] for people with comorbid insomnia and OA or spinal pain has not been evaluated. Furthermore health service delivery trials would need to be undertaken to evaluate the effectiveness of such referrals.

Due to the bidirectional relationship between pain and insomnia, the ESI alone for people with OA or LBP may prove to be limited in improving pain symptoms. In our review, the efficacy of combining first line treatments for insomnia with first line treatment for OA or LBP is not known as this has not been evaluated in any trial. We propose that the combination of ESI with guideline endorsed musculoskeletal pain interventions may compound their beneficial effects on sleep and pain. Further research evaluating this combination for people with comorbid insomnia and OA or spinal pain is required to determine their efficacy over usual management.

Author contributions

Kevin Ho: Conception and design; Acquisition of data; Analysis and interpretation of the data; Drafting of the article; Final approval of the article.

Paulo Ferreira: Conception and design; Analysis and interpretation of the data; Drafting of the article; Final approval of the article.

Marina Pinheiro: Conception and design; Analysis and interpretation of the data; Drafting of the article; Final approval of the article.

Danielle Aquino Silva: Acquisition of data; Drafting of the article; Final approval of the article.

Christopher Miller: Analysis and interpretation of the data; revising it critically for important intellectual content; Final approval of the article.

Ron Grunstein: Analysis and interpretation of the data; revising it critically for important intellectual content; Final approval of the article.

Milena Simic: Conception and design; Analysis and interpretation of the data; Drafting of the article; Final approval of the article.

Competing interest statement

All authors have no competing interests to declare.

Role of the funding source

This review has received no specific grant from any funding agency, commercial or not-for-profit sectors.

Appendix 1. Search strategy for MEDLINE

	Search strategy for MEDLINE
Sleep	1. exp Sleep/
	2. exp Sleep Wake Disorders/
	3. (sleep or insomnia).mp.
	4. 1 or 2 or 3
Osteoarthritis or spinal pain	5. exp Osteoarthritis/
	6. (osteoarth* or arthrosis).mp.
	7. exp Back Pain/
	8. exp Neck Pain/
	9. (cervical or thoracic or lumbar or back or neck or spine or spinal or vertebra*).mp.
	10. Pain.mp.
	11. 9 AND 10
	12. 5 or 6 or 7 or 8 or 11
Randomized control trials	13. Randomized controlled trial.pt
	14. exp randomized controlled trial/
	15. “Randomized controlled trial”.mp.
	16. Exp random allocation/
	17. Placebo.mp
	18. exp placebos
	19. exp placebo effect/
	20. “controlled clinical trial”.mp
	21. exp controlled clinical trial
	22. Random*.ab,ti.
	23. Trial.ab.ti
	24. 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23
	25. 4 AND 12 AND 24
Limits	26. Limit 25 to humans

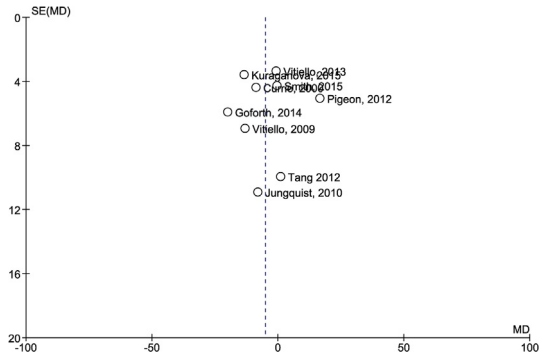
Appendix 2. Other characteristics of included studies

Author, Year	Country	Recruitment	Baseline outcomes	Post baseline assessments	Outcomes					
					Pain	Sleep	Activity Limitation	HRQoL	Anxiety	Depression
Bergholdt, 2008	DEN	Patients and community	VAS pain 5.2/10 Duration of pain: 3 years Sleep duration: 6.3 h BMI: 25.5	Post-intervention	COBRA scale (VAS)	Sleep duration	ADL	COBRA scale	*	*
Bernateck, 2007	GER	Patients and community	Pain intensity: 2.72/5 Pain radiation: 89% Has sleep disturbance (71%) BMI: 27.8	Post-intervention 3/12 6/12 9/12 12/12	Pain intensity	Sleep disturbance	*	*	*	*
Cheung, 2014	USA	Patients	WOMAC Total: 44.35/98 WOMAC pain: 8.5/20 PSQI: 6.1/21 BMI: 29 SF-MCS: 52.2/100 SF-PCS: 36.7/100	Post-intervention	WOMAC pain	PSQI	SPPB	SF-MCS SF-PCS	*	*
Currie, 2000	CAN	Patients and community	MPI: 12.3/21 Sleep efficiency: 71% PSQI: 15.4/21 BDI: 12.7/63	Post-intervention	MPI	Sleep efficiency PSQI	*	*	*	Beck Depression Inventory
Eadie, 2013	IRE	Community	NRS: 5.67/10 ISI: 12.9/28 PSQI: 10.7/21 SF-MCS: 37.8/100 SF-PCS: 40.8/100 HADS-A: 9.7/21 HADS-D: 7.35/21 BMI: 29.3	Post-intervention 3/12 6/12	NRS (VAS)	ISI PSQI	ODI	SF-MCS SF-PCS	HADS-A	HADS-D
Field, 2007	USA	Community	VITAS: 4.75/10 Sleep disturbance scale: 36.15/100 STAI: 36.3/80 POMS: 8.6/60	Post-intervention	VITAS (VAS)	Sleep disturbance scale	*	*	STAI	POMS
Goforth, 2014	USA	Community	VAS: 51.2/100 Sleep efficiency: 73.26% ISI: 19.6/28 Sleep duration: 5.8 h Hamilton depression: 6.7/50	Post-intervention	VAS	Sleep efficiency ISI	RMDQ	*	*	Hamilton depression
Gutenbrunner, 1999	GER	Patients	Pain intensity: 2.72/5 Pain radiation: 89% Has sleep disturbance (71%) BMI: 27.8	Post-intervention 3/12 6/12 9/12	Pain intensity	Sleep disturbance	*	*	*	*
Hernandez, 2009	USA	Community	VITAS: 5.05/10 Sleep disturbance scale: 33.35/100 STAI: 35.05/80 POMS: 10.85/60	Post-intervention	VITAS (VAS)	Sleep disturbance scale	*	*	STAI	POMS
Huang, 2010	USA	Patients	WOMAC pain: 227/500 PSQI: 10.5/21	Post-intervention 1/12	WOMAC pain	PSQI	*	*	*	*
Jochem, 1997	NL	Community	VAS: 29.47/100 BMI: 27.2	Post-intervention	VAS	Times awoken (NR)	*	*	*	*
Jungquist, 2010	USA	Community	VAS: 4.8/10 Sleep efficiency 80%	Post-intervention	VAS	Sleep efficiency ISI	*	MFI	*	Beck Depression Inventory

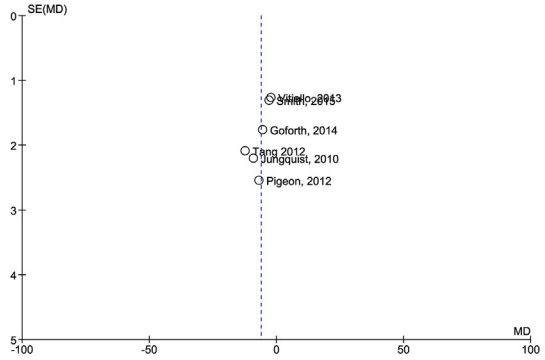
			ISI: 17.4/28 BDI: 12.5/63							
Kurganova, 2015	RUS	Patients	VAS: 4.52/10 ISI: 10.1/28 PSQI: 7.06/21	Post-intervention 3/12	VAS	PSQI (NR)	*	*	*	Beck Depression Inventory
Lavin, 1997	USA	Community	VAS: 4.4/10	Post-intervention	VAS	Sleep compared to previous night	*	*	*	*
Lee, 2016	KOR	Patients	VAS: 58/100 PSQI: 11.15/21 BMI:22.2	Post-Intervention	VAS	PSQI	NDI	EuroQOL	*	*
Lu, 2017	CHI	Patients	WOMAC: 9.1/10 Sleep efficiency: 84.6% PSQI: 7.2/21 SF-MCS: 51.00/100 SF-PCS: 46.64/100 BMI: 25.1	Post-intervention	WOMAC	Sleep efficiency PSQI	SPPB	SF-MCS SF-PCS	*	*
McCurry, 2014	USA	Patients	VAS: 4.8/10 Sleep efficiency: 82.6% ISI: 11.5/28 Sleep duration: 7 h GDS: 6.7/30	Post-intervention 9/12 18/12	VAS	Sleep efficiency ISI	AIMS	*	*	GDS
Pigeon, 2012	USA	Community	MPI 9.3/21 Sleep efficiency: 76.2% ISI: 16.4/28 CESD-R: 14.7/60	Post-Intervention	MPI	Sleep Efficiency ISI	*	MFI	*	CESD-R
Smith, 2015	USA	Patients	K/L Score: 2.3 VAS: 47/100 WOMAC pain: 4.81/10 Knee pain duration: 7.3 years Sleep efficiency: 68% ISI: 17/28 BMI: 31.5	Post-intervention 3/12 6/12	VAS	Sleep efficiency ISI	*	*	*	*
Tang, 2012	UK	Patients	BPI-present pain intensity: 5.95/10 Pain duration: 8.5 years Sleep efficiency: 68% ISI: 20.3/28 HADS-A: 9.65/21 HADS-D 9.6/21 BMI: 28.75	Post-intervention	BPI BPI-PPI	Sleep efficiency ISI	*	MFI	HADS-A	HADS-D
Van Wieringen, 2001	NL	Patients	Symptom duration: 2.1 years Dim light melatonin onset 11:12 pm	Post-intervention	Hours of pain, Pain intensity (NR)	DLMO	*	SF-36 (NR)	*	*
Vitello, 2009	USA	Community, Paid volunteers	SF-pain score: 53.35/100 Insomnia duration: 4.15 years Sleep duration: 5.8 h Sleep efficiency: 70.6% GDS: 5.45/30	Post-intervention	SF-pain score	Sleep efficiency ISI	*	SF-36	*	GDS
Vitello, 2013	USA	Patients	VAS: 4.8/10 ISI: 11.5/28 Sleep efficiency: 82.6% Sleep duration: 7 h GDS: 6.7/30	Post-intervention 9/12	VAS	Sleep efficiency ISI	AIMS	*	*	GDS
Wepner, 2008	GER	Patients	VAS: 47.5/100 SF-MCS: 46/100 SF-PCS:35/100	Post-intervention	VAS	Sleep duration Sleep latency	RMDQ	SF-36	*	*

* Not Reported.

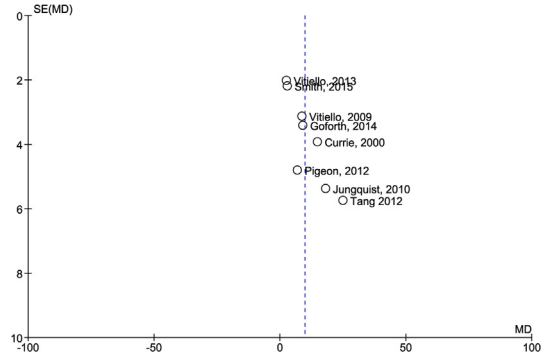
Appendix 3. Funnel Plots



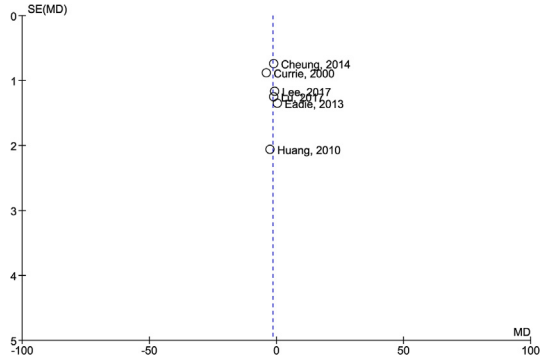
Funnel Plot 1. ESI for pain at post-intervention.



Funnel Plot 3. ESI for Insomnia Severity Index at post-intervention.



Funnel Plot 2. ESI for sleep efficiency at post-intervention.



Funnel Plot 4. All sleep interventions for Pittsburgh Sleep Quality Index at post-intervention.

Appendix 4.

Table I
Other meta-analyses: subgroup analyses by conditions for pain and sleep, and analyses for other health outcomes

		No of studies (Ref)	Intervention	Comparison	Overall effect (95% CI)	I^2	Sensitivity analyses (Mean difference, 95% CI, *I* squared, participants per group, number of RCTs)	
							Comparator: Placebo/ Control	Comparator: Pain interventions
Pain† (0–100)								
OA	Post	6[27,32,33,40,43,57]	226	245	−8.72 [−17.07, −0.38]*	66%	n/a (Same)	−1.93 [−8.76, 4.91], 0%, 119 vs 123, 2[33,57]
Spinal	Post	15[34–37,41,42,44,51–54,56,58,59,61]	364	340	−5.41 [−10.26, −0.55]*	69%	−6.00 [−12.73, 0.72], 76%, 251 vs 218, 10[34–37,41,42,52,54,55,61]	−6.89 [−10.98, −2.79]*, 3%, 119 vs 127, 6[35,44,51,53,58,59]
LBP	Post	8[34,36,41,42,51,53,54,56]	198	181	−10.41 [−13.68, −7.15]*	26%	−12.76 [−17.21, −8.31]*, 0%, 141 vs 113, 6[34,36,41,42,54,56]	−0.23 [−21.18, 20.72], 78%, 57 vs 68, 2[51,53]
Neck	Post	4[44,52,58,59]	132	127	−1.48 [−4.41, 1.45]	0%	n/a (None)	n/a (Same)
ISI† (0–28)								
OA	Post	2[32,33]	167	169	−2.41 [−4.19, −0.63]*	0%	n/a (Same)	n/a (One RCT)[33]
Spinal	Post	5[35–37,41,53]	84	65	−6.37 [−10.97, −1.76]*	84%	−8.36 [−11.50, −5.23]*, 56%, 68 vs 48, 4[35–37,41]	−3.47 [−13.34, 6.41], 94%, 22 vs 21, 2[35,53]
LBP	Post	3[36,41,53]	68	51	−4.22 [−10.05, 1.61]	85%	−6.78 [−9.47, −4.09]*, 40%, 52 vs 34, 2[36,41]	n/a (One RCT)[53]
PSQI† (0–21)								
Spinal	Post	3[34,44,53]	71	66	−1.53 [−4.24, 1.18]	78%	n/a (One RCT)[34]	−0.23 [−1.96, 1.49], 0%, 39 vs 38, 2[44,53]
OA (Knee)	Post	3[40,43,57]	47	47	−1.02 [−2.17, 0.13]	0%	n/a (Same)	n/a (One RCT)[57]
Sleep efficiency‡ (0–100)								

Table I (*continued*)

		No of studies (Ref)	Intervention	Comparison	Overall effect (95% CI)	I^2	Sensitivity analyses (Mean difference, 95% CI, *I* squared, participants per group, number of RCTs)	
							Comparator: Placebo/ Control	Comparator: Pain interventions
OA	Post	4[27,32,33,43]	192	216	4.43 [1.93, 6.93]*	31%	3.92 [1.27, 6.56]*, 33%, 169 vs 193, 3[27,32,33]	n/a (One RCT)[43]
Spinal	Post	5[34–37,41]	99	71	14.01 [8.36, 19.67]*	51%	n/a (Same)	n/a (One RCT)[35]
LBP	Post	3[34,36,41]	83	57	12.87 [8.32, 17.42]*	15%	n/a (Same)	n/a (None)
Physical function‡ (0–100)								
OA	Post	3[33,40,43]	153	163	8.46 [5.08, 11.83]*	35%	n/a (Same)	n/a (One RCT)[33]
Spinal	Post	5[41,44,51,53,61]	130	127	0.13 [−5.67, 5.96]	0%	3.13 [−4.04, 10.29] 0%, 114 vs 110, 4[41,44,51,61]	n/a (One RCT)[53]
LBP	Post	4[41,51,53,61]	107	106	−1.08 [−7.33, 5.17]	0%	1.17 [−8.79, 11.08], 0%, 50 vs 38, 2[41,61]	−2.54 [−10.58, 5.50] 10%, 57 vs 68, 2[51,53]
Mental quality of life‡ (0–100)								
Overall	Post	4[40,43,53,61]	75	76	−0.89 [−3.43, 1.66]	0%	−0.69 [−3.41, 2.03], 4%, 59 vs 59, 3[40,43,61]	n/a (One RCT)[53]
Exercise	Post	3[40,43,53]	57	58	−1.10 [−3.83, 1.62]	2%	−0.91 [−3.86, 2.04], 48%, 41 vs 41, 2[40,43]	n/a (One RCT)[53]
Physical quality of life‡ (0–100)								
Overall	Post	4[40,43,53,61]	75	76	−0.53 [−2.62, 1.57]	0%	−0.11 [−2.39, 2.17], 0%, 59 vs 59, 3[40,43,61]	n/a (One RCT)[53]
Exercise	Post	3[40,43,53]	57	58	−0.77 [−3.01, 1.46]	0%	−0.33 [−2.80, 2.13], 0%, 41 vs 41, 2[40,43]	n/a (One RCT)[53]
Anxiety† (0–100)								
Overall (Spinal)	Post	4[37,53,54,56]	53	54	−1.77 [−10.59, 7.05]	66%	−4.04 [−15.78, 7.71], 74%, 37 vs 37, 3[37,54,56]	n/a (One RCT)[53]
LBP	Post	3[53,54,56]	43	44	2.70 [−2.79, 8.19]	0%	2.08 [−4.37, 8.52], 0%, 27 vs 27, 2[54,56]	n/a (One RCT)[53]
Massage	Post	2[54,56]	27	27	2.08 [−4.37, 8.52]	0%	n/a (Same)	n/a (None)
Depression† (0–100)								
LBP	Post	6[34,36,41,53,54,56]	126	101	−3.50 [−6.06, −0.93]*	30%	−4.10 [−6.76, −1.45]*, 6%, 110 vs 84, 5[34,36,41,54,56]	n/a (One RCT)[53]
	1–9 Mth	2[34,53]	48	45	−2.16 [−6.59, 2.27]	5%	n/a (One RCT)[34]	n/a (One RCT)[53]

LBP = Low Back Pain, OA = Osteoarthritis, Spinal = Low Back Pain and Neck Pain, Mth: Months, CI = Confidence Interval.
Detailed pain and sleep analyses have pooled all sleep interventions.
Other health outcomes have pooled analyses of all sleep interventions and subgroup analyses by type of sleep intervention.
* Denotes statistical significance.
† Lower scores are better.
‡ Higher scores are better.

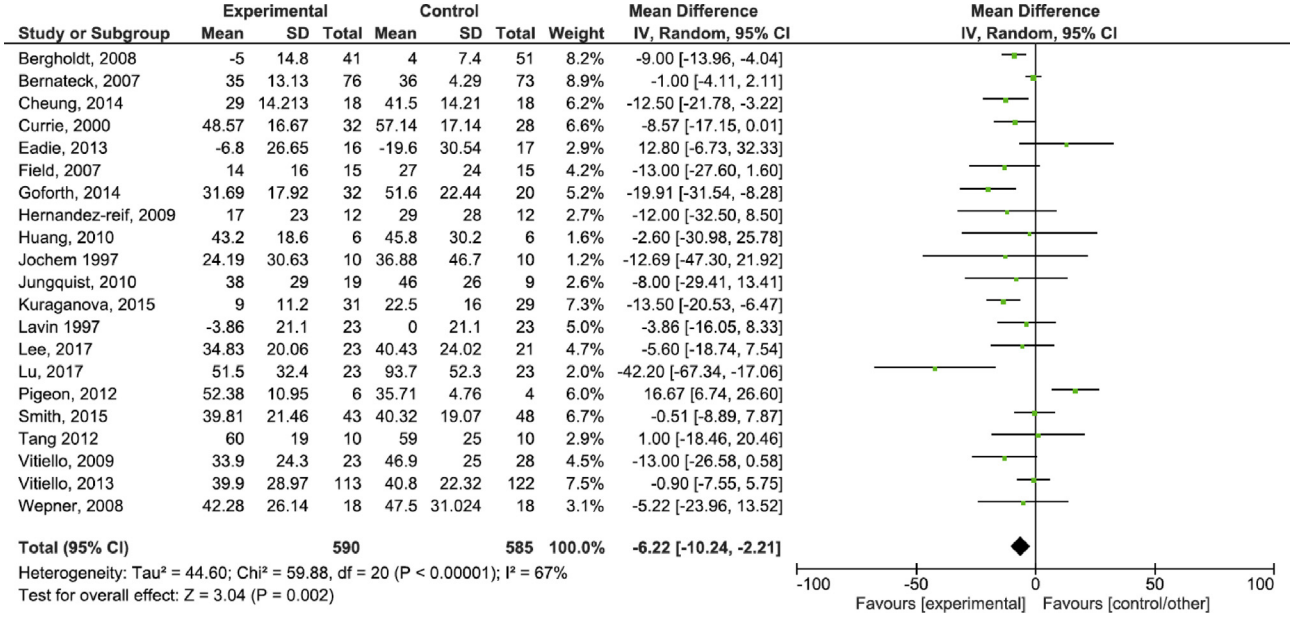


Fig. 2A. Forest plot overall pain post. Scores converted to 0–100 scale, lower better.

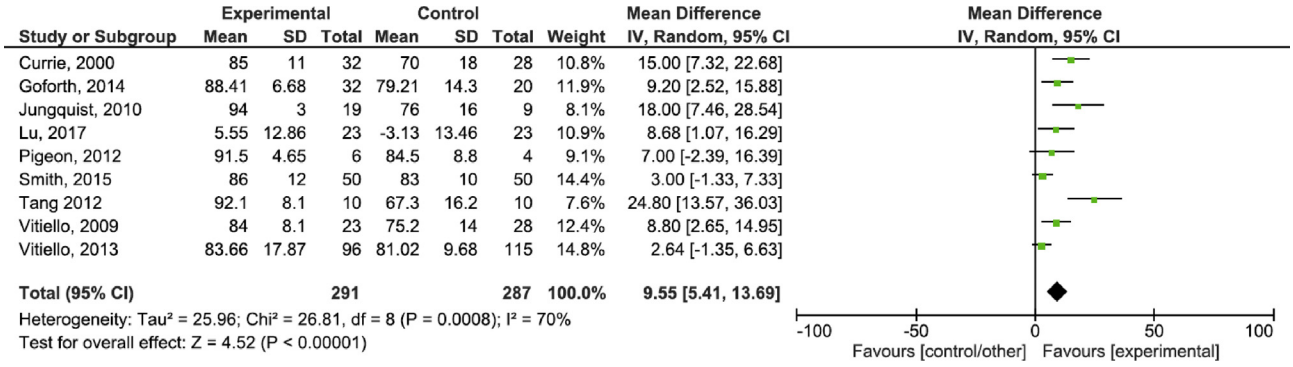


Fig. 2B. Forest plot: overall sleep efficiency post. 0–100 scale, higher better.

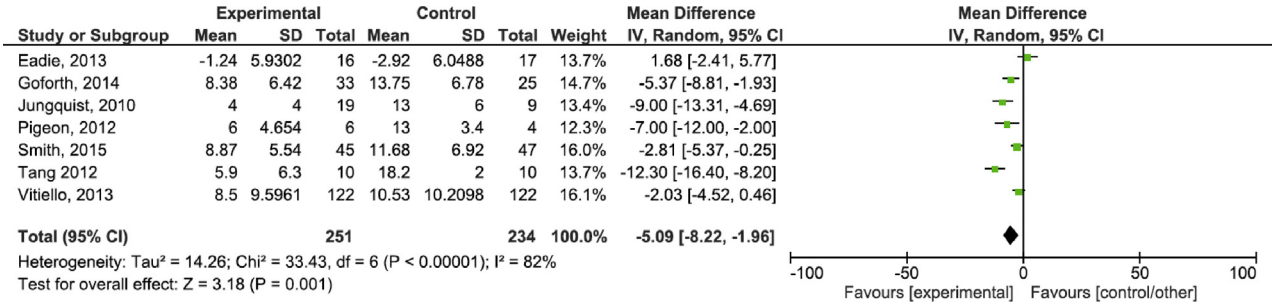


Fig. 2C. Forest plot: overall Insomnia Severity Index post. 0–28 scale, lower better.

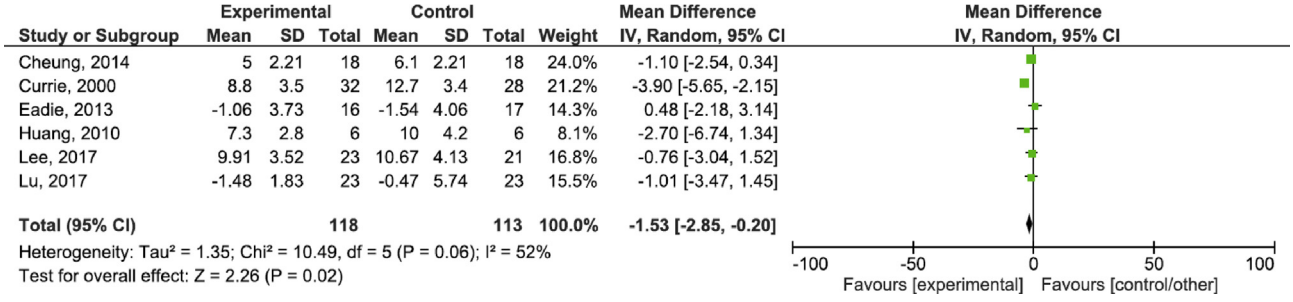


Fig. 2D. Forest plot: overall Pittsburgh Sleep Quality Index post. 0–28 scale, lower better.

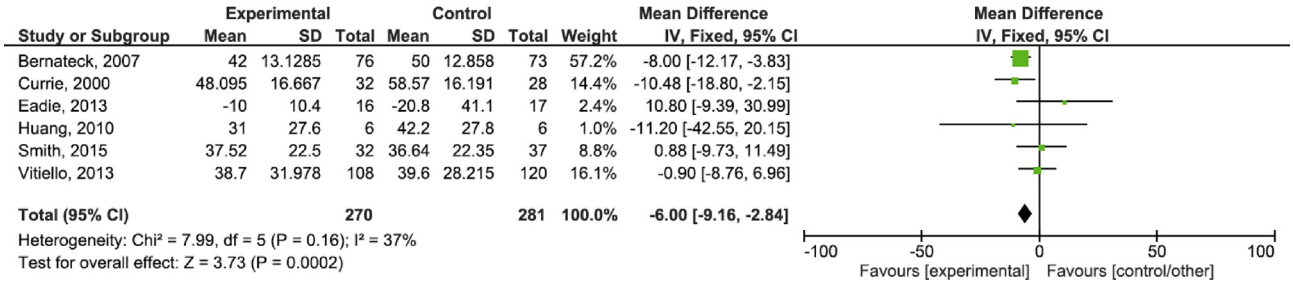


Fig. 3A. Forest plot: overall pain 1–9 months. Scores converted to 0–100 scale, lower better.

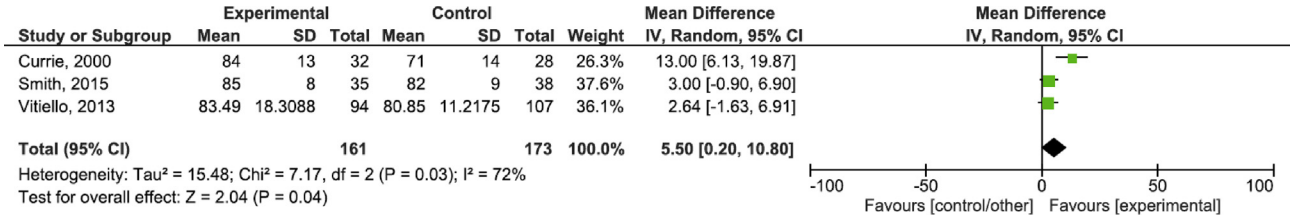


Fig. 3B. Forest plot: overall sleep efficiency 1–9 months. 0–100 scale, higher better.

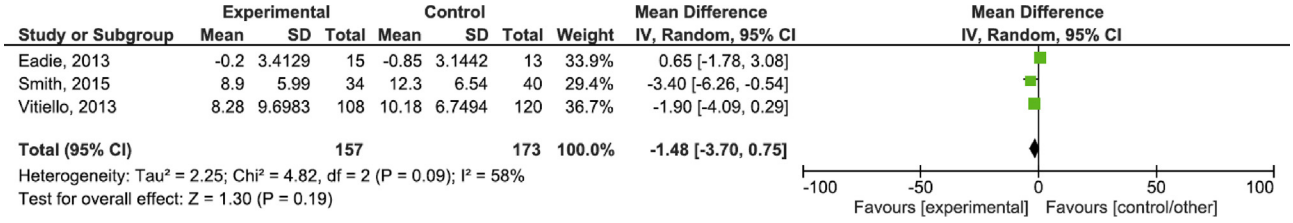


Fig. 3C. Forest plot: overall Insomnia Severity Index 1–9 months. 0–28 scale, lower better.

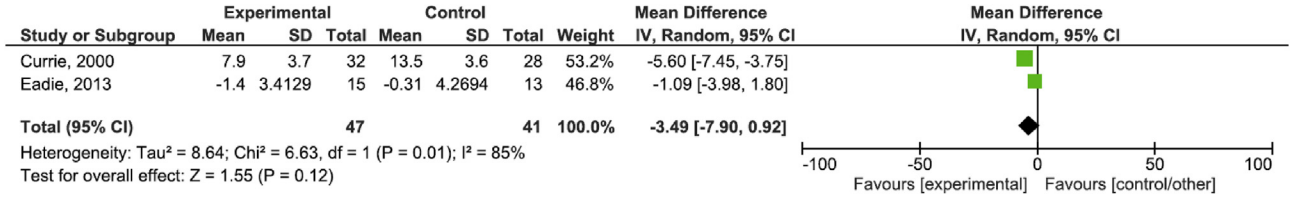
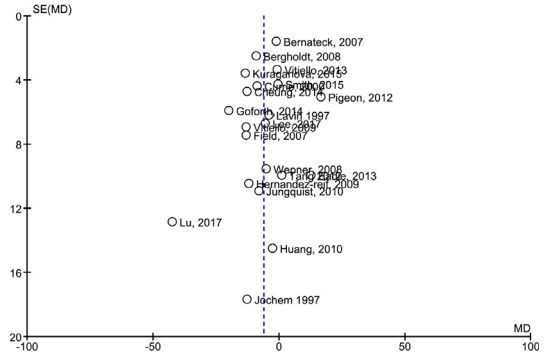


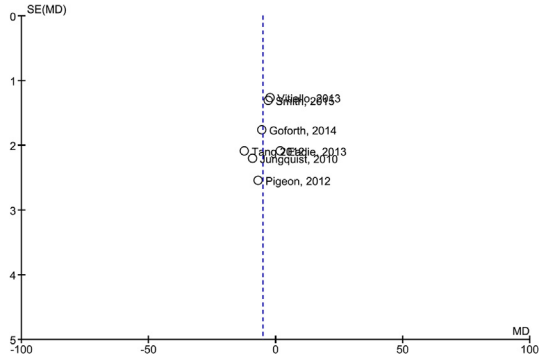
Fig. 3D. Forest plot: overall Pittsburgh Sleep Quality Index 1–9 months. 0–21 scale, lower better.

Appendix. Funnel Plots

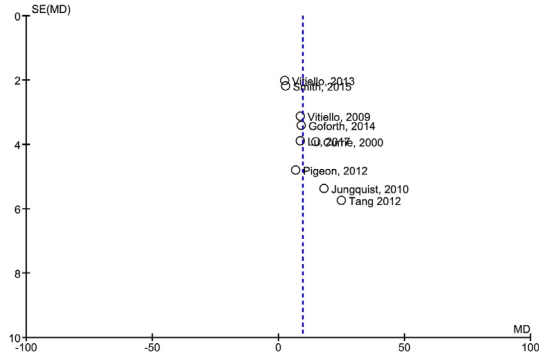
Pain Overall Post.



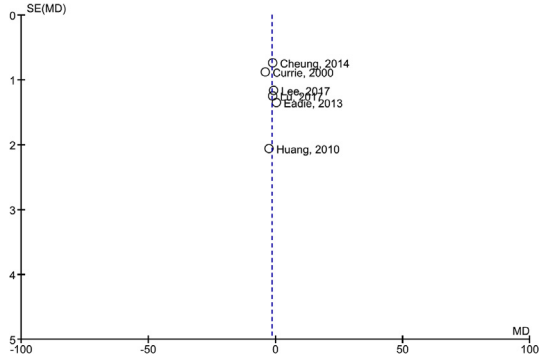
ISI Overall Post.



Sleep Efficiency Overall Post.



PSQI Overall Post.



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