

Nature exposure reduces self-reported pain: a systematic review and meta-analysis

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Pain is a global health issue with substantial individual, societal and economic impacts. Given the risks of pharmacological treatments, complementary approaches to pain management are essential. Nature exposure has emerged as a promising nonpharmacological strategy, but evidence of its effectiveness is inconclusive. Here in this systematic review and meta-analysis we examined 62 studies (96 effects) across 21 countries, including 4,439 participants, to assess the impact of nature exposure on self-reported pain. The results indicate a significant small-to-moderate reduction in pain associated with nature exposure (standardized mean difference of 0.53), but studies exhibited moderate-to-high risk of bias and substantial heterogeneity. Studies evaluating nature against matched comparators reported effects roughly half the size of those using nonmatched controls and multisensory stimuli tended to show stronger effects. These findings support nature as a promising complementary pain management strategy. However, high heterogeneity and risk of bias warrant caution and highlight the need for more rigorous research.


Pain is a major global health issue, with more than a fifth of adults experiencing pain regularly or chronically^{1–3}. This burden not only affects individuals, contributing to disabilities and impairing daily life activities, but also imposes substantial costs on societies and economies. Treatments associated with back pain alone account for approximately 1.5% of Europe's gross domestic product annually, while chronic pain is the single most expensive medical issue^{4–6}. Moreover, pain and mental disorders often co-occur⁷ and more pain is associated with more severe mental health symptoms⁸, exacerbating the negative impact of pain. Consequently, effective treatments are needed to alleviate individual and socioeconomic burdens and costs. However, the complex and multifaceted nature of pain represents a major challenge to identifying such treatments.

Pain treatment often involves multimodal approaches rooted in biopsychosocial frameworks, integrating pharmacological and non-pharmacological strategies^{9,10}. While pharmacological treatments,

such as opioid and nonopioid medications, are well-established and effective¹¹, they carry substantial risks, including side effects, tolerance and the potential for addiction^{12,13}. Furthermore, given the biopsychological nature of pain, integrative approaches—including psychological (for example, cognitive behavioral therapy), physiological (for example, massage) and complementary treatments (for example, acupuncture)—play an important role alongside pharmacological interventions⁹. While these treatments are widely adopted by individuals experiencing pain¹⁴, there is a growing need to systematically evaluate the effectiveness of these adjunct strategies. One increasingly recognized adjunct strategy is nature exposure, which has been repeatedly linked to analgesic effects^{15,16}.

Previous studies have shown that nature exposure is associated with reduced self-reported acute or chronic pain, with several pathways proposed to explain how nature may achieve this effect¹⁷. For one, factors indirectly facilitated by contact with nature might be important.

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For example, nature contact promotes physical activity and social integration¹⁸, both known to positively affect pain regulation^{19,20}. For another, exposure to specific natural elements, such as volatile organic compounds and environmental microbiota, may also influence pain. This may explain why residing near greenspaces and rural areas is associated with healthier microbiome signatures²¹ that are, in turn, linked to improved pain outcomes²². While several of these pathways have been predominantly explored in chronic pain, evidence suggests that acute pain induced by medical or experimental procedures can also be alleviated by nature. Notably, in such settings, mere exposure to nature sights and sounds may be sufficient to reduce self-reported pain.

Consequently, several studies have investigated whether nature stimuli alone can reduce pain, but results are mixed, leaving the evidence inconclusive. In a seminal study, Ulrich¹⁶ showed that following painful surgery, patients with a room offering a view of greenspace required lower doses of analgesics compared to those who could only see a brick wall from their hospital bed. Subsequent studies across various contexts involving experimental or medical procedures that induced acute pain have supported this finding. For example, research has shown that viewing or listening to nature can reduce acute self-reported pain during procedures such as flexible bronchoscopy²³, colonoscopy^{24,25}, dental treatments¹⁵, burn wound dressings^{26,27} or experimentally induced pain²⁸. However, the reported effects vary widely, with some studies indicating no effects^{29,30} and others showing detrimental outcomes (that is, an increase in pain)^{31,32}.

Variations and inconsistencies in research designs probably contributed to these inconclusive findings as studies differed in methodological choices. For instance, studies varied widely in their selection of comparators. As with other complementary pain management approaches, the literature features diverse comparator conditions and is marked by methodological shortcomings¹⁴. A common approach is to compare nature interventions to no alternative stimulation or treatment as usual (TAU)³³, introducing several challenges. Comparisons with no stimulation complicate isolating the intervention's specificity as they are influenced by both its impact and placebo or expectancy effects³⁴. In addition, such comparisons do not clarify whether the effect is uniquely attributable to nature or stems from generic aspects shared with other environments or stimuli. While using TAU as a comparator is clinically relevant, it can hinder cross-study comparisons as TAUs may vary depending on the medical procedure or institution³⁵. Furthermore, the studies differed in the types of nature stimuli used. Some studies used simple, unimodal stimuli, such as listening to nature sounds³⁶ or viewing still images of nature³⁷, while others employed multimodal, highly interactive interventions³⁸, which may more effectively reduce pain. Thus, understanding the relative effectiveness of nature, considering both the conditions it is compared against and the specifics of its implementation, is crucial for guiding practitioners and researchers toward its optimal application. Identifying the contexts and factors that maximize the effectiveness of nature exposure underscores the need for a thorough investigation into the underlying causes of outcome variations.

Therefore, although nature exposure has garnered significant attention as a potential adjunct analgesic method, its effectiveness in reducing self-reported pain remains underspecified and inconsistently explored. Existing studies appear to vary widely in study design, methodological characteristics and overall quality, yet the extent and implications of this variability have not been systematically assessed. To address these gaps, we conducted a preregistered systematic review and meta-analysis to quantitatively integrate the available evidence. We exclusively included studies investigating the effects of nature exposure on acute or spontaneously occurring chronic pain. Our aims were to estimate the overall effect of nature exposure on pain, assess its robustness and generalizability, evaluate methodological quality and potential bias and examine how design and contextual factors contribute to variability in findings. Specifically, we hypothesized

that nature exposure (versus non-nature controls) would significantly reduce self-reported acute or spontaneously occurring chronic pain, and preregistered several potential moderators related to study design and methodological features. By systematically coding and analyzing these features, we aimed not only to clarify the evidence base but also to critically reflect on current research practices—ultimately contributing to the development of more rigorous and methodologically sound studies in this emerging interdisciplinary research domain³⁹.

Results

Study characteristics

Figure 1 summarizes the selection of studies and the applied exclusion criteria for each step in a Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) flow diagram. After the initial screening of the abstracts and titles, we identified 85 potentially relevant studies. Of these, 23 studies were further excluded following inspection of their precise content using the full texts (Supplementary Table 1). The final sample included $n = 62$ studies encompassing $k = 96$ extracted effects and a total sample size of $N = 4,439$ participants, ranging from $n = 8$ to $n = 270$ participants per study. Table 1 summarizes the included studies, reporting effect sizes per study, a brief description of the pain procedure, its context and measurement as well as the nature and control conditions. A comprehensive overview, including full references, detailed effect size information, study design and context, sample sizes, pain types and measurements, detailed descriptions of nature and control conditions (with moderator coding for purity, immersiveness, interactivity and type of control) and sources of extracted data for each study, is provided in Supplementary Table 2. The studies were published between 1992 and 2024 and conducted across 21 different countries, including Brazil (1; 1.6%), China (5; 7.7%), Denmark (2; 3.2%), France (1; 1.6%), Germany (1; 1.6%), Hong Kong (2; 3.2%), Iran (6; 9.7%), Israel (2; 3.2%), Italy (1; 1.6%), Japan (1; 1.6%), Jordan (1; 1.6%), Malaysia (1; 1.6%), the Netherlands (3; 4.8%), Poland (2; 3.2%), Spain (2; 3.2%), Sweden (1; 1.6%), Switzerland (1; 1.6%), Thailand (1; 1.6%), Turkey (8; 12.9%), the UK (3; 4.8%) and the USA (17; 27.4%).

In terms of study design, 26 studies (41.9%) utilized a between-participant design, 17 studies (27.4%) employed a within-participant design and the remaining 19 studies (30.6%) adopted a pre–post control group design. Most studies (47; 75.8%) were conducted in medical settings, while the remaining studies (15; 24.2%) were conducted in experimental settings (these two categories were coded for moderator analyses as context). Notably, one study included two separate experiments, one in a medical setting and the other in an experimental setting¹⁵. Studies conducted in medical settings were characterized by a diverse range of pain induction procedures, ranging from relatively minor (for example, blood draws) to moderate (for example, colonoscopy) and major (for example, burn wound dressing) medical procedures. Notably, two studies conducted in the medical setting assessed chronic pain that occurred spontaneously rather than being induced by a specific procedure^{38,40}. In experimental settings, pain was induced through heat, cold, electrical or ischemic pain. The pain was measured in 32 cases (51.6%) using ratings on a visual analog scale (VAS), in 20 cases (32.3%) on a numerical rating scale (NRS) and in 4 cases (6.4%) on a graphical rating scale (GRS). In the remaining 6 cases (9.7%) pain threshold and/or tolerance measures were used. All results based on ratings assessed the intensity of the painful experience, that is, the perceived strength of the sensation rather than emotional or motivational reactions.

Our inclusion criterion required studies to feature interventions involving one or more stimuli primarily using natural elements (Methods). As a result, the included nature interventions used in the studies covered a broad spectrum of stimuli. These ranged from relatively simple stimuli, such as murals or still images of natural environments or nature soundscapes (for example, waterscapes, birds or forest sounds), to more complex multimodal stimuli. Complex stimuli included images

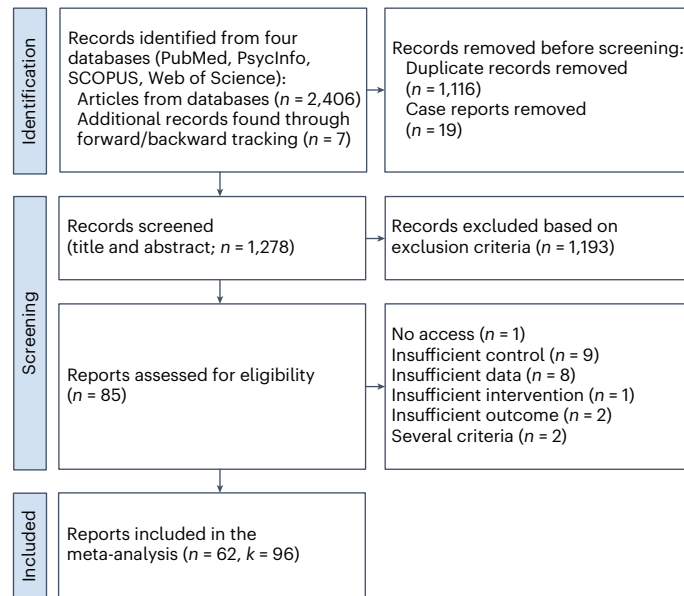


Fig. 1 | PRISMA flow chart for the systematic review and meta-analysis.

Inclusion criteria were as follows: (1) adult participants from healthy or clinical populations, (2) exposure to a painful medical or experimental procedure, (3) at least one primarily natural stimulus targeting one or more sensory modalities, (4) at least one control group or condition involving exposure to a non-natural stimulus, (5) measurement of self-reported pain, (6) articles published in English and (7) peer-reviewed articles containing original research (that is, no reviews or opinion pieces).

or videos with accompanying soundscapes, virtual reality (VR) environments that facilitated active-navigation and interaction using controller devices, or real-life (in situ) exposure, where participants were seated in outdoor greenspaces or interacted with biotic (for example, plants) and abiotic elements (for example, soil). Out of 96 extracted effects, 48 (50%) involved pure nature interventions characterized solely by natural stimuli, while the remaining 48 (50%) involved nature interventions that also included non-natural, potentially confounding elements, including calming music, video game aspects (for example, target shooting), guided meditation, autohypnosis, breathing (respiration) exercises or narration. Immersiveness corresponded to the number of sensory modalities stimulated by the intervention (for example, an intervention with nature sights and sounds was coded as ‘two’). Thirty-three (33.4%) of the nature interventions were manually coded for our analyses with an immersiveness level of one (mainly vision only), 44 (45.8%) with a level of two, 16 (16.7%) with a level of three and the remaining three (3.1%) effects with a level of four. All effects categorized as level ‘four’ corresponded to interventions conducted in real outdoor settings. In these cases, based on the information provided in the papers, we assumed that participants could see, hear, smell and touch their surroundings. Regarding the interactivity of the nature interventions, we coded 31 (32.3%) effects as passive-attending (observing the nature stimulus without the possibility for interaction), 24 (25%) effects as active-attending (exploring the stimulus via head movements in 360° presentations of static images or videos), 11 (11.5%) effects as active-navigation (navigating the stimulus for example, with VR controllers) and 24 (25%) effects as active-manipulation (direct interaction or manipulation of the stimulus). Six effects (6.3%) could not be coded owing to incomplete information and were treated as having missing data.

Comparators varied widely across studies. We coded comparators (72; 75%) as either nonmatched (for example, TAU) or relatively matched (21; 21.9%). Three effects (3.1%) could not be coded due to insufficient information in the articles. Nonmatched comparators included TAU, viewing a black computer screen or a fixation cross,

or wearing (deactivated) devices, such as turned-off headphones or head-mounted displays (HMD), to control for delivery effects. Matched comparators had notable variations in how closely they were matched to the nature interventions. Some were closely matched (for example, images of nature scenes versus images of urban scenes or natural biotic and abiotic elements versus their synthetic imitations). Others targeted the same sensory modalities but presented less well-matched content (for example, comparing the soundscape of a beach with audio recordings of affirmative sentences). The remaining comparators were only loosely matched in content or sensory modalities engaged (for example, a 360° VR scene of a beach walk compared to squeezing a stress ball).

We used the revised Cochrane risk of bias tool⁴¹, a standardized framework that evaluates bias across five domains (Methods). Each study received domain-specific and overall ratings of ‘low’, ‘some concerns’ or ‘high’ risk of bias, based on responses to predefined signaling questions. Using the tool, 33 studies (53.2%) were classified as having a ‘high’ overall risk of bias, while the remaining 29 (46.8%) were coded as having at least ‘some concerns’. The most frequent ratings of ‘some’/‘high’ concerns were observed in categories D4 (measurement of the outcome; 96.7%), D1 (randomization process; 66.1%) and D5 (selection of reported result; 50%). The almost universal category D4 concerns reflect that the studies in this review focused on self-reported pain and participants were typically aware of the intervention they received (or that they received an intervention, compared to TAU). For D5, most concerns were related to study protocols not being registered (32.2%). Categories D2 (deviations from intended interventions) and D3 (missing outcome data) generally exhibited low concern across studies (95.2% and 90.3%, respectively).

In summary, the included studies employed different research designs, were predominantly conducted in medical settings and primarily assessed pain using VAS or NRS. There was considerable heterogeneity in the nature interventions, comparators and types of pain assessed. The pain varied from minor to major interventions or procedures and most studies compared nature to nonmatched comparators. Notably, half of the effects examining nature interventions included confounding factors and most interventions were characterized by low-to-moderate levels of immersion or interactivity. Last, primarily owing to the subjective nature of the outcome variable, the overall concern for risk of bias was rated as moderate-to-high across all studies. However, this concern largely reflects limitations inherent to the research question, such as the subjectivity of the outcome variable or the difficulty of blinding participants to nature interventions, rather than avoidable flaws in design, execution, or interpretation.

Effects of nature exposure on self-reported pain

We conducted a three-level intercept-only meta-analysis with robust variance estimation (RVE), specifying random effects for individual effect sizes nested within studies to estimate the overall effect of nature exposure on self-reported pain. We found a significant estimated standardized mean effect size of standard mean difference (SMD) 0.535, 95% confidence interval (CI) 0.37 to 0.70, $t(59.4) = 6.37$, $P < 0.001$. On average, nature exposure was associated with lower self-reported pain relative to comparators, corresponding to a reduction of 1.08 points on commonly used 0–10 pain scales. Figure 2 displays the forest plot for all 96 individual effect estimates (Supplementary Fig. 1 shows a plot using within-study aggregated estimates). We found substantial heterogeneity across and within studies. The test for heterogeneity was significant ($Q(95) = 1,053.74$, $P < 0.001$) with a broad prediction interval (95%) for the SMD (−0.78 to 1.85). The I^2 index indicated high heterogeneity (95.9%), with 28.5% attributed to within-study and 67.4% to between-study variance. Comparing the original model with models that constrained level 2 (within-study) or level 3 (between-study), variances revealed significant within-study, $\chi^2(2) = 13.43$, $P < 0.001$ and between-study heterogeneity, $\chi^2(2) = 323.30$, $P < 0.001$.

Table 1 | Studies included in the multilevel meta-analysis (with key characteristics)

Ref.	k	Pain (context; outcome)	Nature intervention	Comparator
27	1	Wound care (med; NRS)	Nature scene (2D) + music	TAU
64	2	Sigmoidoscopy (med; VAS)	1: Nature sounds; 2: Nature scene (2D HMD) and sounds	TAU
139	2	Ischemic (exp; 1: Thr; 2: Tol)	Nature scene (2D HMD)	Black screen
140	2	Ischemic (exp; 1: Thr; 2: Tol)	Nature scene (2D HMD)	Black screen
23	1	Bronchoscopy (med; NRS)	Nature mural and sounds	TAU
141	1	Thermal (exp; GRS)	Icy canyon (VR) + interactive elements (SnowWorld)	Fixation cross
24	2	Colonoscopy (med; VAS)	1: Nature scene (2D HMD) + music; 2: Nature scene	TAU
142	1	Thermal (exp; GRS)	Icy canyon (VR) + interactive elements (SnowWorld)	Fixation cross
97	2	Dental (med; VAS)	Interactive botanical garden (VR)	1: Movie; 2: Sham HMD
32	1	Nerve block (med; NRS)	Nature scene (2D) and sounds + music	TAU
54	2	Bone marrow biopsy (med; VAS)	Nature mural and sounds	1: TAU; 2: Urban mural and sounds
26	1	Wound care (med; GRS)	Icy canyon (VR) + interactive elements (SnowWorld)	TAU
36	2	Thermal (exp; VAS)	Nature sounds: 1 (rain); 2 (water)	Pink noise
99	2	Laser-evoked potential (exp; VAS)	VR nature waiting room: 1 (chronic); 2 (healthy)	VR standard waiting room
94	1	Mechanical ventilation (med; VAS)	Nature sounds	Sham headphones
88	2	Wound care (med; VAS)	Nature scenes and sounds: 1 (2D); 2 (VR)	Not specified
52	1	Wound care (med; NRS)	Icy canyon (VR) + interactive elements (SnowWorld)	TAU
65	2	Chemotherapy (med; VAS)	Nature sounds	1: Affirmative sentences; 2: TAU
66	1	Cancer-related pain (med; VAS)	Nature scene (window)	Urban scene (window)
37	2	Surgery (med; VAS)	Nature scene (2D)	1: Music; 2: TAU
143	1	Electric (exp; VAS)	Nature scene (2D)	Black screen
144	1	Burn wounds (exp; GRS)	Icy canyon (VR) + interactive elements (SnowWorld)	TAU
15	4	1–2: Thermal (exp; NRS); 3–4: Dental (med; NRS)	Nature scene (VR): 2 (passive), 1, 3 and 4 (interactive)	1–3: Sham HMD; 4: Urban scene (interactive VR)
145	2	Cesarean section (med; VAS)	Nature sounds	1: Sham headphones; 2: TAU
40	1	Chronic pain (med; VAS)	Nature scene (VR) and sounds + music and guided meditation	TAU
28	2	Thermal (exp; 1: Thr; 2: Tol)	Nature scene (VR) and sounds + music	Opera scene (VR) + music
146	2	Thermal (exp; Tol)	Interactive nature scene (VR)	1: Interactive VR; 2: Black screen
147	2	Electrical (exp; NRS)	Nature scene (VR) and sounds: 1 (interactive); 2 (passive)	Black screen
148	1	Wound care (med; VAS)	Nature scene (VR) and sounds	TAU
149	2	Intramuscular injection (med; VAS)	Nature scene (not specified)	1: Optical illusions; 2: TAU
80	1	Colonoscopy (med; VAS)	Nature scene (VR) and sounds + music	TAU
67	1	Hysteroscopy (med; NRS)	Nature scene (VR) + narration	TAU
29	2	Vasectomy (med; VAS)	Nature scene: 1 (2D HMD); 2 (VR)	TAU
68	1	Breast biopsy (med; VAS)	Nature scene (VR) and sounds + music	TAU
81	4	Electric (exp; 1 and 3: Thr, 2 and 4: Tol)	Nature scene: 1–2 (2D); 3–4 (in situ; green)	Black screen
93	1	Cystoscopy (med; NRS)	Nature scene (VR) and sounds	TAU
82	1	Amniocentesis (med; VAS)	Nature scene (not specified)	TAU
69	1	Labor contractions (med; NRS)	Nature scene (VR) and sounds	TAU
30	2	Chemotherapy (med; NRS)	Nature scene: 1 (window and mural; green); 2 (interactive VR)	TAU
91	1	Hysteroscopy (med; NRS)	Nature scene (VR) and sounds + music	TAU
96	2	Prostate biopsy (med; VAS)	Nature scene (VR)	1: Stress ball; 2: TAU
70	1	Colonoscopy (med; VAS)	Nature scene (VR) + music	TAU
25	1	Colonoscopy (med; VAS)	Nature scene (not specified) + music	Sham HMD
76	1	Intravenous catheter (med; VAS)	Interactive nature scene (VR)	Sham HMD
95	1	Surgery (med; NRS)	Nature scene (not specified) + music	TAU
71	2	Surgery (med; VAS)	Nature scene (VR)	1: Educational VR; 2: TAU
100	1	Thermal (exp; NRS)	Nature scene (VR) and sounds + guided respiration	Not specified

Table 1 (continued) | Studies included in the multilevel meta-analysis (with key characteristics)

Ref.	k	Pain (context; outcome)	Nature intervention	Comparator
83	3	Colonoscopy (med; VAS)	Nature scene (VR) and sounds + music	1: Stress ball; 2: Music; 3: TAU
98	1	Surgery (med; NRS)	Nature scene (2D HMD) + narration and music	Music
72	2	Knee arthroplasty (med; VAS)	Interactive nature scene + biofeedback: 1 (2D); 2 (VR)	TAU
77	1	Endovascular procedure (med; NRS)	Interactive nature scene (VR) + respiration and hypnosis	TAU
87	4	Thermal (exp; NRS)	Nature scene and sounds + respiration: 1 and 3 (2D); 2 and 4 (VR)	Fixation cross
31	2	Traumatic injury (med; NRS)	Nature scene + music: 1 (2D); 2 (VR)	Sham HMD
92	1	Hysteroscopy (med; VAS)	Interactive nature scene (VR) + music	TAU
150	1	Prostate biopsy (med; VAS)	Nature scenes (VR) + music	TAU
73	1	Hysteroscopy (med; NRS)	Interactive nature scene (VR) + music and respiration	TAU
74	1	Various stimuli (med; NRS)	Nature scene (not specified)	TAU
78	1	Bronchoscopy (med; VAS)	Nature scene (VR) + music	TAU
75	2	Electrical (exp; Thr)	Nature scene (2D HMD) + music	1: Video game; 2: Not specified (TAU)
84	1	Colonoscopy (med; VAS)	Nature scene (VR) + music	TAU
33	1	Breast biopsy (med; VAS)	Nature scene (VR) and sounds	TAU
38	1	Chronic pain (med; NRS)	Interact with natural materials	Interact with synthetic materials

For studies including more than one effect, the conditions are indicated by numbers within corresponding rows. Exp, experimental; k, number of effects; med, medical; thr, threshold; tol, tolerance.

To assess the robustness of the overall effect and explore sources of heterogeneity, we conducted sensitivity analyses by excluding outliers, influential cases or studies measuring spontaneous chronic pain. All adjusted models yielded significant mean effect sizes, although with reduced magnitude (Supplementary Results). When excluding outliers—conservatively defined as effects whose 95% CIs did not overlap with the pooled effect CI—the SMD decreased to 0.485 (95% CI 0.40 to 0.56), with a substantially narrower prediction interval of 0.07 to 0.90. Similarly, removing influential cases identified via Cook's distance and DFBEAs reduced the SMD to 0.447 (95% CI 0.34 to 0.55) and narrowed the prediction interval to -0.27 to 1.17. These results suggest that a notable portion of the heterogeneity stemmed from influential and outlier cases.

To assess potential sources of heterogeneity, we conducted ten unimoderator meta-regression models (four preregistered and six exploratory) each testing the moderating effect of a single variable. Table 2 presents the overall test of moderation for each variable, along with category-specific estimates for categorical moderators and regression coefficients for continuous moderators. Orchard plots illustrating differences in levels of categorical moderators are shown in Fig. 3.

We found no significant moderation effects for the following variables: study context (medical versus experimental; preregistered), interactivity (passive-attending versus active-attending versus active-navigation versus active-manipulation, preregistered), study design (between-participant, within-participant or pre-post control group designs, not preregistered), type of outcome (rating scales versus tolerance or threshold measures, not preregistered) or purity (confounded versus nonconfounded, not preregistered). However, we observed two moderators that had an impact on the overall effect size. First, type of control (preregistered) significantly moderated the effect ($F(1, 16.2) = 9.01, P = 0.008; Q(91) = 987.04, P < 0.001$). Nature interventions were roughly half as effective when compared to matched comparators ($k = 21, SMD 0.31, 95\% CI 0.13 to 0.49, t(18.97) = 3.60, P = 0.002$) as when compared to nonmatched comparators (for example TAU, $k = 72, SMD 0.61, 95\% CI 0.41 to 0.81, t(16.19) = 3.00, P < 0.001$; Fig. 3a and Table 2). Second, while the overall moderator test for immersiveness (number of sensory modalities; preregistered) was not statistically significant ($F(1, 22.4) = 2.52, P = 0.102; Q(90) = 956.48, P < 0.001$,

studies targeting three modalities showed a significantly larger effect compared to studies targeting one modality ($\beta = 0.52, P = 0.04, 95\% CI 0.03 to 1.02$) with an estimated SMD of 0.87 versus 0.35, respectively (Fig. 3a and Table 2).

In addition, we conducted moderation analyses, including measures of bias, and found that out of three bias-related variables, two were nonsignificant moderators. First, there was no difference between studies with 'some' versus 'high' risk of bias (not preregistered) and second, we did not find an effect of publication year (not preregistered). When including standard error of the effect size as a moderator (a common proxy for small-study effects and funnel plot asymmetry) we found a significant positive association with effect size ($\beta = 0.473, s.e.m. 0.095, t(19.7) = 4.95, P < 0.001$), suggesting that studies with lower precision tended to report larger effects. Visual inspection of the contour-enhanced funnel plot⁴² showed asymmetry favoring studies that reported reductions in pain from nature exposure (Fig. 4). However, the presence of numerous nonsignificant effects indicated limited evidence for publication bias based solely on statistical significance.

Discussion

This preregistered systematic review and meta-analysis assessed whether nature exposure reduces self-reported acute pain or spontaneously occurring chronic pain. We found evidence for a small-to-moderate analgesic effect across published studies conducted in diverse settings, countries and employing various experimental and clinical procedures, suggesting that nature exposure can indeed reduce pain. However, substantial heterogeneity in study design and outcomes led to considerable variation in effect sizes, indicating that effectiveness depends on contextual and methodological factors. Examining this heterogeneity using moderator analyses, we did not find significant effects for study context, stimulus interactivity, study design, outcome type, purity or overall risk of bias. However, effects differed by comparator type (matched versus nonmatched) and number of sensory modalities targeted. Evidence that smaller studies tended to report larger effects, combined with widespread risk of bias, underscores the need for caution when interpreting the specificity and magnitude of these findings.

The observed small-to-moderate estimated mean effect (SMD 0.535) corresponds to an approximate reduction of 1.08 points on a

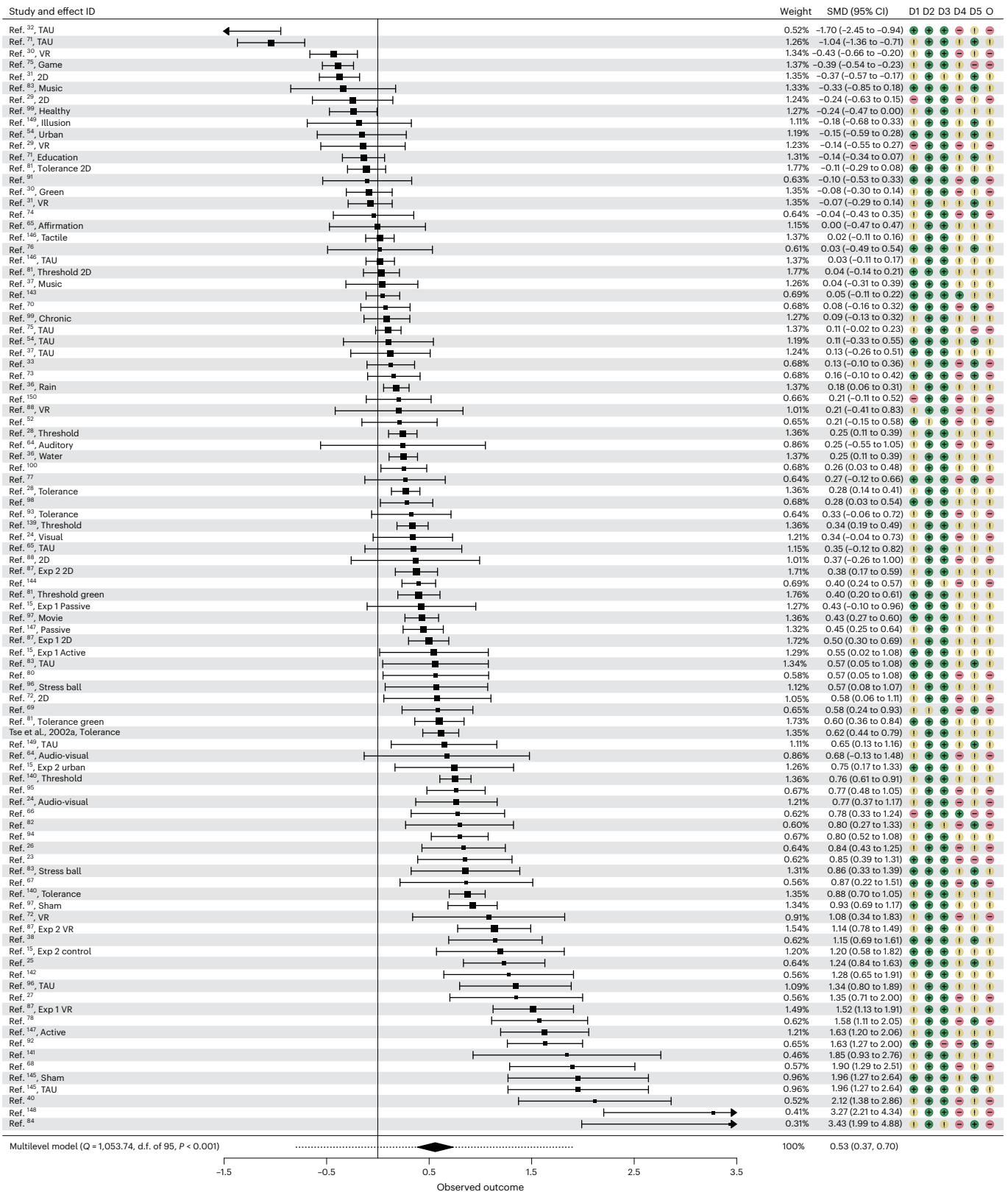


Fig. 2 | Forest plot depicting the effect of nature interventions on self-reported pain using individual effect sizes. For a plot using within-study aggregated estimates, see Supplementary Fig. 1. The descriptions for effect IDs indicate the individual effects for studies with multiple effect sizes (Table 1). Individual effect sizes (SMD) are shown as squares, with error bars indicating the 95% CIs. Higher and positive values represent reductions in self-reported pain associated with nature interventions. The estimated mean effect size (SMD 0.535, $P = 0.00000029$) and its 95% CI are shown as a diamond based on $k = 96$ effects

from $n = 62$ studies. The dotted line indicates the prediction interval for the estimated mean effect size (-0.78 to 1.85). The estimated mean effect is based on a three-level intercept-only meta-analysis with RVE (two sided). The annotations D1–D5 correspond to the domains of the Cochrane Risk of Bias assessment. O, overall bias. Note that the risk of bias was assessed at the individual level of the studies. The risk of bias for each domain is color coded: green represents low concern, yellow represents some concern and red represents high concern.

Table 2 | Moderator analyses separated by preregistered and exploratory moderator variables

Moderator	Test of overall moderator effect	Categorical moderator	SMD (95% CI)
Preregistered			
Context	$F(1, 18.9)=1.07, P=0.312$	Experimental Medical	0.42 (0.17 to 0.67) 0.57 (0.35 to 0.80)
Interactivity	$F(3, 10.9)=0.96, P=0.445$	Passive-attending Active-attending Active-navigation Active-manipulation	0.44 (0.18 to 0.69) 0.41 (0.11 to 0.72) 0.59 (0.01 to 1.17) 0.75 (0.44 to 1.07)
Immersiveness	$F(2, 22.4)=2.52, P=0.102$	One modality Two modalities Three modalities	0.35 (0.13 to 0.57) 0.51 (0.25 to 0.76) 0.87 (0.43 to 1.32)
Type of control	$F(1, 16.2)=9.01, P=0.008$	Matched Nonmatched	0.31 (0.13 to 0.49) 0.61 (0.41 to 0.81)
Exploratory			
Design	$F(2, 39.2)=0.99, P=0.378$	Between Within Pre-post control	0.39 (0.16 to 0.64) 0.59 (0.28 to 0.89) 0.68 (0.29 to 1.07)
Type of outcome	$F(1, 6.4)=3.15, P=0.123$	Threshold/tolerance Scale	0.28 (0.01 to 0.55) 0.57 (0.38 to 0.76)
Purity	$F(1, 26.9)=2.58, P=0.120$	Nonconfounded Confounded	0.41 (0.21 to 0.62) 0.64 (0.40 to 0.89)
Overall bias level	$F(1, 58.7)=0.46, P=0.498$	Some concern High concern	0.48 (0.27 to 0.68) 0.59 (0.32 to 0.87)
		Continuous moderator	β (95% CI)
Publication year	$F(1, 12.9)=0.51, P=0.487$	Year (centered)	-0.05 (-0.21 to 0.11)
Standard error	$F(1, 19.7)=24.5, P<0.001$	s.e.m. (centered)	0.47 (0.27 to 0.67)

Owing to missing or ambiguous data we excluded effect sizes for the following variables: interactivity (six studies excluded), immersiveness (three studies excluded) and type of control (three studies excluded). Furthermore, we excluded effect sizes for the studies with immersiveness coded as '4' (three studies), reflecting interventions conducted in real outdoor settings where the number of sensory modalities involved was unclear. The estimated mean effects are based on a three-level intercept-only meta-analysis with RVE using the respective variable as a moderator (two sided). *P* values across moderators were not adjusted for multiple comparisons. The exact *P* value for the moderator 'standard error' is $P=0.00000000082$.

0–10 pain rating scale. This magnitude is comparable to other non-pharmacological interventions, including behavioral or exercise therapy⁴³, music interventions^{44,45} and some distraction techniques for children⁴⁶. It is also similar to analgesic responses of three to four standard alcoholic drinks⁴⁷ or cannabinoid administration⁴⁸. However, it is considerably smaller than the short-term pain reductions typically observed with opioid or nonopioid treatments, which can decrease self-reported pain by three to four scale points^{49,50}. Although statistically significant, the effect falls short of the two-point threshold for "moderately important improvements" according to IMMPACT guidelines, but qualifies as a 'minimally important difference'⁵¹, supporting its clinical meaningfulness. Importantly, given the low-cost, minimal risk and potential scalability of nature-based interventions, even this minimally important difference holds considerable potential for meaningful population-level benefits. Our findings thus suggest that nature exposure serves best as an adjunct or complementary approach to pharmacological strategies since it may reduce the required dose of analgesics or enable the substitution of stronger medications with weaker ones^{16,52,53} (but see refs. 31,54). This can help mitigate dose escalations, a process of gradually increasing dosages to maintain pain relief, which is often ineffective in alleviating subjective pain in the medium-to-long term⁵⁵ and is associated with increased adverse outcomes. Consequently, it could potentially help to disrupt cycles of medication overuse or abuse.

In addition, nature exposure could alleviate the broader burden of pain by targeting mental health symptoms that commonly co-occur with pain-related conditions. Pain and mental health are closely interlinked, with both acute and chronic pain associated with various mental health challenges, including depression, catastrophizing, substance abuse, fear or anxiety^{7,56}. For example, anxiety not only

exacerbates acute pain^{57,58} but is also a strong predictor of chronic postsurgical pain⁵⁹. Conversely, persistent and intense pain elevates the risk for chronic anxiety disorders⁶⁰. Similar bidirectional associations have been suggested for depression and catastrophizing⁶⁰. Nature exposure has been linked to a reduction in mental health symptoms, including anxiety⁶¹, depression⁶² or rumination⁶³. In our meta-analysis, half of the studies assessed state anxiety as a secondary outcome. Of these, 61.3% ($n = 19$) reported reductions in anxiety following nature exposure^{27,28,33,40,64–75}, even when pain levels remained unchanged^{76–78}. By contrast, 32.3% ($n = 10$) found no effect and 6.4% ($n = 2$) reported adverse effects^{31,32,37,52,79–84}. Moreover, recent evidence suggests that access to urban greenspace may buffer the association between pain catastrophizing and intensity in patients⁸⁵. Together, these findings indicate that nature exposure may provide broader biopsychosocial benefits, addressing interrelated mental and physical dimensions of pain.

Given the substantial heterogeneity across studies, along with the risk of bias assessment discussed below, our findings warrant cautious interpretation and point to low certainty of the evidence (Supplementary Results), highlighting the need for more rigorous and homogeneous research. Notably, sensitivity analyses excluding outliers and influential cases yielded markedly narrower prediction intervals, indicating that some heterogeneity was driven by atypical effects. This is especially relevant given that estimates derived from several studies exceeded large (SMD >1) to very large (SMD >2) effect sizes, raising concerns about potential overestimation. However, excluding most of these studies based on outlier or influential diagnostics resulted in an estimated mean effect comparable to that of the full set of studies, thus supporting the robustness of the overall finding. To further investigate possible sources of heterogeneity, we conducted unimoderator

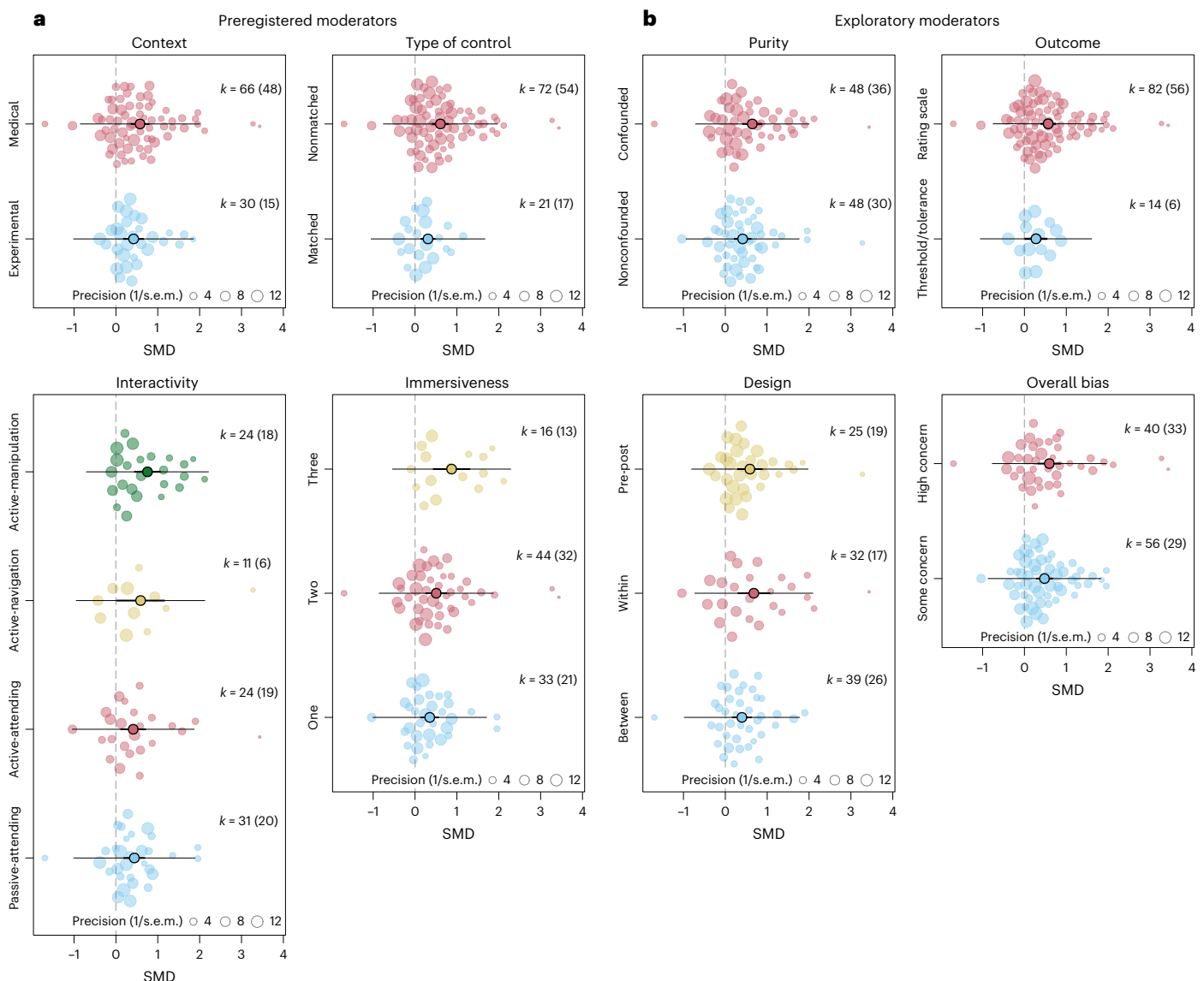


Fig. 3 | Orchard plots of effect sizes grouped by categorical moderators. **a**, Orchard plots depicting effect sizes grouped by preregistered categorical moderators. **b**, Orchard plots depicting effect sizes grouped by exploratory categorical moderators. Each dot represents an individual effect size estimate, with its size indicating the precision (inverse standard error) of the estimate. Estimates are based on three-level intercept-only meta-analysis with RVE using the respective variables as moderators (two sided). *k* denotes the number of individual effect sizes per moderator category, with the number of contributing studies (*n*) shown in parentheses. Black dots indicate estimated mean effect sizes, with thick error bars representing 95% CIs and thin error bars representing

prediction intervals. Estimated mean effect sizes and CIs are based on the following sample sizes: for **a**: medical (*k* = 66, *n* = 48), experimental (*k* = 30, *n* = 15), nonmatched (*k* = 72, *n* = 54), matched (*k* = 21, *n* = 17), active-manipulation (*k* = 24, *n* = 18), active-navigation (*k* = 11, *n* = 6), active-attending (*k* = 24, *n* = 19), passive-attending (*k* = 31, *n* = 20), three (*k* = 16, *n* = 13), two (*k* = 44, *n* = 32), one (*k* = 33, *n* = 21); for **b**: confounded (*k* = 48, *n* = 36), nonconfounded (*k* = 48, *n* = 30), rating scale (*k* = 82, *n* = 56), threshold/tolerance (*k* = 14, *n* = 6), pre-post (*k* = 25, *n* = 19), within (*k* = 32, *n* = 17), between (*k* = 39, *n* = 26), high concern (*k* = 40, *n* = 33), some concern (*k* = 56, *n* = 29).

analyses. Two preregistered moderators emerged as potentially relevant: the type of comparator (matched versus nonmatched) and the immersiveness (number of senses engaged).

Studies comparing nature interventions to nonmatched comparators (for example, TAU or no stimulation) revealed nearly double the effect size of those using relatively matched comparators (for example, non-natural urban environments). Importantly, while the estimated mean effects from both study categories differed significantly from zero, this finding suggests that more rigorous designs are needed to more accurately assess nature's potential impact. Furthermore, interventions targeting three modalities showed over twice the effect size compared to those targeting just one, suggesting that richer, multisensory approaches may enhance analgesic outcomes.

Rather than relying on, for instance, two-dimensional (2D) displays of images, interventions should incorporate sounds, scents or interactive elements. Only three studies exposed participants to 'real' nature, which may offer the greatest benefits by inherently engaging multiple senses. Where 'real' nature is unfeasible (for example, medical environments), VR presents a promising alternative⁸⁶. Studies comparing 2D and VR presentations of the same stimuli generally found stronger effects^{28,31,72,87} with VR (but see refs. 29,88) and among the ten largest effects, many involved VR delivery in clinical settings. However, VR has limitations, including motion sickness, cost and limited availability in socioeconomically disadvantaged populations. Notwithstanding these challenges, increasing the immersiveness of nature experiences may be a feasible way to amplify its analgesic potential.

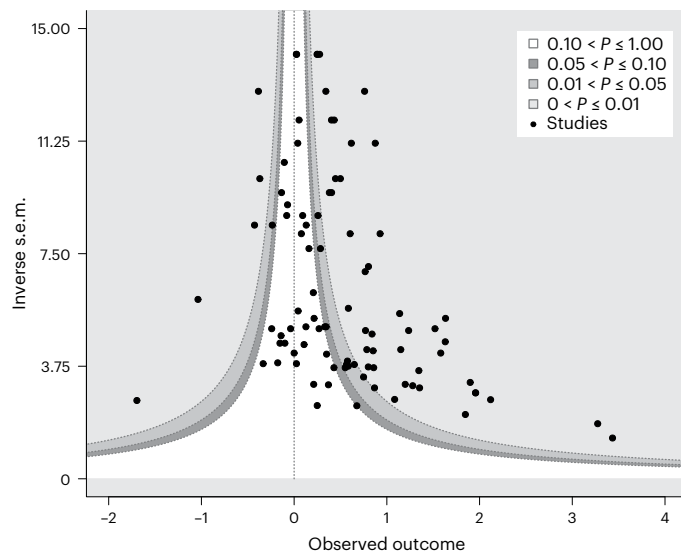


Fig. 4 | Contour-enhanced funnel plot displaying individual effect sizes (SMD) plotted against their inverse standard errors. Each dot represents a single effect size from the studies included in the meta-analysis. The shaded regions indicate conventional thresholds of statistical significance ($P < 0.05$, $P < 0.01$, $P < 0.001$; two sided), which serve as visual guides to assess potential small-study effects or publication bias. The vertical line at a SMD of 0 indicates no effect of nature interventions on self-reported pain. No formal statistical test for funnel plot asymmetry was conducted, as this plot is intended for qualitative assessment only (for further details, see Supplementary Methods).

Other potential moderators, such as interactivity, type of outcome, the presence of confounding elements and study design or context, did not demonstrate significant effects. First, contrary to our preregistered hypothesis, stimulus interactivity showed no moderating effect. However, its strong association with immersiveness ($\omega = 0.92$) complicates the interpretation, as it probably reflects substantial shared variance between the two variables (for a complete overview of pairwise associations among moderators, see Supplementary Results). Moreover, only one study directly investigated interactivity¹⁵, highlighting the need for focused research on this factor. Second, studies employing tolerance or threshold measures tended to report smaller effects than those using pain scales, but this comparison did not reach significance. Third, interventions confounded by additional elements (for example, music, meditation and hypnosis) showed larger effects than nature alone, implying these elements may amplify analgesic outcomes. Yet the lack of significant differences suggests that nature exposure by itself was effective and not impacted severely by these elements. Fourth, no significant variation in effect sizes emerged across different study designs, indicating comparable treatment effect estimation⁸⁹. Last, analyses showed no significant difference between experimental or medical settings, indicating that nature exposure was similarly effective across experimental methods and medical settings. However, the available evidence limited deeper exploration of how specific subtypes of medical and experimental pain procedures might be differentially impacted. For example, low analgesic effects were seen in studies involving medical procedures eliciting minimal self-reported pain^{30,65,76} (for example, blood draws or chemotherapy infusion), probably owing to bottom effects. Further research should clarify which pain conditions are most responsive to nature to better explain interstudy variability.

Beyond concerns about generalizability, the studies can be characterized as carrying considerable risk of bias. Specifically, using the Cochrane risk of bias tool⁴¹ indicated that all included studies exhibited some concern or high risk of bias. However, a moderator analysis found no significant differences in effect sizes based on overall bias

classification, suggesting that methodological shortcomings did not substantially impact the overall effect. Nevertheless, the prevalence of bias calls for caution in interpreting the results. Notably, over half of the included studies raised concerns about randomization and failed to report on allocation concealment. Furthermore, the absence of preregistration in most studies limited transparency around outcome selection and selective reporting. While this is unsurprising for research conducted in earlier decades when (pre)registration was less common, it highlights an important methodological shortcoming. Moving forward, a greater adherence to open science practices, including preregistration, transparent reporting and data sharing, is necessary to strengthen the evidence base.

A key consideration was risk of bias related to outcome measurement, with all but two studies rated as potentially biased. According to the Cochrane risk of bias tool, studies where knowledge of the intervention by the participants could influence self-reported outcomes were categorized as having some or high concern, since self-reported pain is inherently vulnerable to expectancy effects, placebo responses and demand characteristics. These challenges are not unique to nature exposure research. For instance, up to 50% of self-reported analgesic effects in pharmacological agents have been linked to expectancy mechanisms⁹⁰. Given the experiential and inherently subjective nature of pain, self-reports remain not only valuable but are key to capturing the essence of pain as a subjective experience. However, increased effort should be invested to complement them with more objective and mechanistic measures. For instance, psychophysiology or neuroimaging methods offer useful alternatives for measuring pain. Notably, several studies have collected additional data on pulse and heart rate or their variability^{25,28,30,31,33,72,77,81,83,84,91–95}, blood pressure^{30,54,77,81,83,84,92,93,96–98}, respiratory rate^{72,84,91,94–96} and skin conductance^{25,28,33}. Only a few studies have utilized neuroimaging methods such as electroencephalography^{87,99,100} or functional magnetic resonance imaging (fMRI). Leveraging neuroscience can complement self-reports and uncover the underlying mechanisms driving nature's analgesic effects. For example, a recent preregistered fMRI study from our group (published after the study inclusion cutoff of this review), found that exposure to nature, compared to well-matched urban or indoor environments, reduced both self-reported pain and brain responses linked to lower-level nociceptive processing¹⁰¹. These results indicated that nature's analgesic effects may involve neural pathways distinct from those implicated in expectancy or placebo responses. Similarly, another fMRI study showed that virtual nature lessened secondary hyperalgesia and was associated with altered insulo-thalamic effective connectivity¹⁰². Future well-controlled, mechanistic studies incorporating primary and secondary pain outcomes, less susceptible to bias, are critical to guide the development of optimized interventions with meaningful clinical impact and clarify the specific neural mechanisms involved.

Nature's analgesic effects may stem from various psychological and physiological mechanisms, which remain largely unexplored. One likely mechanism is attentional modulation. Attention restoration theory¹⁰³ suggests that certain natural elements are highly engaging and may redirect attentional resources away from pain more effectively than other stimuli. Supporting this, our recent neuroimaging work linked nature exposure to reduced activity in sensory-discriminative brain regions involved in nociceptive signaling, paralleling findings from mindfulness-based interventions, which similarly modulate attention-related neural circuits¹⁰¹. Stress recovery theory¹⁰⁴ provides an alternative perspective, proposing that specific aspects of nature induce positive affective changes and reduce stress, both known to modulate pain^{105,106}. Both frameworks suggest that nature is not intrinsically analgesic but facilitates pain relief through changes in cognitive and affective processes that can also be targeted by other interventions, such as mindfulness-based stress reduction^{107,108} or cognitive behavioral therapy¹⁰⁹. Nature may differ from these approaches in its

low cognitive demand and accessibility, evoking regulatory effects with minimal effort or training. Further studies should directly compare nature exposure with established psychological treatments and integrate environmental psychology theories with pain research¹¹⁰ to clarify its mechanisms of action.

Future research should also identify which elements of nature are most effective for pain relief and which individual differences are important. It remains uncertain whether features known to improve mood and restoration, such as biotic and abiotic sounds^{111,112}, the presence of water¹¹³, environmental complexity¹¹⁴ and perceived possibilities for prospect or refuge¹¹⁵, also enhance nature's analgesic effect. Aside from one study showing no pain differences across prospect-refuge combinations¹¹⁶, their specific role in pain modulation remains underexplored. Benefits may also vary across subgroups. For instance, individuals who feel psychologically closer to nature may experience greater pain relief¹¹⁷. It also remains unclear whether these effects extend to children and adolescents as these groups were excluded from this review owing to comparability issues with self-reported pain measures¹¹⁸. In addition, identifying which pain types respond best to nature and which environment-pain combinations are particularly effective needs to be established. For example, 'cold' environments may benefit burn-injured patients more than 'warm' ones¹¹⁹. Last, nearly all the summarized evidence focused on acute pain, which offers greater experimental control but limits generalizability to chronic pain¹²⁰, highlighting the need for future studies on nature's impact in chronic pain populations.

Beyond the limited generalizability to chronic pain, the limitations discussed earlier critically shape the interpretation of our findings. The certainty of the findings is constrained by substantial heterogeneity across studies and their generally modest methodological quality. While the wide prediction interval reflects considerable inconsistency, sensitivity analyses showed that excluding outliers and extreme cases reduced this inconsistency without altering the estimated mean effect. The moderate-to-high risk-of-bias assessments further underscores the need for more rigorous primary research in this field. Notably, the risk-of-bias assessment was largely driven by the reliance on subjective pain ratings as the primary outcome, which are inherently vulnerable to various forms of bias. Our focus on subjective outcomes was justified by the following considerations. Pain is an inherently personal experience¹²¹, and thus requires some sort of subjective report to capture how it is experienced by a person. This is why self-reported ratings are the widely accepted standard in pain research and clinical practice⁵¹. Their frequent use across studies also enabled the synthesis of a broad evidence base. However, future research should complement subjective ratings with additional measurements and experimental manipulations to address bias and provide deeper insights into the mechanisms underlying these effects. Last, because this study relied solely on secondary, anonymized data from previously published studies, detailed information on sex or gender was not available for all studies. We have summarized the number of female and male participants in the methods section. However, it was not feasible to conduct separate analyses based on sex or gender.

Conclusions

Nature exposure is associated with a small-to-moderate reduction in self-reported acute or spontaneous chronic pain across diverse studies. However, substantial heterogeneity and potential bias warrant cautious interpretation and call for more rigorous research to clarify the effect's generalizability, specificity and underlying mechanisms. Interventions appeared most beneficial with multisensory stimuli and when contrasted against nonmatched comparators, suggesting that context and methodological choices shape outcomes. Although evidence for the analgesic effects of nature is growing, further studies are needed. Their emphasis should expand beyond acute pain, which was the primary focus here, to chronic and recurrent pain, and

examine how individual-level factors and characteristics of nature influence its impact. We particularly advocate for rigorous studies adhering to open science practices and integrating both subjective and objective measures of pain. Such research will help uncover underlying mechanisms and optimize nature-based approaches as complementary pain-management strategies. Given the high global burden of pain, showing that such complementary, accessible and scalable interventions may reduce pain represents an important step toward expanding nonpharmacological treatment options and improving patient outcomes.

Methods

This systematic review and meta-analysis followed the guidelines of the Cochrane Handbook for Systematic Reviews of Interventions¹²² and the PRISMA 2020 statement¹²³. The completed PRISMA checklist is included at the end of the Supplementary Information. We pre-registered the systematic review and meta-analysis on PROSPERO (reference ID CRD42023478942) and report both preregistered and exploratory analyses.

Eligibility criteria

We included studies involving adult participants from healthy and clinical populations undergoing experimental or medical procedures typically experienced as painful. Studies had to feature at least one intervention that stimulated one or more sensory modalities (for example, visual, auditory, tactile) primarily using natural stimuli—such as videos of natural scenes, natural soundscapes or tactile interaction with natural materials—and include some form of comparator (matched or nonmatched; see below). Although this broad inclusion criterion introduced variability in the specific natural stimuli and delivery formats, the unifying feature across all interventions was that nature-based sensory input was the central component of the intervention. Self-reported pain was required as an outcome, assessed using either scales (VAS, NRS or GRS) or measures of pain threshold or tolerance. When multiple pain dimensions were assessed, we prioritized self-reported pain intensity as it was the most consistently reported measure across studies, allowing for the inclusion of the broadest possible dataset. We selected those closest to the painful stimulation for studies with multiple ratings at different time points. We included studies with between-participant, within-participant or pre-post control group designs. Eligible studies had to be published in English, peer-reviewed journals and present original research (excluding opinion pieces, reviews and so on). Studies were deemed ineligible if they employed inadequate interventions, comparators, and outcomes or provided insufficient data (Supplementary Methods and Supplementary Table 1). Furthermore, we excluded gray literature (for example, dissertations, conference abstracts and so on).

Study search, selection and coding

We searched the extent of the literature up until 31 January 2024 (no restrictions on earlier publication date) using four different databases: PsycINFO, PubMed, Web of Science and SCOPUS. We combined terms related to nature interventions, pain outcomes and exclusion criteria (Supplementary Methods). The same terms were used across all four databases, with adjustments made for database-specific search rules. In addition, we performed reference tracing through forward and backward tracking. Two reviewers (M.O.S. and J.P.N.) independently reviewed, coded (for example, study characteristics, moderators, risk of bias and certainty) and extracted data from all studies. Initially, we assessed titles and abstracts against our inclusion criteria, excluding those that did not meet them. We then reviewed the full text of the remaining articles. Discrepancies and ambiguities were resolved through direct discussion between the reviewers. The final sample included 62 studies encompassing a total sample size of $N = 4,439$ participants. Data on sex/gender was reported in 58 out of 62 studies

from which 1,989 (44.98%) were male and 2,433 were female (55.02%). Mean age was reported in 52 out of 62 studies and ranged from 20.33 to 70.94 years, with a weighted arithmetic mean of 44.91 years. For a PRISMA flow chart, see Fig. 1.

To investigate heterogeneity in intervention characteristics and study designs, we coded the studies for several factors and used these in moderator analyses. This allowed us to explore whether different forms of nature exposure or study features moderated the observed effects. To this end, we coded the studies for eight categorical factors (Supplementary Methods). First, we differentiated between medical (that is, clinical) and experimental studies. Second, we coded the level of interactivity of the nature interventions using four levels: passive-attending, active-attending, active-navigation and active-manipulation. Third, we coded the level of immersiveness of the nature interventions, representing the number of sensory modalities engaged. Fourth, we coded comparators as either matched or nonmatched. Matched comparators were active controls, such as a non-nature stimulus presented through the same or a similar medium as the nature stimulus or any other intervention participants might reasonably construe as an active intervention (for example, squeezing a stress ball). Nonmatched comparators included control conditions that did not offer additional stimulation (for example, TAU or turned-off devices such as blank screens or headphones without audio). Fifth, we assessed the study design type and differentiated between-participant, within-participant and pre-post control group designs. Sixth, we coded nature interventions as either pure or non-pure. Non-pure interventions included additional and potentially confounding elements such as relaxing music or autohypnosis. Pure interventions consisted solely of nature elements. Seventh, we coded the type of outcome to distinguish between studies measuring pain with scales (NRS, GRS and VAS) and those measuring pain through threshold and tolerance assessments. Eighth, we differentiated between studies with some or high risk of bias based on the revised Cochrane risk of bias tool. For an exhaustive list of all studies, including additional extracted details such as moderator coding or the location of the original data within each article, see Supplementary Table 2.

Data synthesis and analysis

We extracted means and s.d. from the text or raw data whenever possible. We contacted the study's first and last authors if no values were available. We converted medians, quartiles, interquartile ranges or s.e.m. to means or s.d. using established methods^{124–126}. If none of this information was provided but the article included figures, we manually extracted data using WebPlotDigitizer¹²⁷. We conducted all analyses in R (v4.2.1; R Core Team 2022) using the packages metafor¹²⁸ and ClubSandwich¹²⁹. We used SMD as effect sizes (for details, see Supplementary Methods). To ensure the comparability of SMDs across different study designs^{89,130}, all SMDs were based on raw score metrics calculated using the `escalc()` function from the metafor package. We performed a three-level intercept-only meta-analysis and used RVE to estimate the s.e.m. and CIs of the fixed effects¹³¹. We chose this approach to address dependencies in effect sizes and sampling errors, as multiple effect sizes within our dataset originated from the same study or included overlapping samples. Compared to traditional methods, multilevel meta-analysis and RVE are more effective for handling these dependencies^{132,133}. Random effects were specified for individual effect sizes nested within studies, and we used the `vcalc()` function of the metafor package to approximate the variance-covariance matrix of the sampling errors of dependent effect sizes. After running the main model, we performed sensitivity analyses by excluding outliers, influential cases and studies assessing spontaneous chronic pain¹³⁴.

We calculated Cochran's Q test and the I^2 statistics to assess heterogeneity, assessed the within and between-study variance for significance and interpreted the I^2 value according to recommended

guidelines^{132,135,136}. Figures 2–4 were created using the packages metafor¹²⁸ and orchaRd¹³⁷. Details on specifications of the main model, sensitivity analyses, heterogeneity and funnel plot asymmetry are reported in the Supplementary Information. All statistical tests were two sided.

Moderator analyses

We conducted moderation analyses using ten variables: (1) context, (2) interactivity (3) immersiveness, (4) type of control, (5) study design, (6) type of outcome, (7) purity, and (8) overall bias, (9) publication year and (10) the standard error of effect sizes. This last moderator analysis was used as a test for funnel plot asymmetry and can also be regarded as an Egger's test for multilevel meta-analysis, as suggested by Rodgers and Pustejovsky¹³⁸. The first four variables were preregistered. First, we examined the influence of study context by comparing medical versus experimental settings. Second and third, we assessed the impact of interactivity and immersiveness of the nature intervention. Fourth, we compared outcomes based on the type of control condition, distinguishing between matched and nonmatched comparators. The remaining six variables were not preregistered. They were added after collecting and reviewing all eligible articles, as we identified their relevance only after familiarizing ourselves with the existing literature. Accordingly, we investigated different study design types by contrasting between-participant, within-participant and pre-post control group designs. Furthermore, we differentiated between studies using pain rating scales and those employing pain threshold and tolerance measures. Pain rating scales, commonly used to assess self-reports of pain, typically require participants to select a value between 'no pain' to 'worst pain possible'. By contrast, pain threshold and tolerance measures assess the time it takes for participants to identify a stimulus as painful (threshold) or too intense to bear (tolerance). While both methods operationalize subjective pain experiences, they differ in their approaches to measurement and capture slightly different aspects of the pain experience. We therefore evaluated their relevance in this review. In addition, we contrasted pure nature interventions with those potentially confounded by additional elements. Furthermore, we investigated the impact of overall study bias by comparing studies with some or high risk of bias. Last, we examined the effect of publication year (centered) and precision (standard error; centered) of the effect size. For a detailed description of moderator coding, see the Supplementary Methods.

Risk of bias

Risk of bias was evaluated for each included study using the revised Cochrane risk of bias tool⁴¹ covering five domains: (D1) randomization process, (D2) deviations from intended interventions, (D3) missing outcome data, (D4) measurement of the outcome and (D5) selection of reported results. We also assessed the overall risk of bias according to the toolbox guidelines, where studies with 'some' or 'high' concern in at least one domain were given an overall assessment of 'some' or 'high' concern, respectively.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

The extracted data, including means, standard deviations, sample sizes, study and effect IDs, and moderator coding, are available via OSF at <https://osf.io/hmf4r/>. Source data are provided with this paper.

Code availability

The code used for the meta-analysis, including all supplementary analyses, is available via OSF at <https://osf.io/hmf4r/>. In addition, the code for reproducing all figures is provided alongside the Source data.

References

- Nahin, R. L., Feinberg, T., Kapos, F. P. & Terman, G. W. Estimated rates of incident and persistent chronic pain among US adults, 2019–2020. *JAMA Netw. Open* **6**, e2313563 (2023).
- Zimmer, Z., Fraser, K., Grol-Prokopczyk, H. & Zajacova, A. A global study of pain prevalence across 52 countries: examining the role of country-level contextual factors. *Pain* **163**, 1740–1750 (2022).
- Breivik, H., Collett, B., Ventafridda, V., Cohen, R. & Gallacher, D. Survey of chronic pain in Europe: prevalence, impact on daily life, and treatment. *Eur. J. Pain* **10**, 287–287 (2006).
- Gaskin, D. J. & Richard, P. The economic costs of pain in the United States. *J. Pain* **13**, 715–724 (2012).
- Phillips, C. J. Economic burden of chronic pain. *Expert Rev. Pharmacoecon. Outcomes Res.* **6**, 591–601 (2006).
- Vos, T. et al. Global, regional, and national incidence, prevalence, and years lived with disability for 328 diseases and injuries for 195 countries, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016. *Lancet* **390**, 1211–1259 (2017).
- Hooten, W. M. Chronic pain and mental health disorders. *Mayo Clin. Proc.* **91**, 955–970 (2016).
- Gureje, O. et al. The relation between multiple pains and mental disorders: results from the World Mental Health Surveys. *Pain* **135**, 82–91 (2008).
- Cohen, S. P., Vase, L. & Hooten, W. M. Chronic pain: an update on burden, best practices, and new advances. *Lancet* **397**, 2082–2097 (2021).
- Macintyre, P. E. & Schug, S. A. *Acute Pain Management: A Practical Guide* (CRC, 2021).
- Schug, S. A. & Goddard, C. Recent advances in the pharmacological management of acute and chronic pain. *Ann. Palliat. Med.* **3**, 263–275 (2014).
- Vowles, K. E. et al. Rates of opioid misuse, abuse, and addiction in chronic pain: a systematic review and data synthesis. *Pain* **156**, 569–576 (2015).
- Voon, P., Karamouzian, M. & Kerr, T. Chronic pain and opioid misuse: a review of reviews. *Subst. Abuse Treat. Prev. Policy* **12**, 1–9 (2017).
- Nahin, R. L., Stussman, B. J. & Herman, P. M. Out-of-pocket expenditures on complementary health approaches associated with painful health conditions in a nationally representative adult sample. *J. Pain* **16**, 1147–1162 (2015).
- Tanja-Dijkstra, K. et al. The soothing sea: a virtual coastal walk can reduce experienced and recollected pain. *Environ. Behav.* **50**, 599–625 (2018).
- Ulrich, R. S. View through a window may influence recovery from surgery. *Science* **224**, 420–421 (1984).
- Stanhope, J., Breed, M. F. & Weinstein, P. Exposure to greenspaces could reduce the high global burden of pain. *Environ. Res.* **187**, 109641 (2020).
- Hartig, T., Mitchell, R., de Vries, S. & Frumkin, H. Nature and health. *Annu. Rev. Public Health* **35**, 207–228 (2014).
- Che, X., Cash, R., Chung, S., Fitzgerald, P. B. & Fitzgibbon, B. M. Investigating the influence of social support on experimental pain and related physiological arousal: a systematic review and meta-analysis. *Neurosci. Biobehav. Rev.* **92**, 437–452 (2018).
- Heneweer, H., Staes, F., Aufdemkampe, G., Van Rijn, M. & Vanhees, L. Physical activity and low back pain: a systematic review of recent literature. *Eur. Spine J.* **20**, 826–845 (2011).
- Gacesa, R. et al. Environmental factors shaping the gut microbiome in a Dutch population. *Nature* **604**, 732–739 (2022).
- Guo, R., Chen, L.-H., Xing, C. & Liu, T. Pain regulation by gut microbiota: molecular mechanisms and therapeutic potential. *Br. J. Anaesth.* **123**, 637–654 (2019).
- Diette, G. B., Lechtzin, N., Haponik, E., Devrotes, A. & Rubin, H. R. Distraction therapy with nature sights and sounds reduces pain during flexible bronchoscopy: a complementary approach to routine analgesia. *Chest* **123**, 941–948 (2003).
- Lee, D. et al. Can visual distraction decrease the dose of patient-controlled sedation required during colonoscopy? A prospective randomized controlled trial. *Endoscopy* **36**, 197–201 (2004).
- Liu, Q. et al. Implementation of virtual reality technology to decrease patients' pain and nervousness during colonoscopies: a prospective randomised controlled single-blinded trial. *Clin. Med.* **22**, 237–240 (2022).
- Maani, C. V. et al. Virtual reality pain control during burn wound debridement of combat-related burn injuries using robot-like arm mounted VR goggles. *J. Trauma* **71**, S125–S130 (2011).
- Miller, A. C., Hickman, L. C. & Lemasters, G. K. A distraction technique for control of burn pain. *J. Burn Care Rehabil.* **13**, 576–580 (1992).
- Colloca, L. et al. Virtual reality: physiological and behavioral mechanisms to increase individual pain tolerance limits. *Pain* **161**, 2010–2021 (2020).
- Dings, S. J. M., van Stralen, K. J., Struben, V. M. D. & Noordzij, M. A. Pain and anxiety during vasectomies while distracting patients with video glasses or virtual reality glasses. *BJU Int.* **128**, 561–567 (2021).
- Verzwyvelt, A. L., McNamara, A., Xu, X. & Stubbins, R. Effects of virtual reality v. biophilic environments on pain and distress in oncology patients: a case-crossover pilot study. *Sci. Rep.* **11**, 20196 (2021).
- Morris, N. A. et al. Adjunctive virtual reality pain relief after traumatic injury: a proof-of-concept within-person randomized trial. *Pain* **164**, 2122–2129 (2023).
- Nikolajsen, L., Lyndgaard, K., Schriver, N. B. & Moller, J. F. Does audiovisual stimulation with music and nature sights (MuViCure) reduce pain and discomfort during placement of a femoral nerve block?. *J. Perianesth. Nurs.* **24**, 14–18 (2009).
- Girishan-Prabhu, V. G. et al. The impact of virtual reality on anxiety and pain during US-guided breast biopsies: a randomized controlled clinical trial. *J. Breast Imaging* **6**, 45–52 (2024).
- Howick, J. et al. Are treatments more effective than placebos? A systematic review and meta-analysis. *PLoS ONE* **8**, e62599 (2013).
- Löfholm, C. A., Brännström, L., Olsson, M. & Hansson, K. Treatment-as-usual in effectiveness studies: what is it and does it matter?. *Int. J. Soc. Welfare* **22**, 25–34 (2013).
- Garza-Villarreal, E. A., Brattico, E., Vase, L., Østergaard, L. & Vuust, P. Superior analgesic effect of an active distraction versus pleasant unfamiliar sounds and music: the influence of emotion and cognitive style. *PLoS ONE* **7**, e29397 (2012).
- Nielsen, E., Wählén, I. & Frisman, G. H. Evaluating pictures of nature and soft music on anxiety and well-being during elective surgery. *Open Nurs. J.* **12**, 58–66 (2018).
- Gungormus, D. B., Fernández-Martín, M., Ortigosa-Luque, M. E. & Pérez-Mármol, J. M. Effects of nature-based multisensory stimulation on pain mechanisms in women with fibromyalgia syndrome: a randomized double-blind placebo-controlled trial. *Pain Manag. Nurs.* **25**, 46–55 (2024).
- Mavridis, D., Giannatsi, M., Cipriani, A. & Salanti, G. A primer on network meta-analysis with emphasis on mental health. *BMJ Ment. Health* **18**, 40–46 (2015).
- Mohammad, E. & Ahmad, M. Virtual reality as a distraction technique for pain and anxiety among patients with breast cancer: a randomized control trial. *Palliat. Supp. Care* **17**, 29–34 (2019).
- Sterne, J. A. C. et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. *Br. Med. J.* **366**, l4898 (2019).

42. Peters, J. L., Sutton, A. J., Jones, D. R., Abrams, K. R. & Rushton, L. Contour-enhanced meta-analysis funnel plots help distinguish publication bias from other causes of asymmetry. *J. Clin. Epidemiol.* **61**, 991–996 (2008).
43. Keller, A., Hayden, J., Bombardier, C. & Van Tulder, M. Effect sizes of non-surgical treatments of non-specific low-back pain. *Eur. Spine J.* **16**, 1776–1788 (2007).
44. Kühlmann, A. Y. R. et al. Meta-analysis evaluating music interventions for anxiety and pain in surgery. *Br. J. Surg.* **105**, 773–783 (2018).
45. Richard-Lalonde, M. et al. The effect of music on pain in the adult intensive care unit: a systematic review of randomized controlled trials. *J. Pain Symptom Manage.* **59**, 1304–1319 (2020).
46. Birnie, K. A. et al. Systematic review and meta-analysis of distraction and hypnosis for needle-related pain and distress in children and adolescents. *J. Pediatr. Psychol.* **39**, 783–808 (2014).
47. Thompson, T., Oram, C., Correll, C. U., Tsermentseli, S. & Stubbs, B. Analgesic effects of alcohol: a systematic review and meta-analysis of controlled experimental studies in healthy participants. *J. Pain* **18**, 499–510 (2017).
48. Yanes, J. A. et al. Effects of cannabinoid administration for pain: a meta-analysis and meta-regression. *Exp. Clin. Psychopharmacol.* **27**, 370–382 (2019).
49. Bijur, P. E., Friedman, B. W., Irizarry, E., Chang, A. K. & Gallagher, E. J. A randomized trial comparing the efficacy of five oral analgesics for treatment of acute musculoskeletal extremity pain in the emergency department. *Ann. Emerg. Med.* **77**, 345–356 (2021).
50. Chang, A. K., Bijur, P. E., Esses, D., Barnaby, D. P. & Baer, J. Effect of a single dose of oral opioid and nonopioid analgesics on acute extremity pain in the emergency department: a randomized clinical trial. *JAMA* **318**, 1661 (2017).
51. Dworkin, R. H. et al. Interpreting the clinical importance of treatment outcomes in chronic pain clinical trials: IMMPACT recommendations. *J. Pain* **9**, 105–121 (2008).
52. McSherry, T. et al. Randomized, crossover study of immersive virtual reality to decrease opioid use during painful wound care procedures in adults. *J. Burn Care Res.* **39**, 278–285 (2017).
53. Gamal, M., Rady, A., Gamal, M. & Hassan, H. Efficacy of virtual reality distraction technique for anxiety and pain control in orthopedic forearm surgeries performed under supraclavicular brachial plexus block: a randomized controlled study. *Egypt J. Anaesth.* **39**, 468–476 (2023).
54. Lechtzin, N. et al. A randomized trial of nature scenery and sounds versus urban scenery and sounds to reduce pain in adults undergoing bone marrow aspirate and biopsy. *J. Altern. Complement Med.* **16**, 965–972 (2010).
55. Hayes, C. J. et al. Impact of opioid dose escalation on pain intensity: a retrospective cohort study. *Pain* **161**, 979–988 (2020).
56. Michaelides, A. & Zis, P. Depression, anxiety and acute pain: links and management challenges. *Postgrad. Med.* **131**, 438–444 (2019).
57. Pinto, P. R., McIntyre, T., Almeida, A. & Araújo-Soares, V. The mediating role of pain catastrophizing in the relationship between presurgical anxiety and acute postsurgical pain after hysterectomy. *Pain* **153**, 218–226 (2012).
58. Fernández-Castro, M. et al. The influence of preoperative anxiety on postoperative pain in patients undergoing cardiac surgery. *Sci. Rep.* **12**, 16464 (2022).
59. Giusti, E. M., Lacerenza, M., Manzoni, G. M. & Castelnuovo, G. Psychological and psychosocial predictors of chronic postsurgical pain: a systematic review and meta-analysis. *Pain* **162**, 10–30 (2021).
60. Gerrits, M. M. J. G. et al. Impact of pain on the course of depressive and anxiety disorders. *Pain* **153**, 429–436 (2012).
61. Liu, Z. et al. Green space exposure on depression and anxiety outcomes: a meta-analysis. *Environ. Res.* **231**, 116303 (2023).
62. Roberts, H., Van Lissa, C., Hagedoorn, P., Kellar, I. & Helbich, M. The effect of short-term exposure to the natural environment on depressive mood: a systematic review and meta-analysis. *Environ. Res.* **177**, 108606 (2019).
63. Bratman, G. N., Hamilton, J. P., Hahn, K. S., Daily, G. C. & Gross, J. J. Nature experience reduces rumination and subgenual prefrontal cortex activation. *Proc. Natl Acad. Sci. USA* **112**, 8567–8572 (2015).
64. Lembo, T. et al. Audio and visual stimulation reduces patient discomfort during screening flexible sigmoidoscopy. *Am. J. Gastroenterol.* **93**, 1113–1116 (1998).
65. Yildirim, M. et al. Symptom management: the effects of self-affirmation on chemotherapy-related symptoms. *Clin. J. Oncol. Nurs.* **21**, E15–E22 (2017).
66. Emami, E., Amini, R. & Motalebi, G. The effect of nature as positive distractibility on the healing process of patients with cancer in therapeutic settings. *Complement. Ther. Clin. Pract.* **32**, 70–73 (2018).
67. Deo, N. et al. Virtual reality for acute pain in outpatient hysteroscopy: a randomised controlled trial. *BJOG* **128**, 87–95 (2021).
68. Karaman, D. & Taşdemir, N. The effect of using virtual reality during breast biopsy on pain and anxiety: a randomized controlled trial. *J. Perianesth. Nurs.* **36**, 702–705 (2021).
69. Momenyan, N., Safei, A. A. & Hantoushzadeh, S. Immersive virtual reality analgesia in un-medicated laboring women (during stage 1 and 2): a randomized controlled trial. *Clin. Exp. Obstet. Gynecol.* **48**, 110–116 (2021).
70. Ketsuwan, C. et al. Prospective randomized controlled trial to evaluate effectiveness of virtual reality to decrease anxiety in office-based flexible cystoscopy patients. *World J. Urol.* **40**, 2575–2581 (2022).
71. Abbasnia, F., Aghebati, N., Miri, H. H. & Etezadpour, M. Effects of patient education and distraction approaches using virtual reality on pre-operative anxiety and post-operative pain in patients undergoing laparoscopic cholecystectomy. *Pain Manag. Nurs.* **24**, 280–288 (2023).
72. Girishan-Prabhu, V. G., Stanley, L., Morgan, R. & Shirley, B. Designing and developing a nature-based virtual reality with heart rate variability biofeedback for surgical anxiety and pain management: evidence from total knee arthroplasty patients. *Aging Ment. Health* **28**, 738–753 (2023).
73. Sewell, T., Fung, Y., Al-Kufaihi, A., Clifford, K. & Quinn, S. Does virtual reality technology reduce pain and anxiety during outpatient hysteroscopy? A randomised controlled trial. *BJOG* **130**, 1466–1472 (2023).
74. Singh, N. et al. The use of immersive audiovisual distraction with virtual reality during pain procedures: a randomized controlled trial. *Pain Med.* **24**, 1204–1206 (2023).
75. Yamashita, Y., Aijima, R. & Danjo, A. Clinical effects of different virtual reality presentation content on anxiety and pain: a randomized controlled trial. *Sci. Rep.* **13**, 20487 (2023).
76. Perdue, M. J., Umar, M. A., Walker, J. D. & Kubena, B. Immersive virtual reality for pain control and anxiety during IV blood draws in adults: a randomized controlled trial. *Mil. Med.* **188**, e2467–e2471 (2022).
77. Gullo, G. et al. Virtually augmented self-hypnosis in peripheral vascular intervention: a randomized controlled trial. *Cardiovasc. Intervent. Radiol.* **46**, 786–793 (2023).
78. Sooriyaghandan, I. V. et al. Satisfaction and tolerability using virtual reality (VR) as adjunctive treatment during flexible bronchoscopy: a randomized control trial. *BMC Pulm. Med.* **23**, 10 (2023).

79. Pati, D., Freier, P., O'Boyle, M., Amor, C. & Valipour, S. The impact of simulated nature on patient outcomes: a study of photographic sky compositions. *HERD* **9**, 36–51 (2016).
80. Cakir, S. K. & Evirgen, S. The effect of virtual reality on pain and anxiety during colonoscopy: a randomized controlled trial. *Turk. J. Gastroenterol.* **32**, 451–457 (2021).
81. Li, H., Zhang, X., Bi, S., Cao, Y. & Zhang, G. Can residential greenspace exposure improve pain experience? A comparison between physical visit and image viewing. *Healthcare* **9**, 918 (2021).
82. Melcer, Y. et al. Analgesic efficacy of virtual reality for acute pain in amniocentesis: a randomized controlled trial. *Eur. J. Obstet. Gynecol. Reprod. Biol.* **261**, 134–138 (2021).
83. Cakir, S. K. & Evirgen, S. Three distraction methods for pain reduction during colonoscopy: a randomized controlled trial evaluating the effects on pain and anxiety. *J. Perianesth. Nurs.* **38**, e1–e7 (2023).
84. Yılmaz, E. D. & Dinçer, N. Ü The effects of virtual reality glasses on vital signs and anxiety in patients undergoing colonoscopy: a randomized controlled trial. *Gastroenterol. Nurs.* **46**, 318–328 (2023).
85. Wells, N. M., Rollings, K. A., Ong, A. D. & Reid, M. C. Nearby nature buffers the pain catastrophizing–pain intensity relation among urban residents with chronic pain. *Front. Built Environ.* **5**, 142 (2019).
86. Berdejo-Espinola, V., Zahnow, R., O'Bryan, C. J. & Fuller, R. A. Virtual reality for nature experiences. *Nat. Hum. Behav.* **8**, 1005–1007 (2024).
87. Li, J. et al. The analgesic effects and neural oscillatory mechanisms of virtual reality scenes based on distraction and mindfulness strategies in human volunteers. *Br. J. Anaesth.* **131**, 1082–1092 (2023).
88. Ebrahimi, H., Namdar, H., Ghahramanpour, M., Ghafourifard, M. & Musavi, S. Effect of virtual reality method and multimedia system on burn patients' pain during dressing. *J. Clin. Anal. Med.* **8**, 485–489 (2017).
89. Morris, S. B. & DeShon, R. P. Combining effect size estimates in meta-analysis with repeated measures and independent-groups designs. *Psychol. Methods* **7**, 105–125 (2002).
90. Bingel, U. et al. The effect of treatment expectation on drug efficacy: imaging the analgesic benefit of the opioid remifentanyl. *Sci. Transl. Med.* **3**, 70ra14 (2011).
91. Fouks, Y. et al. A virtual reality system for pain and anxiety management during outpatient hysteroscopy: a randomized control trial. *Eur. J. Pain* **26**, 600–609 (2022).
92. Pelazas-Hernández, J. A. et al. The effect of virtual reality on the reduction of pain in women with an indication for outpatient diagnostic hysteroscopy: a randomized controlled trial. *J. Clin. Med.* **12**, 3645 (2023).
93. Łuczak, M. et al. Influence of virtual reality devices on pain and anxiety in patients undergoing cystoscopy performed under local anaesthesia. *J. Pers. Med.* **11**, 1214 (2021).
94. Saadatmand, V. et al. Effects of natural sounds on pain: a randomized controlled trial with patients receiving mechanical ventilation support. *Pain Manag. Nurs.* **16**, 483–492 (2015).
95. Yesilot, S. B., Yeşilkuş, R. & Beyaz, F. Use of virtual reality for reducing pain and anxiety after laparoscopic sleeve gastrectomy: a randomized controlled trial. *Pain Manag. Nurs.* **23**, 826–831 (2022).
96. Genc, H., Korkmaz, M. & Akkurt, A. The effect of virtual reality glasses and stress balls on pain and vital findings during transrectal prostate biopsy: a randomized controlled trial. *J. Perianesth. Nurs.* **37**, 344–350 (2022).
97. Furman, E. et al. Virtual reality distraction for pain control during periodontal scaling and root planing procedures. *J. Am. Dent. Assoc.* **140**, 1508–1516 (2009).
98. Demirci, H. et al. Watching a movie or listening to music is effective in managing perioperative anxiety and pain: a randomised controlled trial. *Knee Surg. Sports Traumatol. Arthrosc.* **31**, 6069–6079 (2023).
99. de Tommaso, M. et al. Virtual visual effect of hospital waiting room on pain modulation in healthy subjects and patients with chronic migraine. *Pain Res. Treat.* **2013**, 515730 (2013).
100. Bi, Y. et al. Enhancing pain modulation: The efficacy of synchronous combination of virtual reality and transcutaneous electrical nerve stimulation. *Gen. Psych.* **36**, e101164 (2023).
101. Steininger, M. O. et al. Nature exposure induces analgesic effects by acting on nociception-related neural processing. *Nat. Commun.* **16**, 2037 (2025).
102. Medina, S. & Hughes, S. W. Immersion in nature through virtual reality attenuates the development and spread of mechanical secondary hyperalgesia: a role for insulo-thalamic effective connectivity. *Pain* **166**, 2181–2193 (2025).
103. Kaplan, S. The restorative benefits of nature: toward an integrative framework. *J. Environ. Psychol.* **15**, 169–182 (1995).
104. Ulrich, R. S. et al. Stress recovery during exposure to natural and urban environments. *J. Environ. Psychol.* **11**, 201–230 (1991).
105. Zelman, D. C., Howland, E. W., Nichols, S. N. & Cleeland, C. S. The effects of induced mood on laboratory pain. *Pain* **46**, 105–111 (1991).
106. Melzack, R. Pain and stress: a new perspective. In *Advances in Psychological Science: Biological and Cognitive Aspects* (eds Gatchel, R. J. & Turk, D. C.) 89–106 (Guilford Press, 2014).
107. Wielgosz, J. et al. Neural signatures of pain modulation in short-term and long-term mindfulness training: a randomized active-control trial. *Am. J. Psychiatry* **179**, 758–767 (2022).
108. Riegner, G., Dean, J., Wager, T. D. & Zeidan, F. Mindfulness meditation and placebo modulate distinct multivariate neural signatures to reduce pain. *Biol. Psychiatry* **97**, 81–88 (2024).
109. Ehde, D. M., Dillworth, T. M. & Turner, J. A. Cognitive-behavioral therapy for individuals with chronic pain: efficacy, innovations, and directions for research. *Am. Psychol.* **69**, 153–166 (2014).
110. Smith, A. et al. Harnessing the therapeutic effects of nature for chronic pain: A role for immersive virtual reality? A narrative review. *Eur. J. Pain* **29**, e1p.4727 (2024).
111. Ratcliffe, E. Sound and soundscape in restorative natural environments: a narrative literature review. *Front. Psychol.* **12**, 570563 (2021).
112. Smalley, A. J. et al. Forest 404: using a BBC drama series to explore the impact of nature's changing soundscapes on human wellbeing and behavior. *Glob. Environ. Change* **74**, 102497 (2022).
113. White, M. et al. Blue space: the importance of water for preference, affect, and restorativeness ratings of natural and built scenes. *J. Environ. Psychol.* **30**, 482–493 (2010).
114. Han, K.-T. Responses to six major terrestrial biomes in terms of scenic beauty, preference, and restorativeness. *Environ. Behav.* **39**, 529–556 (2007).
115. Gatersleben, B. & Andrews, M. When walking in nature is not restorative—the role of prospect and refuge. *Health Place* **20**, 91–101 (2013).
116. Vincent, E., Battisto, D., Grimes, L. & McCubbin, J. The effects of nature images on pain in a simulated hospital patient room. *HERD* **3**, 42–55 (2010).
117. Martin, L. et al. Nature contact, nature connectedness and associations with health, wellbeing and pro-environmental behaviours. *J. Environ. Psychol.* **68**, 101389 (2020).
118. Stinson, J. N., Kavanagh, T., Yamada, J., Gill, N. & Stevens, B. Systematic review of the psychometric properties, interpretability and feasibility of self-report pain intensity measures for use in clinical trials in children and adolescents. *Pain* **125**, 143–157 (2006).

119. Phelan, I. et al. Designing effective virtual reality environments for pain management in burn-injured patients. *Virtual Real.* **27**, 201–215 (2021).
120. Simons, L. E., Elman, I. & Borsook, D. Psychological processing in chronic pain: a neural systems approach. *Neurosci. Biobehav. Rev.* **39**, 61–78 (2014).
121. Raja, S. N. et al. The revised International Association for the Study of Pain definition of pain: concepts, challenges, and compromises. *Pain* **161**, 1976–1982 (2020).
122. Chandler, J., Cumpston, M., Li, T., Page, M. J. & Welch, V. *Cochrane Handbook for Systematic Reviews of Interventions* (Wiley, 2019).
123. Page, M. J. et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Br. Med. J.* **372**, n71 (2021).
124. McGrath, S. et al. Estimating the sample mean and standard deviation from commonly reported quantiles in meta-analysis. *Stat. Methods Med. Res.* **29**, 2520–2537 (2020).
125. Cai, S., Zhou, J. & Pan, J. Estimating the sample mean and standard deviation from order statistics and sample size in meta-analysis. *Stat. Methods Med. Res.* **30**, 2701–2719 (2021).
126. Wan, X., Wang, W., Liu, J. & Tong, T. Estimating the sample mean and standard deviation from the sample size, median, range and/or interquartile range. *BMC Med. Res. Methodol.* **14**, 135 (2014).
127. Rohtagi, A. WebPlotDigitizer. *arohatgi* <http://arohatgi.info/WebPlotDigitizer> (2011).
128. Viechtbauer, W. Conducting meta-analyses in R with the metafor package. *J. Stat. Soft.* **36**, 1–48 (2010).
129. Pustejovsky, J. E. clubSandwich: cluster-robust (sandwich) variance estimators with small-sample corrections. *GitHub* <https://jepusto.github.io/clubSandwich/> (2025).
130. Morris, S. B. Estimating effect sizes from pretest–posttest–control group designs. *Organ. Res. Methods* **11**, 364–386 (2008).
131. Pustejovsky, J. E. & Tipton, E. Meta-analysis with robust variance estimation: expanding the range of working models. *Prev. Sci.* **23**, 425–438 (2022).
132. Assink, M. & Wibbelink, C. J. M. Fitting three-level meta-analytic models in R: a step-by-step tutorial. *Tutor. Quant. Methods Psychol.* **12**, 154–174 (2016).
133. Cheung, M. W.-L. Modeling dependent effect sizes with three-level meta-analyses: a structural equation modeling approach. *Psychol. Methods* **19**, 211–229 (2014).
134. Viechtbauer, W. & Cheung, M. W.-L. Outlier and influence diagnostics for meta-analysis. *Res. Synth. Method* **1**, 112–125 (2010).
135. Higgins, J. P. T. & Thompson, S. G. Quantifying heterogeneity in a meta-analysis. *Stat. Med.* **21**, 1539–1558 (2002).
136. Nakagawa, S. & Santos, E. S. A. Methodological issues and advances in biological meta-analysis. *Evol. Ecol.* **26**, 1253–1274 (2012).
137. Nakagawa, S. et al. orchaRd 2.0: an R package for visualising meta-analyses with orchard plots. *Methods Ecol. Evol.* **14**, 2003–2010 (2023).
138. Rodgers, M. A. & Pustejovsky, J. E. Evaluating meta-analytic methods to detect selective reporting in the presence of dependent effect sizes. *Psychol. Methods* **26**, 141–160 (2021).
139. Tse, M. M. Y., Ng, J. K. F., Chung, J. W. Y. & Wong, T. K. S. The effect of visual stimuli on pain threshold and tolerance. *J. Clin. Nurs.* **11**, 462–469 (2002).
140. Tse, M. M. Y., Ng, J. K. F., Chung, J. W. Y. & Wong, T. K. S. The effect of visual stimulation via the eyeglass display and the perception of pain. *Cyberpsychol. Behav.* **5**, 65–75 (2002).
141. Hoffman, H. G. et al. Modulation of thermal pain-related brain activity with virtual reality: evidence from fMRI. *NeuroReport* **15**, 1245–1248 (2004).
142. Hoffman, H. G. et al. The analgesic effects of opioids and immersive virtual reality distraction: evidence from subjective and functional brain imaging assessments. *Anesth. Analg.* **105**, 1776–1783 (2007).
143. Schmidt, K., Gamer, M., Forkmann, K. & Bingel, U. Pain affects visual orientation: an eye-tracking study. *J. Pain* **19**, 135–145 (2018).
144. Soltani, M. et al. Virtual reality analgesia for burn joint flexibility: a randomized controlled trial. *Rehabil. Psychol.* **63**, 487–494 (2018).
145. Farzaneh, M. et al. Comparative effect of nature-based sounds intervention and headphones intervention on pain severity after cesarean section: a prospective double-blind randomized trial. *Anesth. Pain Med.* **9**, e67835 (2019).
146. Czub, M. & Bagrij, A. Tactile and visual virtual reality attention distraction from pain in cold pressor test. *Pol. Psychol. Bull.* **51**, 315–323 (2020).
147. Lier, E. J., Oosterman, J. M., Assmann, R., de Vries, M. & van Goor, H. The effect of virtual reality on evoked potentials following painful electrical stimuli and subjective pain. *Sci. Rep.* **10**, 9067 (2020).
148. Araújo, T. M., da Silva, A. S. J., Brandão, M. G. S. A., Barros, L. M. & Veras, V. S. Virtual reality in pain relief during chronic wound dressing change. *Rev. Esc. Enferm. USP* **55**, e20200513 (2021).
149. Basak, T., Demirtas, A. & Yorubulut, S. M. Virtual reality and distraction cards to reduce pain during intramuscular benzathine penicillin injection procedure in adults: a randomized controlled trial. *J. Adv. Nurs.* **77**, 2511–2518 (2021).
150. Perenic, E., Grember, E., Bassard, S. & Koutlidis, N. Impact of virtual reality on pain management in transrectal MRI-guided prostate biopsy. *Front. Pain Res.* **4**, 1156463 (2023).

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Author contributions

M.O.S. performed the conceptualization, methodology, software, validation, formal analysis, investigation, data curation, writing—original draft, writing—review and editing, visualization and project administration. J.P.N. undertook the conceptualization, methodology, validation, formal analysis, investigation, data curation, writing—original draft, writing—review and editing and supervision. M.P.W. performed the conceptualization, methodology, writing—original draft, writing—review and editing and supervision. C.L. undertook the conceptualization, methodology, resources, writing—original draft, writing—review and editing, supervision and funding acquisition.

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Data collection No custom or commercial software was used to collect data. Studies were identified through manual searches of online databases including PubMed, PsycINFO, Web of Science, and SCOPUS. When outcome data was not available in the text, tables, or accompanying raw data, we extracted data from figures using WebPlotDigitizer (version 5.2; <https://automeris.io>).

Extracted data were recorded and organized using Microsoft Excel - Microsoft Office 365 (2025; version 16.98)

The code used to analyse the data is publicly available under: <https://osf.io/hmf4r/>

Data analysis Meta-analysis - including moderator and sensitivity analyses, as well as data visualization - was conducted using R (R Core Team, 2025; version 4.4.3), and the metafor (Viechtbauer, 2010; version 4.8.0), clubsandwich (Pustejovsky, 2024; version 0.5.11), and orchaRd package (Nakagawa et al., 2023; version 2.0). Furthermore, data were visualized using ggplot2 (Wickham, 2016; version 3.5.1).

Risk of Bias was assessed and coded using the RoB2 Excel tool: Sterne, J. A., Savović, J., Page, M. J., Elbers, R. G., Blencowe, N. S., Boutron, I., Cates, C.J., Cheng, H., Corbett, M.S., Eldridge, S.M., Emberson, J. R., Hernán, M.A., Hopewell, S., Hróbjartsson, A., Junqueira, D.R., Jüni, P., Kirkham, J.J., Lasserson, T., Tianjing, L., ... & Higgins, J. P. (2019). RoB 2: a revised tool for assessing risk of bias in randomised trials. *BMJ*, 366. <https://doi.org/10.1136/bmj.l4898>

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Portfolio [guidelines for submitting code & software](#) for further information.

Data

Policy information about [availability of data](#)

All manuscripts must include a [data availability statement](#). This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A description of any restrictions on data availability
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The extracted data — including means, standard deviations, sample sizes, study and effect IDs, and moderator coding — have been deposited on OSF and are accessible at <https://osf.io/hmf4r/>. Additionally, the Source Data for all Figures and Tables are provided as a separate Source Data file.

Research involving human participants, their data, or biological material

Policy information about studies with [human participants or human data](#). See also policy information about [sex, gender \(identity/presentation\), and sexual orientation](#) and [race, ethnicity and racism](#).

Reporting on sex and gender

The studies included in this systematic review and meta-analysis involved both male and female participants. Data on sex/gender distribution was reported in 58 out of 62 studies. Among these, a total of 4,422 participants had reported sex/gender data: 1,989 male (45%) and 2,433 female (55%). Six studies included only male participants, and eleven studies included only female participants.

No analyses were conducted separately by sex/gender, and no sex- or gender-specific hypotheses were formulated in the systematic review and meta-analysis. Methods for determining sex/gender were not consistently reported across studies, which hindered a clear distinction between the two. The data shared on OSF do not include disaggregated sex/gender data, as this information was not consistently available across studies and individual-level data were not extracted.

Reporting on race, ethnicity, or other socially relevant groupings

The systematic review and meta-analysis did not include analyses based on socially constructed categorization variables such as ethnicity or education, as no hypotheses were specified for these factors. Furthermore only limited data was available in the primary studies, rendering meaningful synthesis challenging. Out of 62 studies 17 (27.4%) reported participant's educational background, and 10 (16.1%) reported ethnicity. However, the methods of classification were not consistent and often not clearly described.

Population characteristics

Population characteristics varied across studies, reflecting differences in design, settings, and participant demographics. Mean age was reported in 52 out of 62 studies and ranged from 20.33-70.94 years with a weighted arithmetic mean of 44.91 years.

Recruitment

We did not recruit participants for this study. All data were obtained from previously published studies.

Ethics oversight

We used secondary anonymized data from existing and published studies, which did not require additional ethical approval.

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

- Life sciences Behavioural & social sciences Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Behavioural & social sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description

We conducted a systematic review and meta-analysis, including sensitivity and moderator (subgroup) analyses of studies investigating the effect of nature exposure on acute self-reported pain. All data represent secondary data and are quantitative.

Research sample

All included studies in the article were collected up until 31/01/2024. We included studies involving adult participants from healthy and clinical populations undergoing experimental or medical procedures typically experienced as painful. Studies had to feature at least one intervention that stimulated one or more sensory modalities (e.g., visual, auditory, tactile) primarily using natural stimuli and include some form of comparator (matched or non-matched). The unifying feature across all interventions was that nature-based sensory input was the central component of the intervention. Self-reported pain was required as an outcome, assessed using either scales (visual analogue (VAS), numerical rating (NRS), or graphical rating scales (GRS)) or measures of pain threshold or tolerance. We included studies with between-participant, within-participant, or pre-post control group designs. Eligible studies had to be published in English, peer-reviewed journals, and present original research (excluding opinion pieces, reviews, etc.). Studies were deemed ineligible if they employed inadequate interventions, comparators, outcomes, provided insufficient data, or were grey literature. As we used secondary data from existing research, the overall sample may not be representative.

Sampling strategy	As we used secondary data of existing and published studies, we did not predetermine sample sizes.
Data collection	<p>We searched the extent of the literature up until January 31, 2024 (with no restrictions on earlier publication date) using four electronic databases: PsychINFO, PubMed, Web of Science (WOS), and SCOPUS. Search terms combined concepts related to nature interventions, pain outcomes, and exclusion criteria. The same terms were used across all four databases, with adjustments made for database-specific search rules. Additionally, we performed reference tracing through forward and backward tracking. Two reviewers (MOS and JPN) independently reviewed, coded (e.g., study characteristics, moderators, and risk of bias), and extracted data from all studies. Titles and abstracts were first screened against predefined inclusion criteria, followed by full-text examinations of eligible articles. Discrepancies and ambiguities were resolved through direct discussion between the reviewers.</p> <p>Data were tabulated and organized using Microsoft Excel (see above for details).</p> <p>The initial search resulted in 2,413 records. After removing 1,116 duplicates and 19 case reports, 1,278 records were screened. Of these 1,194 records were excluded based on title and abstract review. We then examined full-texts of the remaining records from which 23 were excluded for not meeting the inclusion criteria. From the final 62 included studies, we extracted 96 individual effect sizes.</p>
Timing	Studies were identified through two separate searches: The initial search was completed on October 31, 2022, and the final search was completed on January 31, 2024.
Data exclusions	Studies were excluded if they did not meet the inclusion criteria. Eligible studies were required to: (1) include human adults from healthy or clinical populations, (2) involve procedures perceived as painful, (3) feature interventions that primarily stimulated one or more sensory modalities using natural stimuli, (4) include a comparator condition to these stimuli, (5) report self-reported pain as an outcome, (6) be published in English in a peer-reviewed journal, and (7) present original research. All studies not meeting these criteria were excluded. Additionally, 23 studies that passed the initial screening (title and abstract) were excluded after full-text examination. Reasons for exclusion varied and encompassed insufficient control conditions, inadequate data presentation, lack of access to full text, insufficient outcome measures, and inadequate interventions.
Non-participation	Of the 62 studies included in the meta-analysis 17 (27.4%) did not report whether any participants dropped out, 24 studies (38.7%) stated that no participants dropped out after randomization, and 21 studies (33.8%) reported participant dropouts after randomization, with an average dropout rate of 11%. Reported reasons for dropouts varied but commonly included technical issues, protocol violations, missing or poor-data quality, and side effects related to the interventions under investigation.
Randomization	Allocation of participants into experimental groups or conditions was randomized in 59 of the included studies and non-randomized in 3 studies.

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

Methods

n/a	Involved in the study
<input checked="" type="checkbox"/>	<input type="checkbox"/> Antibodies
<input checked="" type="checkbox"/>	<input type="checkbox"/> Eukaryotic cell lines
<input checked="" type="checkbox"/>	<input type="checkbox"/> Palaeontology and archaeology
<input checked="" type="checkbox"/>	<input type="checkbox"/> Animals and other organisms
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<input checked="" type="checkbox"/>	<input type="checkbox"/> Dual use research of concern
<input checked="" type="checkbox"/>	<input type="checkbox"/> Plants

n/a	Involved in the study
<input checked="" type="checkbox"/>	<input type="checkbox"/> ChIP-seq
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Plants

Seed stocks	<i>Report on the source of all seed stocks or other plant material used. If applicable, state the seed stock centre and catalogue number. If plant specimens were collected from the field, describe the collection location, date and sampling procedures.</i>
Novel plant genotypes	<i>Describe the methods by which all novel plant genotypes were produced. This includes those generated by transgenic approaches, gene editing, chemical/radiation-based mutagenesis and hybridization. For transgenic lines, describe the transformation method, the number of independent lines analyzed and the generation upon which experiments were performed. For gene-edited lines, describe the editor used, the endogenous sequence targeted for editing, the targeting guide RNA sequence (if applicable) and how the editor was applied.</i>
Authentication	<i>Describe any authentication procedures for each seed stock used or novel genotype generated. Describe any experiments used to assess the effect of a mutation and, where applicable, how potential secondary effects (e.g. second site T-DNA insertions, mosaicism, off-target gene editing) were examined.</i>