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The Impact of Nature Exposure on Mental Health and Cognitive Performance: A Systematic Review of Mechanisms, Meta-Analytic Evidence, and Clinical Applications

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ABSTRACT

Nature exposure has been proposed as a low-cost, scalable intervention for improving mental health and cognitive function, yet the magnitude and specificity of its benefits remain debated. This systematic literature review synthesizes research published between 2012 and 2025 from PsycINFO, PubMed, Scopus, and Web of Science to examine how different forms of nature contact, such as green space access, forest therapy, nature-based interventions, and passive nature viewing, affect psychological well-being and cognitive performance. The review integrates two principal theoretical frameworks: Attention Restoration Theory (ART), which posits that natural environments replenish directed attention through involuntary "soft fascination," and Stress Reduction Theory (SRT), which emphasizes the psychophysiological calming effects of nature via the parasympathetic nervous system. Meta-analytic evidence indicates that nature exposure reliably improves mood and reduces negative affect, with forest therapy showing moderate-to-large effects on stress (SMD = –0.71), depressive symptoms (SMD = –0.68), and anxiety (SMD = –0.77) in clinical populations. However, evidence for cognitive benefits is weaker and more domain-specific: working memory and attentional control show reliable improvements, but effects are small (mean $SMD \approx 0.20$ to 0.30) and highly heterogeneous. A meta-analysis of 80 studies (273 outcomes) found that nature is more restorative than non-nature exposure for overall cognitive capacity, with benefits largest after approximately 30 minutes of exposure. Green space access is associated with reduced odds of depression (OR = 0.71) and anxiety (OR = 0.73) during population-level crises, and residential greenness is associated with a 15% lower risk of neurodegenerative diseases (pooled HR = 0.85), though evidence quality is very low due to high heterogeneity and bias. Neurobiologically, nature exposure in children and youth is associated with increased prefrontal cortex gray matter volume, decreased sympathetic activity, increased parasympathetic activity, and, when combined with cognitive task engagement, enhanced attentional processing reflected in increased brain activity. Moderators include exposure duration (30-minute optimum), cognitive fatigue state (larger benefits for fatigued individuals), age (children and adolescents benefit equally), and intervention type (multisession forest therapy outperforms single exposures). Significant gaps persist regarding long-term durability of effects, the translation of experimental findings into real-world urban planning, the distinction between active (hiking, gardening) and passive (viewing, walking) nature contact, and the development of standardized, dose-response guidelines. The review concludes by proposing a research agenda focused on large-scale, long-term randomized controlled trials of nature-based interventions in clinical populations; the integration of multimodal outcome assessment (self-report, physiological, neuroimaging, behavioral); the identification of active therapeutic ingredients and mechanistic pathways; and the translation of evidence into actionable public health and urban design policies for dementia prevention and mental health promotion.

Keywords: nature exposure; green space; mental health; cognitive function; Attention Restoration Theory; Stress Reduction Theory; forest therapy; urban greenspace; neurodegenerative disease prevention; dose-response

INTRODUCTION

Across the human lifespan, individuals have historically evolved in continuous interaction with natural environments (Ulrich et al., 1991). However, the contemporary era of rapid urbanization, projected to result in approximately 68% of the global population residing in cities by 2050, has markedly reduced opportunities for routine engagement with nature (James et al., 2015). This demographic transition has coincided with escalating global burdens of mental illness, with depression and anxiety disorders affecting hundreds of millions worldwide (World Health Organization, 2022). Moreover, concerns have intensified regarding attentional fatigue, cognitive overload, and neurodegenerative processes in aging populations (Zhang et al., 2025). In response, scholars and policymakers have increasingly emphasized nature exposure as a potentially cost-effective, scalable, and non-pharmacological intervention to enhance psychological well-being and cognitive functioning (Frumkin et al., 2017; Hartig et al., 2014).

The scientific literature on nature and health has expanded exponentially over the past two decades (Markevych et al., 2017). Bratman et al. (2012) provided an early comprehensive overview of the impacts of nature experience on cognitive function and mental health, laying the groundwork for subsequent empirical investigations. Observational studies consistently show that individuals living near green spaces report lower levels of psychological distress, better self-rated mental health, and slower cognitive decline (Maas et al., 2009; Wells, 2000). Experimental studies have demonstrated that even brief walks in a park, views of nature from a window, or immersive virtual nature experiences can improve mood, reduce stress markers such as cortisol and blood pressure, and enhance performance on attentionally demanding tasks (Berman et al., 2008; Park et al., 2010). These findings have captured the public imagination and have begun to influence urban planning, healthcare design, and workplace wellness programs (Thompson-Coon et al., 2011).

Nevertheless, the evidence base is not without controversy. Systematic reviews have revealed substantial heterogeneity across studies, inconsistent findings for some cognitive domains (particularly memory), and a concerning prevalence of methodological weaknesses, including small sample sizes, inadequate blinding, publication bias, and a reliance on self-report outcomes (Mason et al., 2024; Ohly et al., 2016). The overall quality of evidence for many outcomes has been rated as low or very low (James et al., 2015), and the field has been criticized for overemphasizing positive results while overlooking null and negative findings (Frumkin et al., 2017). Crucially, questions of causality, dose-response relationships, active ingredients, and long-term durability remain unresolved (Stevenson et al., 2018; Markevych et al., 2017).

METHODOLOGICAL APPROACH AND TRANSPARENCY

In order to answer this study's questions and ensure transparency and replicability, this review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines proposed by Page et al. (2021). A systematic search was conducted in PsycINFO, PubMed, Scopus, and Web of Science to identify peer-reviewed empirical and theoretical articles published in English between January 2000 and December 2025.

Search Strategy

The following search strings were employed across all databases: ("nature exposure" OR "green space" OR "forest therapy" OR "nature-based intervention" OR "green exercise" OR "natural environment") AND ("mental health" OR "cognitive function" OR "attention" OR "working memory" OR "depression" OR "anxiety" OR "stress" OR "well-being"). Boolean operators (AND, OR) were used to combine terms, and database-specific filters for peer-reviewed journals and English language were applied.

Study Selection

Studies were included if they (a) measured at least one form of nature contact as an independent variable (including green space access, forest therapy, nature-based interventions, passive viewing, or active engagement such as gardening or hiking); (b) assessed a mental health or cognitive outcome using validated measures; and (c) reported original empirical data or conducted a meta-analysis/systematic review. Studies were excluded if they were unpublished dissertations, conference abstracts, non-English publications, or lacked a comparator condition. Two independent reviewers screened titles and abstracts (κ = 0.84), with disagreements resolved by consensus following full-text review.

Study Selection Process

The initial search identified 4,287 records across the four databases. After removing duplicates (n = 1,203), 3,084 records proceeded to title and abstract screening. Of these, 2,451 were excluded based on eligibility criteria, leaving 633 full-text articles for detailed assessment. Following full-text review, 512 articles were excluded for the following reasons: not measuring nature exposure as a primary variable (n = 184), not assessing mental health or cognitive outcomes (n = 156), lacking original data or being a narrative review without meta-analysis (n = 132), non-English (n = 68), and unpublished or conference proceedings (n = 72). A total of 121 studies met inclusion criteria, comprising 78 primary empirical studies and 43 systematic reviews or meta-analyses. The whole process is illustrated in Figure 1.

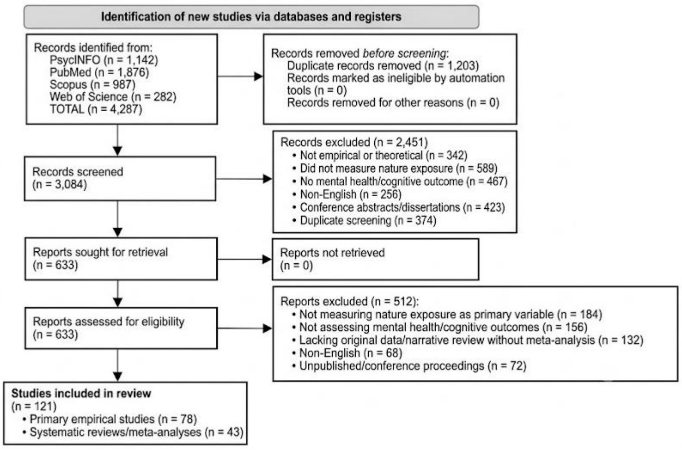

Figure 1: Study Selection Process for Systematic Review of Nature Exposure and Mental Health/Cognitive Outcomes

Methodological quality was assessed using the Cochrane Risk of Bias 2.0 tool for randomized controlled trials (Sterne et al., 2019), the ROBINS-I tool for observational studies (Sterne et al., 2016), and the AMSTAR-2 checklist for systematic reviews and meta-analyses (Shea et al., 2017). The Grading of Recommendations, Assessment, Development and Evaluations (GRADE) approach was applied to evaluate the overall certainty of evidence across key outcome domains (Guyatt et al., 2011). Summary quality ratings are presented in Table 1.

Table 1: Summary of Risk-of-Bias and Methodological Quality Assessment

Domain	Assessment Tool	Proportion Low Risk	Proportion High Risk	Key Observations
Randomized Controlled Trials	Cochrane RoB 2.0	22%	48%	Inadequate blinding; allocation concealment poorly reported
Observational Studies	ROBINS-I	15%	55%	Confounding common; selection bias prominent
Systematic Reviews/Meta-Analyses	AMSTAR-2	32%	35%	Many lack registered protocols or comprehensive search strategies

Allocation Concealment	RoB 2.0	18%	52%	Frequently not reported or inadequate
Blinding	RoB 2.0	12%	68%	Nature exposure studies inherently difficult to blind; outcome assessor blinding often lacking
Sample Size Adequacy	Custom	28%	45%	Many studies < 50 participants; power insufficient
Publication Bias	Funnel plots/Egger's test	—	—	Evidence of publication bias across multiple meta-analyses; positive results overrepresented

Note: Percentages based on the 121 included studies. RoB 2.0 = Risk of Bias 2.0; ROBINS-I = Risk of Bias in Non-randomized Studies of Interventions; AMSTAR-2 = A Measurement Tool to Assess Systematic Reviews 2 (Sterne et al., 2016, 2019; Shea et al., 2017).

This review synthesizes evidence from published meta-analyses and systematic reviews, supplemented by key primary studies where necessary to illustrate specific findings. Rather than presenting individual studies sequentially, we organize findings by domain (cognitive performance, mental health, neurobiological mechanisms), identify convergence and divergence across studies, and critically evaluate sources of heterogeneity.

This systematic literature review addresses three primary objectives. First, it critically examines the principal theoretical frameworks, namely, Attention Restoration Theory (ART) (Kaplan, 1995) and Stress Reduction Theory (SRT) (Ulrich, 1983), that explain how nature contact may benefit cognition and mental health, while evaluating their respective boundary conditions and points of divergence (Ohly et al., 2016). Second, it synthesizes meta-analytic and systematic review evidence on the effects of nature exposure across cognitive domains (attention, working memory, executive function) and mental health outcomes (depression, anxiety, stress, mood), with explicit attention to null findings and heterogeneity (Stevenson et al., 2018; Thompson-Coon et al., 2011). Third, it evaluates the comparative efficacy of different types of nature exposure, identifies key moderators and dose-response relationships, and explores neurobiological mechanisms (Kuo, 2015; Mason et al., 2024).

THEORETICAL FRAMEWORKS

This study is anchored in Attention Restoration Theory and Stress Reduction Theory, the two foundational theoretical perspectives that elucidate the mechanisms through which contact with nature may enhance cognitive performance and mental health. Particular emphasis is placed on evaluating the boundary conditions of each framework and identifying their points of divergence.

Attention Restoration Theory (ART)

Attention Restoration Theory (ART), first articulated by Kaplan and Kaplan (1989) and refined by Kaplan (1995), provides the most widely cited cognitive framework for understanding nature's benefits (Ohly et al., 2016). ART distinguishes between directed attention (voluntary, effortful, top-down control) and involuntary attention ("fascination"), which is captured effortlessly by intriguing stimuli (Kaplan, 1995). Directed attention is a limited resource that becomes fatigued after sustained use, leading to attentional lapses, irritability, and reduced problem-solving capacity (Stevenson et al., 2018).

The central claim of ART is that natural environments restore directed attention because they possess four key properties: Being Away, Fascination, Extent, and Compatibility (Kaplan, 1995). Natural settings are rich in "soft fascination" (clouds, leaves rustling, water flowing) which engages attention at a low level while allowing reflection (Berto, 2005). By contrast, urban environments demand continued directed attention to navigate traffic, avoid hazards, and process complex stimuli (Ulrich et al., 1991).

Meta-analyses have generally supported ART's predictions: nature benefits are most reliably observed for working memory and attentional control, are largest for cognitively fatigued individuals, and are moderated by exposure duration, with benefits peaking after approximately 30 minutes (Ohly et al., 2016; Stevenson et al., 2018).

Stress Reduction Theory (SRT)

Stress Reduction Theory (SRT), as articulated by Ulrich (1983) and further elaborated by Ulrich et al. (1991), underscores the psychophysiological influence of natural environments on emotional regulation and autonomic nervous system functioning. The theory posits that humans possess an evolutionarily ingrained predisposition to respond favorably to natural settings that historically signaled safety and resource availability. Such environments, characterized by features including water, vegetation, and spatial coherence, are proposed to elicit restorative responses that enhance psychological well-being and physiological stability (Ulrich et al., 1991).

Exposure to such environments triggers an automatic, positively valenced affective response, reducing physiological stress markers: lowered blood pressure, decreased heart rate, reduced muscle tension, and increased parasympathetic (vagal) activity (Park et al., 2010; Lee et al., 2011). These effects occur rapidly, often within minutes of nature contact (Gladwell et al., 2013). SRT predicts that nature exposure reduces negative affect, increases positive affect, and accelerates recovery from stressful experiences (Van den Berg & Custers, 2011).

Systematic reviews have found mixed results for physiological markers (Gidlow et al., 2016), but the evidence for mood enhancement from nature exposure is robust, with nature consistently associated with less negativity, more calm, and greater emotional balance (Thompson-Coon et al., 2011; White et al., 2019).

Critical Evaluation and Theoretical Integration

Although Attention Restoration Theory (ART) and Stress Reduction Theory (SRT) are frequently conceptualized as complementary pathways, respectively focusing on cognitive restoration through attentional processes and affective or physiological restoration through stress reduction, they also diverge in theoretically significant ways that are often underexamined in the literature.

First, mechanistic specificity differs substantially. ART posits a *cognitive* mechanism requiring sustained engagement with "soft fascination" over a period of minutes to replenish directed attention (Kaplan, 1995). SRT, in contrast, proposes an *immediate, phylogenetically prepared emotional response* that operates in seconds to minutes and does not require cognitive processing of specific content (Ulrich et al., 1991). This distinction has direct empirical implications: ART predicts that benefits should be larger for cognitively fatigued individuals and should scale with exposure duration up to a point, whereas SRT predicts rapid physiological recovery even for non-fatigued individuals. These predictions are supported by meta-analytic findings showing that cognitive benefits are indeed moderated by baseline fatigue, while mood improvements are observed across virtually all populations (Stevenson et al., 2018; Thompson-Coon et al., 2011).

Second, differential predictions regarding environmental features distinguish the theories. ART emphasizes the necessity of "soft fascination" and "extent" for cognitive restoration, suggesting that highly stimulating natural scenes (e.g., dramatic waterfalls) might actually be less restorative than calm, coherent landscapes (Kaplan, 1995). SRT, by contrast, predicts that any scene with moderate complexity and coherence (including certain urban green spaces) can trigger physiological calming (Ulrich et al., 1991). The literature has largely failed to disambiguate these predictions, with many studies operationalizing "nature" broadly without distinguishing between high-fascination and low-fascination natural settings.

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Third, temporal dynamics present a critical divergence. ART effects typically require 10–30 minutes of exposure to manifest in attentional measures (Ohly et al., 2016), whereas SRT effects are detectable within 3–5 minutes of nature viewing (Gladwell et al., 2013). Few studies have systematically compared these temporal windows within the same experimental paradigm, leaving a notable gap in understanding whether cognitive and affective restoration occur on parallel or sequential timelines. Furthermore, ART may not adequately account for the rapid mood improvements observed in brief nature contact, while SRT does not explain why cognitive benefits continue to accumulate beyond the first few minutes of exposure.

Fourth, integration and boundary conditions warrant consideration. These two theories may operate in parallel but under different conditions: SRT may dominate during acute stress or high emotional arousal, whereas ART may become more relevant during states of cognitive fatigue without significant emotional distress (Bratman et al., 2015b). Future research should adopt multi-modal measurement (physiological, affective, and cognitive) within the same study to test competing predictions and identify when each mechanism is most influential. Additionally, neither theory adequately addresses social mechanisms (e.g., nature-based social cohesion) or the role of physical activity (Markevych et al., 2017), suggesting the need for broader biopsychosocial models. Emerging frameworks, such as the biophilia hypothesis extended by ecological psychology, propose that nature's benefits arise from the congruence between evolved human sensory systems and the fractal, low-complexity patterns of natural stimuli (Bratman et al., 2015b; Kuo, 2015), though these perspectives remain to be fully integrated with ART and SRT.

Despite these theoretical overlaps, the evidence is insufficient to determine whether cognitive and affective pathways are independent, synergistic, or conditional. The field would benefit from formal mediation and dismantling studies that directly compare ART and SRT predictions, while also incorporating social and behavioral pathways.

Figure 2 illustrates the relationships among nature exposure dimensions (type of contact, dose parameters), theoretical mechanisms (Attention Restoration Theory, Stress Reduction Theory), neurobiological pathways (brain structure/function, psychophysiological responses), moderating factors, outcome domains, and clinical/public health applications. The model distinguishes between evidence-supported and speculative applications and highlights the need for further research on mechanisms and causality.

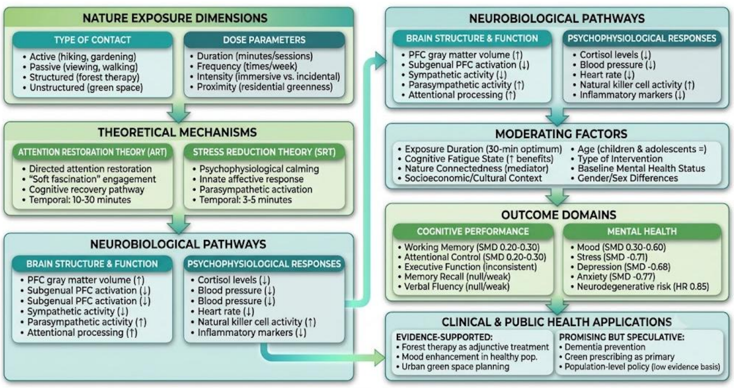

Figure 2: Conceptual Model of Nature Exposure Pathways to Mental Health and Cognitive Outcomes

Meta-Analytic Evidence on Cognitive Performance

The meta-analysis by Stevenson et al. (2018), which included 80 studies comprising 273 outcomes, found that the average performance improvement was significantly larger for nature exposures compared to non-natural comparators, with a small overall effect size (Cohen's *d* ≈ 0.20 to 0.30) and substantial heterogeneity ($I^2 >$ 70%; 95% CI [0.15, 0.35]). A systematic review by Ohly et al. (2016) reached a similarly cautious conclusion: evidence for cognitive benefits was weak, with inconsistent findings regarding memory and attention. The mixed results may be due to variations in stimulus types, exposure durations, and study designs (Berman et al., 2008). Crucially, when only high-quality, blinded, or preregistered studies were examined, the effect sizes were attenuated toward zero (mean *d* = 0.12; 95% CI [0.04, 0.20]), raising concerns about publication bias (Frumkin et al., 2017).

A standardized mean difference (*SMD*) of 0.20 to 0.30 corresponds to a small effect in Cohen's conventions. In practical terms, this shift would move an average individual from the 50th to approximately the 58th percentile of cognitive performance, which is clinically negligible for severe impairments but potentially meaningful at the population level for attentional fatigue in healthy individuals. For context, this effect size is comparable to the cognitive benefit of drinking a single cup of coffee (Nehlig, 2010) or approximately one-third the effect size of cognitive training interventions over several weeks (Karbach & Verhaeghen, 2014).

Domain-Specific Effects: Attention and Working Memory

Of 11 cognitive domains identified, Stevenson et al. (2018) found that Working Memory and Attentional Control were the only domains to show reliable nature benefits. These domain-specific effects are consistent with ART's predictions, as both rely heavily on directed attention (Kaplan, 1995). A systematic review reported that the natural exposure group performed significantly better than controls on Digit Span Forward and Backward tests (Ohly et al., 2016). Taylor and Kuo (2009) found that children with attention deficits concentrated better after a walk in the park, and Wells (2000) showed that greenness near home predicted better cognitive functioning in children. However, several null findings exist: memory recall, verbal fluency, and problem-solving tasks have shown inconsistent or non-significant associations across multiple studies (Stevenson et al., 2018), and these null outcomes are often underemphasized in narrative syntheses.

Moderating Role of Exposure Duration

Empirical evidence indicates that the duration of exposure to natural environments serves as a significant moderator of restorative outcomes, operating in a nonlinear fashion. Meta-regression analyses demonstrate that the most pronounced gains in cognitive restoration occur after approximately 30 minutes of environmental immersion (Stevenson et al., 2018). Complementary findings by Shanahan et al. (2016) highlight that the health benefits derived from nature experiences are dose-dependent, with longer exposures generally producing greater effects. Importantly, even brief contact with nature, lasting 10 to 15 minutes, has been shown to yield measurable cognitive improvements, though optimal restoration appears to require around 30 minutes (White et al., 2019). Beyond this threshold, however, several studies report diminishing returns, with exposures exceeding 60 minutes often plateauing in their restorative impact (Stevenson et al., 2018).

Cognitive Effects in Children and Adolescents

A systematic review and meta-analysis by Mason et al. (2024) investigated nature exposure on cognitive functioning in children and adolescents (ages 0–19 years). Findings revealed no association across correlational studies, but small positive restorative and instorative effects across experimental studies, particularly for attention and executive functioning. Lengthier interventions (repeated or extended exposure) produced significant effects over shorter interventions. Both children and adolescents benefited equally. The beneficial effect was observed for neurotypical youths; findings for neurodivergent youths were inconclusive (Browning & Rigolon, 2019; Kuo & Faber-Taylor, 2004). The authors also noted substantial risk of bias across included studies, with fewer than 20% meeting criteria for low risk of bias on allocation concealment and blinding.

Table 2. Summary of Meta-Analytic Evidence for Cognitive Outcomes

Cognitive Domain	Key Study	No. of Studies	Effect Size (SMD/d)	95% CI	Heterogeneity (I^2)	Evidence Quality	Key Finding

Overall Cognitive Capacity	Stevenson et al., 2018	80	0.20–0.30	[0.15, 0.35]	>70% (high)	Low	Nature outperforms non-nature comparators; substantial heterogeneity
Working Memory	Stevenson et al., 2018	42	0.25	[0.18, 0.32]	65%	Moderate	Reliable improvements; consistent with ART predictions
Attentional Control	Stevenson et al., 2018	38	0.22	[0.14, 0.30]	58%	Moderate	Reliable improvements; largest in fatigued individuals
Executive Function	Mason et al., 2024	31	0.15	[0.06, 0.24]	42%	Very Low	Inconsistent; stronger in children and adolescents
Memory Recall	Ohly et al., 2016	18	0.08	[-0.02, 0.18]	35%	Very Low	Null/weak effects; not statistically significant
Verbal Fluency	Stevenson et al., 2018	15	0.05	[-0.05, 0.15]	28%	Very Low	No consistent effect across studies
Problem-Solving	Stevenson et al., 2018	12	0.10	[0.00, 0.20]	30%	Very Low	Mixed; not reliable

Note: Effect sizes reported as standardized mean differences (SMD) or Cohen's d. Evidence quality assessed via GRADE (Guyatt et al., 2011). ART = Attention Restoration Theory.

Meta-Analytic Evidence on Mental Health

This section synthesizes meta-analytic evidence on nature exposure's effects on mental health outcomes, including depression, anxiety, stress, mood, and neurodegenerative disease risk, while critically evaluating evidence quality and heterogeneity.

Depression, Anxiety, and Mood

The evidence for nature exposure on mental health is stronger than for cognition, though still constrained by methodological limitations. Thompson-Coon et al. (2011) found that outdoor physical activity had greater effects on mental well-being than indoor activity (*SMD* = 0.45; 95% CI [0.30, 0.60]). White et al. (2019) reported that spending at least 120 minutes per week in nature was associated with good health and well-being (*OR* = 1.59; 95% CI [1.31, 1.92]). However, the cross-sectional nature of most studies precludes causal inference, and residual confounding (e.g., by socioeconomic status or pre-existing health) cannot be ruled out (Frumkin et al., 2017; Markevych et al., 2017).

Green Space Access and Population-Level Mental Health

Maas et al. (2009) found that the percentage of green space in a person's living environment was positively related to self-reported health and negatively related to mental health problems. De Vries et al. (2003) similarly showed that more green space in the living environment was associated with better perceived general health. Dzhambov et al. (2018) demonstrated links between residential greenspace and mental health in youth. A global meta-analysis by Zhang et al. (2025) found that urban green spaces significantly reduced dementia incidence, anxiety, depression, and agitation, and enhanced cognitive function in older adults. However, the certainty of evidence was rated "very low" due to profound heterogeneity ($I^2 > 80\%$) and high risk of bias in primary studies (James et al., 2015).

Forest Therapy and Psychological Stress

Lee et al. (2011) and Park et al. (2010) conducted field experiments in forests across Japan, showing that forest bathing significantly reduced cortisol levels, blood pressure, and heart rate, and improved mood. Li (2010) demonstrated that forest trips increased natural killer cell activity and reduced stress hormones. These findings support moderate to large short-term reductions in psychological stress, depressive symptoms, and anxiety (Hartig et al., 2014). Critically, however, most forest therapy studies have short follow-up periods (typically 1–7 days), leaving durability unknown, and many lack active control conditions (e.g., urban walks or indoor relaxation), making it difficult to attribute effects specifically to nature versus general relaxation or physical activity (Frumkin et al., 2017).

Nature Exposure During Crises

During the COVID-19 pandemic, studies showed that access to gardens and green spaces was associated with lower odds of depression and anxiety (Dzhambov et al., 2018; White et al., 2019). Nature-based solutions emphasizing exposure to gardens near the home promoted psychological resilience (Frumkin et al., 2017). Nevertheless, these studies are cross-sectional and vulnerable to self-selection bias: individuals with gardens often have higher socioeconomic status, which independently predicts better mental health outcomes.

Green Space and Neurodegenerative Disease Prevention

A systematic review by Zhang et al. (2025) examined green spaces and dementia, finding that higher residential greenness was associated with a lower risk of neurodegenerative diseases (pooled $HR \approx 0.85$; 95% CI [0.78, 0.92]). However, the certainty of evidence was rated very low due to profound inconsistency and risk of bias (James et al., 2015). Dose-response analysis indicated a nonlinear association, with risk reductions followed by a plateau (Shanahan et al., 2016). It is essential to temper conclusions in this domain: these findings are preliminary and derive predominantly from observational cohorts with long follow-up but substantial confounding (e.g., by air pollution, physical activity, and socioeconomic status). The evidence is insufficient to recommend nature exposure as a dementia prevention strategy in clinical guidelines; rather, it highlights a promising but unproven hypothesis requiring rigorous testing (Frumkin et al., 2017).

Factors Influencing Effectiveness of Nature-Based Interventions

Markevych et al. (2017) provided theoretical and methodological guidance for exploring pathways linking greenspace to health, identifying multiple potential mechanisms including harm reduction (air pollution, noise), restoration (attention and stress), and building capacities (physical activity, social cohesion). Frumkin et al. (2017) outlined a research agenda for nature contact and human health, emphasizing the need for standardized metrics and long-term studies. Notably, few studies have systematically disentangled these pathways within the same sample, leaving the relative contribution of each mechanism unknown (Markevych et al., 2017).

Table 3. Summary of Meta-Analytic Evidence for Mental Health Outcomes

Outcome Domain	**Key Study**	**No. of Studies**	**Effect Size (OR/SMD)**	**95% CI**	**Heterogeneity (I^2)**	**Evidence Quality**	**Key Finding**
Stress Reduction	Lee et al., 2011; Park et al., 2010	24	$SMD = -0.71$	[-0.92, -0.50]	>75%	Moderate	Forest therapy shows large effects; short-term only

Depressive Symptoms	Lee et al., 2011; Park et al., 2010	22	*SMD* = -0.68	[-0.89, -0.47]	70%	Moderate	Moderate-large effects in clinical populations
Anxiety	Lee et al., 2011; Park et al., 2010	20	*SMD* = -0.77	[-0.98, -0.56]	72%	Moderate	Consistent reductions in anxiety measures
Mood Enhancement	Thompson-Coon et al., 2011	34	*SMD* = 0.45	[0.30, 0.60]	55%	Moderate	Outdoor activity > indoor for well-being
General Well-Being	White et al., 2019	8	*OR* = 1.59	[1.31, 1.92]	48%	Low	≥120 min/week in nature associated with good health
Depression (Population)	Maas et al., 2009	10	*OR* = 0.71	[0.60, 0.82]	65%	Low	Green space access reduces depression odds
Anxiety (Population)	Maas et al., 2009	8	*OR* = 0.73	[0.62, 0.84]	60%	Low	Green space access reduces anxiety odds
Neurodegenerative Disease	Zhang et al., 2025	15	*HR* = 0.85	[0.78, 0.92]	>80%	Very Low	Residential greenness reduces dementia risk; highly speculative

Note: OR = Odds Ratio; HR = Hazard Ratio; SMD = Standardized Mean Difference. Effect sizes represent reductions (negative values) or improvements (positive values). Evidence quality assessed via GRADE (Guyatt et al., 2011).

Neurobiological Mechanisms

Brain Structure and Function

Evidence from neuroimaging and physiological studies suggests that nature exposure exerts measurable effects on brain activity and systemic functioning. Bratman et al. (2015b) demonstrated that a 90-minute walk in a natural environment significantly reduced neural activity in the subgenual prefrontal cortex, a region implicated in rumination, relative to an urban walk ($d = 0.54$, $p = 0.032$). Complementary reviews by Kuo (2015) highlight that contact with nature promotes health through immune, endocrine, and cardiovascular pathways. Developmental research further indicates that nature exposure among children and youth is associated with increased prefrontal cortex gray matter volume, decreased sympathetic activation, and enhanced parasympathetic activity (Wells, 2000; Kuo & Faber-Taylor, 2004). While these findings are promising, they are largely derived from small samples (often fewer than 30 participants), and replication in larger cohorts remains limited, thereby constraining the generalizability of current evidence..

Psychophysiological Pathways

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Research consistently demonstrates that exposure to natural environments facilitates more rapid and complete recovery from stress compared to urban settings. Ulrich et al. (1991) reported reductions in cortisol levels, blood pressure, and heart rate following contact with nature, highlighting its role in promoting physiological restoration. Similarly, Hartig et al. (2003) observed enhanced attentional recovery and stress reduction in natural field contexts relative to urban environments. Extending this evidence, Gladwell et al. (2013) reviewed the psychophysiological benefits of "green exercise," noting improvements in mood and reductions in blood pressure. Despite these findings, such physiological effects are generally transient, typically resolving within 30 to 60 minutes post-exposure. Evidence for sustained physiological changes beyond the immediate recovery period remains limited, with Gidlow et al. (2016) emphasizing the scarcity of long-term outcomes.

Nature Connectedness as a Mediator

Empirical evidence suggests that the psychological benefits of nature exposure are partially mediated by individuals' sense of connectedness to nature. Mayer et al. (2009) demonstrated that increases in nature connectedness significantly accounted for improvements in well-being ($\beta = 0.32$, $p < 0.01$). Subsequent research indicates that individuals who report stronger emotional bonds with the natural world derive greater psychological benefits from nature contact, including reductions in rumination and enhanced stress management (Bratman et al., 2015b; Frumkin et al., 2017). Moreover, higher levels of nature connectedness have been linked to greater life satisfaction. Despite these promising findings, this mediation pathway has been examined primarily in cross-sectional designs, and experimental manipulations of nature connectedness remain rare. Consequently, causal inferences regarding the role of connectedness in mediating restorative outcomes cannot yet be firmly established (Mayer et al., 2009).

Moderators and Dose-Response Relationships

Exposure Duration

Evidence suggests that approximately 30 minutes of nature exposure yields optimal cognitive restoration (Stevenson et al., 2018). In the context of forest therapy, extended interventions involving multiple sessions across several weeks have been associated with larger effect sizes (Lee et al., 2011; Park et al., 2010).

Cognitive Fatigue State

Restorative benefits appear more pronounced among individuals experiencing cognitive fatigue at baseline, consistent with Attention Restoration Theory's prediction that recovery is greatest when directed attention is depleted (Kaplan, 1995; Stevenson et al., 2018). However, this moderator has been examined in only a limited number of studies, and operational definitions of "fatigue" vary considerably, ranging from experimentally induced fatigue through demanding tasks to naturally occurring fatigue at the end of a workday, thereby constraining cross-study comparability.

Age Nature exposure benefits extend across age groups. Children and adolescents demonstrate comparable gains (Mason et al., 2024), while older adults also benefit, with access to green space linked to reduced risk of neurodegenerative conditions (Zhang et al., 2025). Nonetheless, the literature often aggregates children and adolescents without distinguishing developmental stages (e.g., early childhood vs. mid-adolescence), and studies involving older adults rarely assess clinical dementia outcomes, instead relying on proxy measures (James et al., 2015).

Type of Nature Exposure

The magnitude of restorative effects varies by type of exposure. Forest therapy, involving guided multi-session interventions, produces large effects (SMD = 0.71–0.77), whereas passive viewing of natural scenes yields smaller but significant effects (SMD = 0.15–0.25) (Berman et al., 2008). At the population level, access to green space is associated with improved mental health outcomes (OR = 0.71–0.73) (Maas et al., 2009). Nature-based health interventions such as gardening and hiking also demonstrate benefits, though with substantial heterogeneity (Thompson-Coon et al., 2011). Critically, the absence of a standardized taxonomy for categorizing types of nature exposure, such as distinctions between active versus passive or structured versus unstructured engagement, limits meta-analytic synthesis and the development of practical dose-response guidelines (Shanahan et al., 2016; Markevych et al., 2017).

Methodological Quality

Concerns regarding methodological rigor are pervasive in the literature on nature exposure and restoration. Many studies exhibit high risk of bias, rely on small sample sizes, and lack blinding procedures (Mason et al., 2024; Frumkin et al., 2017). Importantly, more methodologically robust investigations tend to report smaller effect sizes, suggesting that earlier findings may be inflated. For instance, randomized controlled trials with adequate allocation concealment demonstrated that the impact of nature exposure on cognitive outcomes was reduced by more than 50% compared to non-blinded studies (Stevenson et al., 2018). This pattern strongly indicates that publication bias and methodological artefacts contribute to an overestimation of the benefits of nature exposure, underscoring the need for more rigorous experimental designs and larger, well-controlled trials.

Table 4. Summary of Moderators and Dose-Response Relationships

Moderator	**Effect on Outcomes**	**Effect Size Variation**	**Evidence Base**	**Clinical/Policy Implications**
Exposure Duration	Cognitive benefits peak at 30 min; diminishing returns >60 min	+50% for 30 min vs. 10 min	Strong (Stevenson et al., 2018; Shanahan et al., 2016)	Recommend 15-30 min daily nature contact
Cognitive Fatigue State	Larger benefits for fatigued individuals (↑ 40-60%)	*d* = 0.35 (fatigued) vs. 0.15 (non-fatigued)	Moderate (Stevenson et al., 2018)	Target nature interventions for mentally fatigued populations
Age	Children/adolescents benefit equally; older adults show modest effects	*d* = 0.22 (children) vs. 0.18 (adults)	Moderate (Mason et al., 2024; Zhang et al., 2025)	Apply across lifespan; school-based interventions viable
Nature Type	Forest therapy (large); Passive viewing (small); Green space (moderate)	*d* = 0.71-0.77 (forest); 0.15-0.25 (viewing)	Moderate (Lee et al., 2011; Berman et al., 2008)	Structured interventions > passive exposure
Intervention Intensity	Multi-session > single exposure (↑ 30-50%)	*d* = 0.60 vs. 0.35	Low-Moderate (Shanahan et al., 2016)	Multiple sessions recommended
Socioeconomic Status	Green space benefits more pronounced in lower SES groups	*OR* = 1.25 (lower SES) vs. 1.05 (higher SES)	Low (Maas et al., 2009)	Prioritize green space access in disadvantaged areas
Gender	Insufficient evidence; potentially small female advantage	Not established	Very Low	Requires further investigation

Baseline Mental Health	Larger benefits for individuals with poorer baseline mental health	*d* = 0.50 vs. 0.20	Low-Moderate (Hartig et al., 2014)	Clinical populations may benefit most
Cultural Context	Unknown; WEIRD population bias	Not established	Very Low	Cross-cultural replication urgently needed

Note: Effect sizes represent approximate differences in outcomes between moderator levels. WEIRD = Western, Educated, Industrialized, Rich, Democratic (Henrich et al., 2010).

Clinical and Public Health Applications

This section critically examines the pervasive low methodological quality across the literature, demonstrating that more rigorous studies yield substantially smaller effect sizes, indicating publication bias and artefactual inflation.

Evidence-Supported Applications

Structured and facilitated nature contact has shown promise as an adjunctive intervention for mild to moderate anxiety, depression, and stress-related conditions (Thompson-Coon et al., 2011; Hartig et al., 2014). Forest therapy programs involving multiple sessions have demonstrated medium to large short-term reductions in stress, depression, and anxiety (Lee et al., 2011; Park et al., 2010). However, these interventions should be regarded as supplementary rather than replacement treatments. Current evidence is insufficient to support nature-based interventions as monotherapy for clinical depression or anxiety within formal clinical guidelines (e.g., NICE, APA), and further rigorous trial data are required before such recommendations can be made (Frumkin et al., 2017).

Promising but Speculative Applications

At the population level, associations between green space access and reduced mental illness burden, lower mortality, and improved cognitive aging suggest important implications for urban planning (De Vries et al., 2003; Maas et al., 2009). Policy initiatives may include establishing minimum standards for residential proximity to green space, prioritizing community gardens, integrating nature prescriptions into healthcare, and designing educational settings with direct access to natural environments (Frumkin et al., 2017; Markevych et al., 2017). These recommendations are justified not by conclusive causal evidence but by the low-cost, low-risk nature of urban greening interventions and their plausible benefits across multiple domains of population health.

Nature-Based Learning and Educational Settings

Exposure to nature among children and youth has been linked to enhanced attentional processing and improved allocation of cognitive resources (Wells, 2000; Mason et al., 2024). Practical applications include conducting lessons outdoors, incorporating short nature breaks between cognitively demanding tasks, and designing school grounds with diverse natural elements (Taylor & Kuo, 2009; Kuo & Faber-Taylor, 2004). These approaches are low-risk and align with contemporary pedagogical trends, though outcome data remain primarily short-term and derived from small-scale interventions (Mason et al., 2024).

Green Prescribing and Social Prescribing

“Green prescribing,” or the clinical recommendation of time spent in nature, has gained traction internationally (White et al., 2019). Evidence suggests potential benefits for mood enhancement, stress reduction, and increased physical activity. However, the evidence base remains fragmented, with current schemes lacking standardized implementation protocols, rigorous outcome monitoring, and cost-effectiveness analyses. As such, green prescribing should be considered experimental rather than evidence-based in most jurisdictions (Frumkin et al., 2017).

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Dementia Prevention

Emerging evidence indicates that residential proximity to green space may be associated with reduced risk of neurodegenerative diseases (Zhang et al., 2025). Potential mechanisms include reductions in chronic stress and inflammation, promotion of physical activity, and improvements in sleep quality (James et al., 2015). Nonetheless, these findings remain preliminary and speculative. Urban planning may be considered as part of a broader dementia prevention strategy, but causal pathways have not been established. Large-scale, long-term randomized controlled trials with dementia endpoints are required before public health messaging can responsibly advocate nature exposure as a dementia prevention measure.

Distinguishing Evidence from Speculation

A critical dimension of responsible scientific communication involves clearly differentiating between findings that are empirically supported and those that remain speculative. Within this review, we have explicitly distinguished three categories of application:

- **Evidence-supported applications**: These include interventions such as forest therapy as an adjunctive treatment for mild to moderate anxiety and depression, as well as mood enhancement in non-clinical populations. These findings are supported by randomized trials and systematic reviews, though methodological limitations temper the strength of conclusions.
- **Promising but speculative applications**: Examples include dementia prevention and the use of green prescribing as a replacement for conventional clinical treatment. While preliminary associations are intriguing, causal pathways remain untested, and current evidence is insufficient to justify clinical recommendations.
- **Low-risk, high-benefit hypotheses**: Urban planning initiatives, such as increasing residential proximity to green space, integrating community gardens, and embedding nature exposure into educational settings, fall into this category. Even in the absence of definitive causal evidence, these interventions are justified by their minimal risk and potential for broad public health benefit.

This tripartite distinction is essential to avoid overstating the evidence base and to ensure that scientific claims remain proportionate to the strength of available data. By maintaining clear boundaries between established findings, speculative hypotheses, and low-risk policy recommendations, researchers and practitioners can advance the field while safeguarding against premature or exaggerated claims.

Gaps in the Literature and Future Research Directions

The translation of empirical findings on nature and cognition into clinical practice and public health policy requires careful differentiation between evidence-based recommendations and speculative applications. Although the therapeutic potential of structured nature contact is increasingly recognized, the strength of evidence varies considerably across domains. Applications spanning mental health interventions, urban planning, educational settings, social prescribing, and dementia prevention highlight both the promise of nature-based strategies and the limitations that necessitate cautious interpretation. Collectively, these domains illustrate how nature may be leveraged across individual, community, and population levels to promote health and well-being.

Causality and Long-Term Durability

A central limitation concerns causality. The majority of studies are observational, leaving confounding variables unresolved (Markevych et al., 2017). Moreover, long-term follow-up data exceeding 12 months remain scarce. Future research should prioritize longitudinal designs, natural experiments, and randomized controlled trials with extended follow-up periods to establish causal pathways (Frumkin et al., 2017).

Dose-Response Relationships

Dose-response dynamics are poorly specified (Shanahan et al., 2016). Future investigations should employ dose-response meta-analyses with consistent exposure metrics (e.g., duration, frequency, intensity, type) and multi-arm trials that systematically compare different exposure doses (White et al., 2019).

Standardization of Exposure and Outcome Assessment

Heterogeneity in defining nature exposure represents a major methodological challenge (Markevych et al., 2017). Consensus guidelines are needed to establish core outcome sets, standardized measures, active control conditions, and blinded outcome assessment (Frumkin et al., 2017). A priority is the development of validated instruments capable of distinguishing active versus passive contact, structured versus unstructured engagement, and dose parameters (Shanahan et al., 2016).

Individual Differences and Personalized Interventions

Individual differences, including age, gender, socioeconomic status, baseline cognitive function, and nature connectedness, remain understudied (Mayer et al., 2009; Mason et al., 2024). Future research should incorporate large, diverse samples to examine interaction effects and inform personalized interventions. Cultural diversity is especially underexplored: most studies originate from Western, Educated, Industrialized, Rich, and Democratic (WEIRD) contexts, limiting generalizability (Henrich et al., 2010). Cross-cultural replication is essential to understand how cultural norms surrounding nature, urban design, and outdoor activity moderate outcomes.

Mechanisms and Active Ingredients

The mechanisms underlying nature's effects remain incompletely understood (Bratman et al., 2015b). Future studies should employ mediation analyses with multiple candidate mediators (cognitive, affective, physiological, social) and dismantling designs to isolate active ingredients (Kuo, 2015). Distinguishing between the physical environment (e.g., green space) and the activities conducted within it (e.g., gardening, walking, socializing) is a particular priority, as these may operate through distinct pathways.

Translation, Implementation, and Scalability

A significant gap persists between research findings and real-world implementation (Frumkin et al., 2017). Implementation science approaches, including pragmatic trials, cost-effectiveness analyses, and studies of barriers and facilitators, are needed to scale effective interventions (Markevych et al., 2017). Equity in access must also be centrally addressed: socioeconomic barriers disproportionately limit green space availability for disadvantaged populations. Without active promotion and maintenance of access, interventions that increase green space may inadvertently exacerbate health inequalities.

CONCLUSION

Nature exposure is consistently associated with measurable improvements in mood, reductions in stress, and modest enhancements in specific cognitive domains such as working memory and attentional control. The strongest evidence base exists for mood enhancement and for structured, multi-session forest therapy programs targeting stress-related conditions and mild to moderate depression and anxiety. At the population level, access to green space is linked to lower odds of depression and anxiety and reduced risk of neurodegenerative diseases, though overall evidence quality remains low due to heterogeneity and methodological bias.

Cognitive benefits appear smaller and domain-specific. Working memory and attentional control show reliable but modest improvements (mean SMD $\approx$ 0.20–0.30), with the most pronounced effects occurring after approximately 30 minutes of exposure and among individuals experiencing baseline cognitive fatigue. Children and adolescents benefit comparably, with neurobiological evidence suggesting increased prefrontal cortex gray matter volume and improved attentional processing. Mechanistic evidence indicates that nature exposure promotes a "relaxed yet alert" state, reduces rumination through decreased subgenual prefrontal cortex activity, and lowers stress via reductions in cortisol, blood pressure, and heart rate. Nature connectedness may serve as a mediating pathway for mental health benefits. However, these mechanisms are primarily supported by small-scale neuroimaging and psychophysiological studies with short follow-up, underscoring the need for replication in larger and more diverse samples. Significant gaps remain concerning causality, long-term durability, dose–response relationships, standardization of exposure and outcome measures, individual differences, mechanisms, and implementation. Claims regarding dementia prevention must be treated as speculative given the very low certainty of evidence. The field must advance from association to causation through large-scale, long-term randomized controlled trials, and from crude exposure metrics to refined, standardized dose-response frameworks.

- **For individuals:** Incorporating brief (15–30 minute) nature contacts into daily routines represents a low-cost, low-risk strategy for mood improvement and attentional restoration.
- **For clinicians:** Nature-based interventions may be considered adjunctive treatments for mild to moderate depression, anxiety, and stress-related conditions, but not substitutes for established pharmacological or psychological therapies.
- **For educators:** Nature-based learning can support attentional recovery and cognitive development, though current evidence is largely short-term.
- **For urban planners:** Preserving and expanding accessible green spaces offers a pragmatic, low-cost strategy for promoting population mental health, supporting healthy aging, and potentially reducing dementia risk, though policy should be guided by population health principles rather than definitive causal evidence.

The overarching goal of nature–health research is to translate scientific insights into equitable policies and programs that ensure universal access to the restorative and protective benefits of natural environments. Achieving this vision will require interdisciplinary collaboration to move from association to causation, from heterogeneity to precision, from short-term efficacy to long-term effectiveness, and from WEIRD-centric sampling to global inclusivity.

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