



# The role of connection with nature in empirical studies with physiological measurements: a systematic literature review

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## Abstract

It is well described that exposure to nature reduces physiological stress, and connectedness to nature can have a moderating effect. However, few studies have so far examined the construction of the connection with nature in relation to physiological processes. In this systematic review, we collected studies that used a physiological measure and included a scale to measure connectedness to nature. Our aim was to assess the role of nature relatedness at the level of physiological processes and to summarize the results published so far. Our review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement. A literature search was conducted in 3 different databases (PubMed, ScienceDirect and Google Scholar). As keywords, we used all the different questionnaires that measure connectedness to nature, combined with terms related to physiological measures. After final screening, 28 articles met the inclusion criteria for the review. The studies were very diverse in terms of purpose, intervention and methods, so narrative synthesis was conducted without measures of effect. We found evidence for a mediating effect of nature connectedness on the associations between nature exposure and cognitive function, brain activity, blood pressure, cortisol level and mental health. Studies investigating nature relatedness as state-like characteristics have shown that exposure to nature increases the level of connection to nature. Eye-tracking studies have confirmed that this measurement method can be used to investigate nature relatedness at a physiological level, which could be a useful complement to self-report questionnaires in future studies.

**Keywords** Nature relatedness · Connectedness to nature · Physiology · Stress

## Introduction

### The benefits of exposure to nature

A large number of studies have shown that exposure to nature has a positive effect on well-being and physical health (Hartig et al. 2014; Keniger et al. 2013). Individuals living and interacting green spaces report being more energetic, in better general health and with a greater sense of purpose in life (Sifferlin 2016)). More than 2500 years ago, Cyrus the Great intuitively created lush green gardens in the crowded Persian capital to improve people's health and promote a sense of "calm" in the busy city. In the sixteenth century,

the Swiss-German physician Paracelsus stated: "The art of healing comes from nature, not from the physician". Today's scientific evidence confirms what people have long known intuitively: That nature has great benefits for the human brain, reflected in increased happiness, health/well-being and cognition (Williams 2016). The stress-reducing effects of nature are recognized and used in many therapies. The Japanese Shinrin-yoku (taking in the atmosphere of the forest) forest bathing therapy has a long tradition. There are numerous studies demonstrating the beneficial effects of Shinrin-yoku from a physiological and psychological perspective, including studies by Tsunetsugu et al. (2007) and Park et al. (2008, 2010).

These benefits can be explained by various contemporary hypotheses of human–nature interaction (Berto 2014), which explains the mechanisms by which spending time in nature can affect human health (Jimenez et al. 2021). The biophilia hypothesis (Kellert and Wilson 1995) claims that humans have an evolutionarily determined innate tendency to seek connection with nature. The Theory of Attention

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Restoration (ART) suggests that nature facilitates recovery from the mental fatigue associated with a diminished ability to control attention in modern life. According to this theory, spending time in natural environments allows people to recover from mental fatigue and restore the ability to direct attention (Kaplan 1995). Finally, according to the Stress Reduction Theory, physiological symptoms of stress, as measured by cortisol levels and autonomic nervous system activity, are reduced by exposure to nature. Although causal relationships are unclear, these theories complement each other, as attentional restoration has been linked to emotions (Hartig et al. 1997): Attentional fatigue may be an aftereffect of stress and a condition that increases emotional/stress vulnerability (Berto 2014).

As humans have an innate connection to the natural world, exposure to stimuli from natural sources influences feelings or emotions by activating the parasympathetic nervous system to reduce stress and autonomic arousal (Ulrich et al. 1991). Green spaces provide children with opportunities for exploration, creativity, risk-taking, mastery and control, which positively influence various aspects of brain development, according to proponents of the biophilia hypothesis (Kahn and Kellert 2002). Adam György has also emphasized the importance of evolutionary thinking in understanding psychological phenomena (Ádám, 1998). Koivisto and colleagues (2022) found that top-down cognitive processes influence the psychophysiological effects of the environment and hypothesized that individual's associations modulate the innate bottom-up effects of exposure to nature. However, the mechanisms linking nature exposure and health outcomes are diverse, not fully understood, and may act in isolation or synergistically (Kruize et al. 2019).

Additionally, it is important to note that only certain natural elements (safe and comfortable for humans) are beneficial. Similarly, phobias of certain natural elements, such as fear of getting lost (Berg and Heijne 2005), fear of wild animals/dangerous animals or fear of forest (Skår 2010) can be traced back to evolutionary causes.

In this article, nature is defined in a narrow way: As an aspect of modern society, separated from nature. But it is important to realize that nature can also cause stress in the absence of civilisation, which is why people built civilisation. The benefits of interacting with nature are particularly strong in modern, nature deprived societies.

### The role of nature relatedness

Despite this obvious attraction towards nature, there is considerable variability in the extent to which individuals are drawn to nature (Nisbet et al. 2009). Nature relatedness is a trait that indicates how much an individual feels connected to the natural world. The human–nature relationship depends on a number of other factors. These include values, gender,

nationality, the quality of the environment and time spent in nature. Some researchers suggest that positive emotions from exposure to nature lead to a deeper connection with nature (Nisbet & Zelenski 2011), while others suggest the opposite, that attachment to nature influences mood changes during outdoor activities (Mayer et al. 2008).

Nature connectedness is a possible mediator between nature exposure and well-being and quality of life. A study of 863 participants in China examined the associations between nature exposure, nature connectedness and mental well-being (Liu et al. 2022). It found that connection to nature moderated the associations between nature exposure, as measured by the frequency of visitation, amount of nearby green space and parks and mental well-being. Similarly, another recent study found that connection with nature mediated the link between nature exposure and quality of life (Baceviciene and Jankauskiene 2022).

On the other hand, it also has to be noted that there are researches, which found additional mediators between nature relatedness and well-being. Different concepts of connection to nature fostered in different cultural and social contexts modulate relation to nature and subsequent well-being outcomes (Cleary et al. 2017). In addition, other factors, such as spirituality, may moderate the relationship between nature and well-being (Trigwell et al. 2014; Kamitsis and Francis 2013). Another mediating factor, which influences the link between well-being and connectedness to nature could be life purpose, which is also a key dimension of eudemonic well-being, according to Howell and colleagues (2013). Kövi et al. found that gratitude, as a self-transcendent emotion, provides a significant indirect link between nature relatedness, mental health and quality of life (Kövi et al. 2023). Similarly, Kryazh et al. confirmed that trust mediates the relationship between connection to nature and both the subjective well-being and eudemonistic well-being (Kryazh 2019). Research by Zhang et al. has shown that connectedness to nature predicts well-being only when people are emotionally attuned to the beauty of nature (i.e. they have positive emotional responses to the sight of nature's beauty) (Zhang et al. 2014).

Previous studies of exposure to nature (Kjellgren and Buhrkall 2010; McSweeney et al. 2021; Ottosson & Grahn 2005) suggests that past experiences and interactions with nature influence and possibly enhance the benefits of future exposure. It is also known that higher expression of nature relatedness affects the individual's stress recovery and restoration through the positive effects of the natural environment (McEwan et al. 2021; Mcsweeney et al. 2015).

While most studies have focused on the association of nature relatedness with well-being and subjective stress, fewer studies have measured the physiological stress response as indicated by changes in blood cortisol levels, cardiovascular indicators (blood pressure BP), heart rate

(HR) and heart rate variability (HRV), brain activity or respiratory function. As the natural environment can have a significant impact on the body's stress-related physiology (Laumann et al. 2003), it is important to explore how stress manifests itself physiologically. Stress refers to an individual's response to mental, social, environmental and/or physical demands (Selye 1956). Stress can cause a range of physiological and behavioural changes, most notably affecting the functioning of the autonomic nervous system (ANS), which consists of the sympathetic and parasympathetic nervous systems. Depending on the changes in the ANS, a person may feel relaxed, agitated, stressed or rejuvenated. For example, there is evidence that exposure to nature can immediately stabilize breathing and blood pressure in stressed people (Annerstedt and Währborg 2011; Chang and Chen 2005).

### Concepts and measures of connection with nature

A wide range of scales have been used to measure attitudes towards nature (brief summary in Table 1). The convergence and divergence of different questionnaires commitment to nature (COM) (Davis et al. 2009), connectedness to nature (CTN) (Mayer and Frantz 2004), connectivity with nature (CWN) (Dutcher et al. 2007), emotional affinity towards nature (EATN) (Kals et al. 1999), environmental identity (EID) (Clayton and Opatow 2003), inclusion of nature in self (INS) (Schultz 2001) and nature relatedness (NR) (Nisbet et al. 2009) were examined in an empirical study (Tam 2013). According to the results different measures are closely correlated and converge to a single factor, thus they measure the same construct. They were also similarly correlated with different criterion variables (e.g. big five traits, contact with nature, well-being). The following is a brief description of the characteristics of each questionnaire.

The Nature Relatedness Scale is one of the most commonly used measurement tool. Both single-factor and three-factor structures (self, perspective and experience factors) were shown to be viable by Nisbet and colleagues (2009). However, the single-factor structure was considered more promising because in the original form many items loaded on multiple factors, which were highly correlated (Nisbet et al. 2009). Subsequent studies also consistently favoured a single overall NR factor and found high internal consistency of full-scale items (Howell et al. 2011; Nisbet et al. 2011). The short form of the questionnaire (NR-6) is particularly useful when an assessment of elements of connectedness rather than environmental attitudes is needed (Nisbet and Zelenski 2013).

Connectedness to Nature Scale (Mayer and Frantz 2004) has an original and a modified version. While the former treat connectedness to nature as a trait characteristic, the latter is measuring present feelings about nature connection.

Both assess cognitive beliefs instead of affective attitudes (Perrin and Benassi 2009).

Environmental Identity Scale (EID) includes several dimensions: Interaction with natural elements, importance of nature, importance of belonging to nature and positive feelings towards nature (Clayton et al. 2021). Both the original and the short form of the EID showed good internal consistency (Piskóti 2015).

Another concept, Inclusion of Nature in Self (INS), focuses on the cognitive aspect of nature relatedness. Schultz's (2001) graphical measure was based on Aron, Aron, Tudor and Nelson's concept of self (1991). Respondents are shown seven pairs of circles (one is labelled "self" and the other "nature") with varying degrees of overlap, and they select the pair that best describes their relationship with nature.

The Love and Care of Nature Scale (LCN) is a reliable and valid measurement of an individual's feelings towards nature. It also showed higher internal consistency than NR-21 and INS scales (Salatto et al. 2021). The construct of love and deep caring for nature expresses the individual's personal and specifically emotional relationship with nature (Perkins 2010).

The importance of experiencing nature or preferring urban environments appears to differ between individuals (Korpela et al. 2010; Tyrväinen et al. 2007). This difference is measured by the Urban-Nature Orientedness Scale (Ojala et al. 2019).

Two of the studies included in this review used a single-item question to measure nature relatedness. Lau and colleagues (2023) used a scale from zero to 100, in Chen's (2022) study a 5-point scale was used to measure participants' current connectedness to nature.

Overall, there are many different ways of measuring the connectedness with nature, and it is quite certain that many subjective and health indicators are related to this construct. However, the objective physiological links have been little studied, so little is known about how individuals' level of connectedness with nature relates to their different responses to the natural environment. Our aim with this review was to investigate the role of nature relatedness at the level of physiological processes and to summarize the results published so far.

## Methods

The review was conducted by following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Liberati et al. 2009). As keywords, we used all of the different questionnaires for measuring connectedness with nature combined with terms relating to physiological measures (for details see in Table 2).

**Table 1** List of questionnaires used to measure connection with nature

Scale	Acronym	Number of items	Original publication	Concept
Nature relatedness scale	NR-21	21	Original NR-21 (Nisbet et al. 2009)	The original version has three subscales: NR-Self (9 items): represents an internalized identification with nature NR-perspective (6 items): Attitudes towards the environment and nature conservation NR-experience (6 items): Experience in nature
Nature relatedness scale—short version	NR-6	6	Short form version (Nisbet and Zelenski 2013)	6 items from the Nature Relatedness Scale-21 “self” and “experience” dimensions
Connectedness to nature scale—trait version	CTN	14	(Mayer and Frantz 2004)	Measures a person’s sense of “oneness with nature”, a sense of kinship with animals and plants, and equality between self and nature
Connectedness to nature scale—state version	CNS	13	(Mayer et al. 2009)	Almost the same as CTN, but trait items were reformulated in such a way to tap the present feelings of connectedness to the natural world (one item was dropped)
Connectedness to nature index in preschool children	CNI-PPC	16	(Sobko et al. 2018)	A modified version of the original CN index, used for preschool children and completed with their parents
Environmental identity scale	EID	24	(Clayton & Opatow 2003)	Measures self-identification with the natural environment
Environmental identity scale—short form	EID- Short	11	(Lim et al. 2020)	
inclusion of nature in self	INS	1	(Schultz 2001)	Graphical, single-item questionnaire consisted of circles with varying degrees of overlap. It measures the extent to which individuals see nature as part of their identity
Extended inclusion of nature in self-scale	EINS	4	(Martin & Czellar 2016)	Extended version of INS (four items) development of the INS scale. It is composed of four visual items (overlap, size, distance and centrality), each of which contains seven alternatives that characterize the relationship with the natural environment
Love and care of nature scale	LCN	15	(Perkins 2010)	It measures a construct of love and care for nature, which includes two dimensions: (1) feelings of awe, admiration and interest in nature, which are the enduring emotions that give rise to feelings of care; (2) feeling of love
Urban-nature orientedness scale		9	(Tyrväinen et al. 2007)	It consists of two subscales: Urban-orientedness (4 items) and nature orientedness (5 items) subscales. They measure attraction to natural or urban environments

The search engine was set to scan the whole articles (title, abstract and text) for the keywords. Searching was conducted in three databases: PubMed, ScienceDirect and Google Scholar. We performed the screening in January

and February of 2023. Only English articles were included (theses, reviews, meta-analyses, conference papers, books and dissertations were excluded), and no time filter was used. Only articles published in peer-reviewed journals were

**Table 2** Characteristics of literature search

Applied keywords	- “Nature Relatedness” or “Environmental Identity” or “Inclusion of nature in self” or “Commitment to nature” or “Emotional affinity towards nature” or “Connectedness to nature” or “Connectivity with nature” AND - “physiology” or “autonomic” or “vegetative” or “cardiovascular” or “heart rate variability” or “blood pressure” or “brain function” or “EEG” or “skin conductance” or “cortisol” or “EMG” or “eye-tracking”
Database	PubMed, ScienceDirect, Google Scholar
Language	English only
Time filter	none
Documentum type	Peer-reviewed empirical articles
Inclusion criteria	Population: Any human Intervention: Not necessary Comparison: Not necessary Outcome: Objective measure of at least one physiological variable
Exclusion criteria	Theoretical papers, Dissertations, Not empirical papers, Conference materials, non-English articles, Not peer-reviewed papers

eligible in order to maintain the high quality of the articles. Search strategy characteristics and study inclusion/exclusion criteria are reported in Table 2. All empirical studies were included which (1) used any kind of questionnaire measuring connectedness with nature and (2) assessed associations between the aforementioned construct and an objective physiological variable. No restriction was used with respect to age, health status, gender or nationality of the studied sample. To decide on inclusion the two authors (VG and ZsD) read the titles and abstracts of the papers as a first step. In the next step, both authors read the full text of the selected articles and made the final decision on inclusion. In case of any ambiguity, disagreements were resolved by consensus. Initial search identified 5109 records from the three databases and through additional resources. After screening the titles, the abstracts of the relevant articles were checked by the two authors. Ninety-two percentage of the articles were not relevant. Either no nature-related questionnaire was included, or no physiological measurement tool was used. After removing duplicates, 36 unique citations remained and were screened for eligibility (Fig. 1). According to the final screening, 28 articles met the inclusion criteria of the review.

## Results

Of the 28 studies identified, eight measured changes of cortisol (Bakir-Demir et al. 2021; Beil & Hanes 2013; Geniole et al. 2016; Gidlow et al. 2016; Jones et al. 2021; Niedermeier et al. 2019; Souter-Brown et al. 2021; Sumner & Goodenough 2020), thirteen performed cardiovascular assessments (HR, BP) (Chan et al. 2021; Huber et al. 2023; Lau et al. 2023; Lim et al. 2020; McEwan et al. 2021; McSweeney et al. 2021; Michels et al. 2021, 2022; Morris et al. 2021; Ojala et al. 2019; Reeves et al. 2019; Salatto et al. 2021; Schebella et al. 2020) and three applied both type

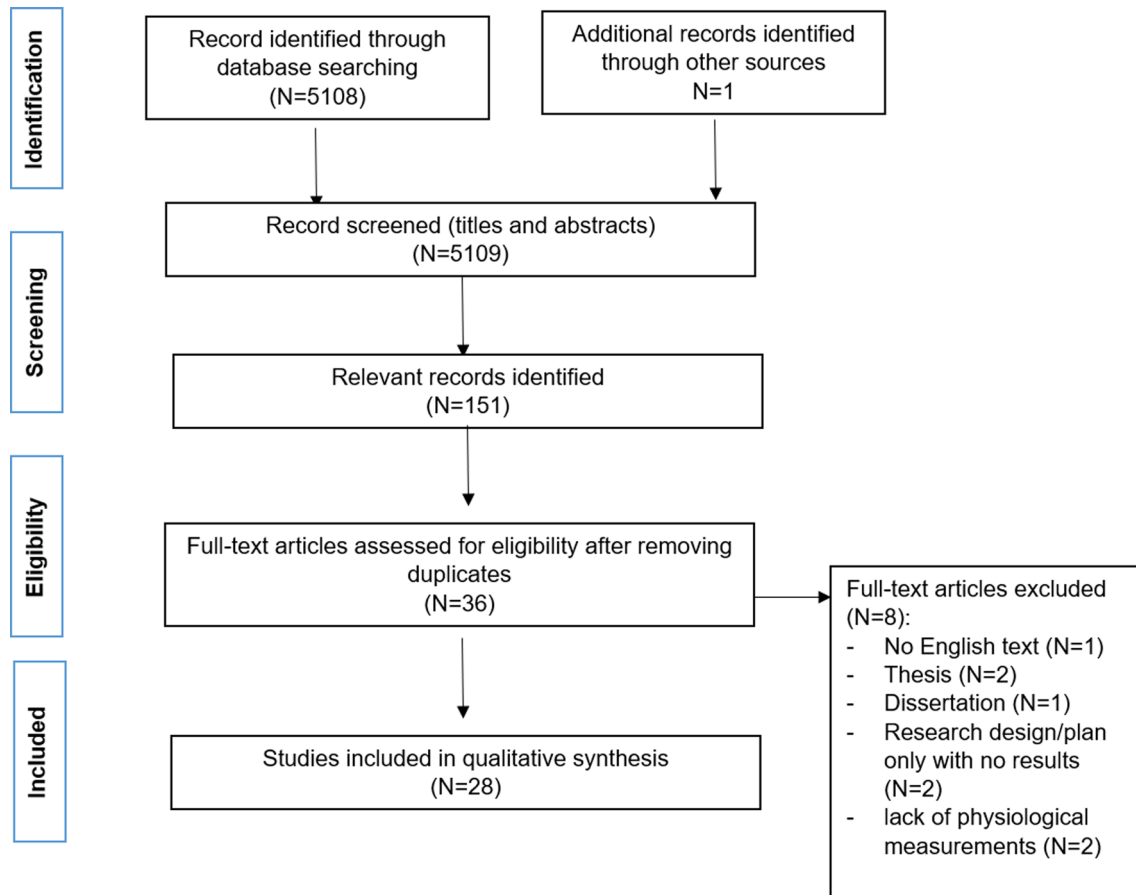
of measurements (Gidlow et al. 2016; Michels et al. 2021; Sumner & Goodenough 2020). Of the remaining seven studies, three investigated neurological functions (Bailey & Kang 2022; Koivisto et al. 2022; Sudimac & Kühn 2022), two examined eye movements (Chen et al. 2022; Giray et al. 2022) and the last two consisted of other measurements (e.g. body composition, faecal serotonin level) (Sobko et al. 2020; Teixeira et al. 2021). In the following, we briefly describe the relevant studies and summarize their main findings about the connection between nature relatedness and physiological changes.

## Neuroendocrine measurements

Eight publications were found that examined the relationship between nature relatedness and changes in cortisol levels due to exposure to nature. While three studies found positive association between the decrease of physiological stress measured by cortisol and nature relatedness (Beil & Hanes 2013; Souter-Brown et al. 2021; Sumner & Goodenough 2020), four studies found no association between them (Bakir-Demir et al. 2021; Geniole et al. 2016; Gidlow et al. 2016; Niedermeier et al. 2019). One study used nature relatedness just as a control variable in a walking in natural and urban environment intervention experiment, hence no specific statistical results were presented (Jones et al. 2021). The results of each study are discussed in detail below.

All three studies which found association between connectedness and nature and decreasing cortisol level used some kind of nature exposure as an intervention. In Sumner and Goodenough’s (2020) investigation, participants walked among free-roaming lemurs in a British safari park while salivary cortisol level and heart rate were measured. The aim was to understand whether a short interaction with non-domestic animals might reduce stress and improve well-being of participants and whether nature relatedness





**Fig. 1** Selection of studies

might influence these changes. According to the results no changes in heart rate were found, but there was a statistically significant reduction in participants' salivary cortisol levels following the animal encounters. The decrease of cortisol level was correlated with nature relatedness level of the individuals. Beil and Hanes (2013) also found a connection between environmental identity and decreasing cortisol level in their cross-over pilot study, where the effect of urban environments on physiological and psychological stress was investigated. Participants were exposed to one of four urban environments settings (very natural, mostly natural, mostly built and very built) in random order for 20 min on separate days. Negative association was found between environmental identity (EID) and changes in salivary cortisol and amylase levels, indicating a possible link between environmental identity and physiological response. The association between personal environmental identification and saliva outcome measures indicates that individuals with higher EID scores may be physiologically more sensitive to their environment. No correlation was found between EID and subjective stress markers, suggesting that physiological sensitivity may be due to sensory-perceptual processing

independent of conscious awareness. In a recent study where salutogenic natural design as a stress-reducing health promotion tool was examined (Souter-Brown et al 2021), negative association between cortisol level and nature relatedness also was detected. Two intervention groups (30-min pastime in a sensory garden or in an urban plaza) and control group were applied with between-subject design and salivary cortisol (also perceived well-being and stress, productivity) were measured before and after the intervention. To understand whether people with higher nature connectedness are more or less affected by the dose of nature, the Nature Relatedness Scale (NR-21) was used. The main findings were that NR increased and cortisol level decreased in the sensory garden group compared to both the urban plaza and control groups. Biodiversity has also been found to increase NR levels.

In contrast to these findings, five studies found no association between cortisol reduction and nature relatedness. In a Turkish questionnaire study (Bakir-Demir et al. 2021), the cumulative cortisol level from a segment of hair was examined instead of saliva. The authors investigated whether connectedness to nature helps young adults cope with stress through emotion regulation. According to their hypothesis

individuals with higher levels of connectedness to nature would have lower levels of subjective and objective cumulative stress. In contrast, the results showed that only perceived stress and connectedness to nature were correlated, but no association was found for the objective cortisol level. Connectedness to nature predicted adaptive emotion regulation strategies. However, non-adaptive regulatory strategies were not related to NR. These results show the importance of examining the different characteristics of stress separately and confirm the hypothesis that connectedness to nature has restorative powers. This effect is particularly apparent for positive outcomes, such as adaptive regulation skills (Bakir-Demir et al. 2021). In the last four studies with cortisol measurements, some form of exercise was used as an intervention. Neither of them found any association between nature relatedness and level of cortisol. Psychological and physiological responses to self-paced 30-min walks in three environments (pleasant urban, natural (green) and natural with water (blue)) were compared in a cross-over field-based trial (Gidlow et al. 2016). There was no difference between the three environments in terms of cortisol and mood, all of which had a positive effect on these variables, although greater restoration experiences and cognitive function improvements were observed in green and blue environments. In these cases, no potential relationship linking nature relatedness with restorative experience or cognitive function were observed. Heart rate variability data from baseline to 30-min after the walk did not show consistent patterns, or any differences in environmental response.

Niedermeier et al (2019) investigated the effects of anthropogenic elements on the physiological response to acute stress during exercise in green environments. A secondary aim of their study was to investigate the possible impact of connectedness to nature on outdoor exercise. The between-subject design consisted of two mountain hiking groups: One encountered fewer anthropogenic elements on the route, the other experienced more of them. Results showed that regardless of the environment in which the tour took place, affective states were positively affected by the intervention, but no association was found between cortisol variation and nature relatedness, nor between affective states and nature relatedness, although the mean nature relatedness level of the participants was high which may have hidden the possible effects of nature connectedness.

Geniole and colleagues (2016) compared the benefits of an outdoor walk in a restored naturalized landfill site and an urban area. During pre–post measurements testosterone and cortisol concentration (both from saliva), attentional control, mood and arousal were measured. It has been hypothesized that the effects of exposure to nature are more pronounced in people who are more connected to nature. According to the results walking in both environments improved energy and attention regulation and reduced cortisol concentrations,

mood improved more in the naturalized area. Connectedness with nature had moderating effects in the case of mood: The mood of men with high nature connectedness improved more after both walks, while the mood of men reporting low nature connectedness improved only after the walk in the natural environment and decreased after the urban interaction. This suggests that being more connected to nature helps to neutralize the negative effects of urbanization. However, this was only true for this subjective variable, with no such link for cortisol.

In the last study (Jones et al. 2021) presented here, no specific results on the effect of nature relatedness were reported, it was only used as a control variable. This between-subject, longitudinal study investigated what “dose” of nature is required for health benefits, and whether repeated visits to the same natural or pleasant urban environments are consistently beneficial to health (measured with salivary cortisol, restorative experience, etc.). No significant effects of the natural environment on mood or salivary cortisol were found.

### Cardiovascular measurements

Twelve studies were found that examined a physiological indicator related to the cardiovascular system and connectedness of nature. Heart rate, heart rate variability, blood pressure and oxygen saturation were used as objective variables, and NR, CNS, EID, INS or LCN questionnaires were applied to measure participants’ relationship with nature. Most of these researches did not investigate the association between physiological measurements and nature relatedness, only examined changes in connectedness with nature as a result of an intervention or used this personality trait to detect demographic differences.

McSweeney and colleagues (2021) examined stress response (i.e. changes in time and frequency domain indices of heart rate variability) associated with indoor environments with and without multi-sensory and immersive natural elements. Also the effect of nature relatedness (NR-6) on HRV outcomes (average NN intervals, HF, LF/HF) was investigated and two attention demanding tasks (Search and Memory test, Digit Span Test) were carried out. According to the results no significant differences between control and exposure groups in heart rate variability were revealed. However, increases in N–N intervals and a significant reduction in LF/HF ratios immediately after attention demanding tasks indicated that indoor nature exposure suppressed the sympathetic nervous system, and provided recovery from stress. Natural elements could facilitate recovery from mental fatigue and stress as a source of stress recovery. Since there was no significant correlation between NR and any HRV markers at any time points, the results also indicated that there is no relationship between physiological stress measured by HRV and connection to nature. It seems to

be that nature is physiologically beneficial regardless of an individual's NR score.

We found seven studies, where connectedness with nature and cardiovascular variables were measured, but the relationship between them was not investigated. They only explored changes in connectedness with nature as a result of different interventions. All but one (Morris et al. 2021) found that exposure to nature (even virtually) and exercise significantly increased participants' affinity to nature (Chan et al. 2021; Huber et al. 2023; Lau et al. 2023; Lim et al. 2020; McEwan et al. 2021; Salatto et al. 2021). As nature connectedness has only been studied to a limited extent, these studies will only be briefly described.

In the study of McEwan et al. (2021), two stress reducer and well-being enhancer intervention was compared: Forest Bathing and Compassionate Mind Training (CMT). Heart rate variability was measured during each session to see, which aspects of the intervention offered the greatest benefit to participants. The results showed that affinity to nature (INS) improved in all groups, and INS scores improved to a greater extent for participants who also participated in forest bathing. Although at the follow-up measurement (4-month post intervention) nature connection scores had decreased. In the case of physiological (HRV) and subjective variables no significant differences were observed between conditions, showing that Forest Bathing has a similar effect to CMT, an established well-being intervention.

The effectiveness of virtual nature contact was investigated in two research (Lau, Chan). In Lau and colleagues' (2023) investigation, increased happiness and relaxation were observed after the nature intervention, also this group had significantly higher level of nature connectedness after the virtual nature exposure. But no significant effects on physiological variables (e.g. cardiovascular responses in BP, HRV and average peripheral oxygen saturation) were detected. The results demonstrated that the heightened nature connectedness of the virtual nature group over the urban group remained during the 2-week follow-up. Also the effects of virtual natural and urban environments on cardiovascular activity (heart rate, HRV), nature connectedness and affect were examined in a Singapore research (Chan et al. 2021). Two studies were implemented, one with young adults and one with senior citizens. They found in both studies that nature connectedness was significantly greater after the nature condition. This resulted in reduced negative affectivity and greater parasympathetic activation in the case of the young sample and in increased positive affectivity in the case of the senior sample.

Salatto et al. (2021) investigated the effect of B-alanine induced painful sensation during outdoor hiking with a double blind, placebo-controlled crossover trial. After participants consumed either B-alanine or a placebo, participants immersed themselves in the natural environment

for 45 min and then completed a short hike uphill as fast as possible without running. According to the results no significant difference in HR was observed between treatments. Connectedness to nature increased with exercise. Pain induced by B-alanine consumption had no effect on connection to nature, so an increase in painful feelings does not necessarily diminish one's connectedness to the natural world. The relationship between green exercise and elevated nature connectedness has practical implications: If someone spends time exercising in a green environment then a deeper connection and love for nature can develop, which increases the desire for subsequent green exercises. This can lead to chronic health improvements.

Nature relatedness also increased due to the intervention in a recent experimental study. In a randomized, controlled clinical trial Huber et al. (2023) studied the effects of two types of 6-day long nature-based therapies (forest therapy and mountain hiking) on sedentary couples. Several physiological (HR, static balance, body composition, aerobic fitness, transepithelial water loss, differential blood counts, fractional exhaled nitric oxide) and psychological variables were investigated. According to the results participants benefited physically and mentally from both interventions, but nature connectedness increased only slightly in both intervention groups.

One of the studies found investigated non-healthy population (Morris et al. 2021). The aim of this research was to offer psychological and/or physiological benefits for people living with cancer with a ten-week exercise programme including nature intervention. Although many physiological (e.g. blood pressure, aerobic fitness, flexibility) and psychological variables have been measured (e.g. sense of coherence), also the results were analysed both quantitatively and qualitatively, but in the case of nature relatedness, the authors only measured its change as a result of the 10-week programme. They found that nature relatedness did not significantly improve over time, but incremental increases were still observed.

In an experimental field study Lim and colleagues (2020) compared the effectiveness of guided and unguided nature immersion on mood, nature connectedness and heart rate. They found that there were no significant differences between guided and unguided immersion in the change in nature connectedness, mood or heart rate, and nature connectedness and mood improved post-immersion in both groups.

In five studies nature relatedness was only used to explore demographic differences (Reeves et al. 2019) or divide participants into groups for statistical analysis (Ojala et al. 2019) or to control its potential confounding effect (Michels et al. 2021, 2022; Schebella et al. 2020)—but no additional analyses with NR were conducted. We have also included these studies in our summary table (see



in the Supplement section), but we will not describe them here in detail.

### Brain functions, EEG measurements

The neural mechanisms underlying the stress-reducing effects of exposure to nature are still largely unexplored. This is also reflected in the number of articles concerning nature relatedness and brain function. We found three studies where nature relatedness and brain function were examined. One research was based on fMRI measurements (Sudimac and Kühn 2022) and two studies used electroencephalography (Bailey and Kang 2022; Koivisto et al. 2022) and they have all found that connectedness with nature has a relevant effect on specific brain functions during exposure to nature.

Sudimac and Kühn (2022) examined in their fMRI-study the effect of natural versus urban environment on amygdala activity, and the potential sex differences in amygdala activity change after a one-hour walk in a natural vs. urban environment. Participants underwent the fMRI scanning procedure including two social stress tasks (Montreal Imaging Stress Task and Fearful Faces Task) before and after the walk. According to the results, after the walk in nature stress reaction measured by amygdala activity decreased and cognitive performance improved, but only in women. Men performed better on the arithmetic task after the walk in the urban environment. Interestingly they also found that the stronger connectedness to nature was in women, the decrease in their amygdala activity was greater during the social stress task after the urban walk. Overall the results suggested beneficial effects of nature exposure on the stress-related brain regions and these salutogenic effects were more pronounced in women.

Koivisto et al. (2022) aimed to test whether top-down cognitive processes (manipulation of stimulus-source attribution of a soundscape) influence the psychophysiological effects of environments. Participants listened to an ambiguous sound that was attributed to either nature (waterfall) or industry (factory). Subjective reports of relaxation and pleasantness, electroencephalography (brain's alpha band activity 8–13 Hz) and electrodermal activity (EDA) were measured in the experiment with within-participants design. According to the results, the influence of source attribution was reflected both in subjective and objective measures. Subjective experiences were more pleasant, and the power of the brain's lower alpha band activity was stronger when the sound was attributed to nature. They also found that nature connectedness moderated the effect of source attribution on theta band power and electrodermal activity. The greater was the nature connectedness, the stronger was the theta activity in the waterfall condition. Overall, it supports the influence of top-down cognitive processes on the psychophysiological effects of environments and assumes that the individual's

meanings and associations modulate the innate bottom-up effects of exposure to nature.

The aim of the last intervention study with EEG measurements was to determine the cognitive and neurological effects of 10-min walking or sitting in an outdoor environment (Bailey and Kang 2022). Mental speed and acuity with Stroop test and theta ( $\theta$ ), alpha ( $\alpha$ ), beta ( $\beta$ ) and gamma ( $\gamma$ ) bandwidths were measured before, after and 10 min post intervention. According to the results both sedentary and walking participants showed improvements in cognitive performance after the outdoor session, regardless the type of the intervention. Higher connection to nature (also state mindfulness during the intervention) were related to lower levels of frontal beta amplitudes during the outdoor intervention in both groups. Since elevated frontal beta is an indicator of rumination, a sense of connection with the natural world can enhance one's ability to be more present in the moment, to get away from everyday stress and enjoy the benefits and mental restoration of the natural environment.

### Eye-tracking measurements

Two studies were found that included eye movement tracking and a scale measuring connection to nature, but only one of them investigated the link between nature relatedness and eye movements (Chen et al. 2022). Participants were shown a 360-degree virtual reality scene with urban and natural environmental elements while eye movements were monitored. NR Scale questionnaire was collected one week later, and all participants were divided into three groups depending on their NR scores. They found that individuals' nature relatedness level correlated with their eye movements in the area of interest. Those who scored low on the NR Scale spent less time looking at green plant elements than buildings, and vice versa. For the medium NR group, no clear difference in eye movement was found between trees and buildings. They also found that NR Self subscale was significantly associated with eye movements characteristic of nature interests, but NR Perspective and NR Experience showed no significant relation with eye-movement tracking scores. The results suggest that this physiological measurement is suitable to investigate nature relatedness. Many existing studies have demonstrated a link between NR and behaviour, but most of them used self-report measures of behaviour, such as interviews and questionnaires (Colléony et al. 2017; Flowers et al. 2016). The study highlights another important aspect, it demonstrates the “top-down” effects of cognition on perception.

In the second study, Giray et al. (2022) investigated the shopping preferences and motivations behind consumption patterns of women with children. They used eye-tracking methods to examine how connectedness to nature and other subjective factors influenced the purchase of organic products.

They also played birdsongs to some participants in order to investigate the effect of this stimulus on mood and connectedness to nature. The results showed that objective and subjective knowledge about the products and visual attention to organic product labels are positively correlated with the purchase of these commodities. However, mood states and connectedness to nature did not show such a correlation with purchase preference. Those who were exposed to birdsongs gave higher CtN and mood scores than respondents who were not listening to bird sounds.

### Other measurement methods in nature relatedness research

We found two studies that did not fit into the categories above in terms of physiological variables, because they examined anthropometric and exercise-related physiological factors. Although both of them used connectedness to nature in their analysis, we thought it important to involve them in this review.

In a Portugal study, the relationship among connectedness with nature, physical activity and body composition was investigated (Teixeira et al. 2021). Several variables were measured, most of which were anthropometric (e.g. body composition (fat mass, visceral fat, skeletal muscle mass, etc.) and exercise-related (accelerometry). The results did not reveal any differences between men and women regarding connectedness to nature scores, but interestingly women with more children and men with dogs had higher CN scores. The results also showed that women who were more connected to nature had a higher number of steps per day. In the case of bioimpedance data no relevant connection with NR was found.

The only study that examined children investigated the effect of a 10-week outdoor nature-related programme (Play&Grow) on gut microbiota, faecal serotonin and perceived stress (Sobko et al. 2020). The results showed that after the environmental programme children in the intervention group were more connected to nature, their perceived general stress levels decreased (particularly anger frequency), the abundance of certain gut microbiota was altered and gut serotonin levels did not decrease (in contrast to the matched control condition). Overall alteration of the gut microbiome may be associated with greater exposure to the natural environment and connectedness to nature, but further mechanistic studies are needed to strengthen the role of gut microbiota in the relationship between connectedness to nature and improved psychosocial behaviour.

### Conclusion

Many previous studies have shown that being in connection with nature is associated with a better quality of life, better physical and mental health and also promotes

proenvironmental behaviours (Geng et al. 2015), which could play an important role in addressing the current environmental crisis. But little research has been done to date on its relationship with objective physiological changes. The purpose of this review was to summarize recent literature on nature relatedness and physiology.

We identified 28 studies, most of them measured cardiovascular variables (13), changes in cortisol level (8), brain functions (3), eye movements (2) and exercise-related or anthropometric variables (2). The most frequently used questionnaire related to nature connection was the Nature Relatedness Scale (NR-21 and NR-6 were also used in 7–7 cases). The trait-type CTN-14 was used in 4 studies and the state-type CNS-13 in 3 studies. Also, several researches applied the INS (3) or its short form (1). The remaining studies used either the EID (2), LCN (1), EINS (1) or other form of measures (e.g. urban-nature orientedness scale, adapted for children, one item question).

Summarizing the results, evidence for mediating effect of nature connectedness on the associations between nature exposure and lower level of cortisol, better cognitive function, altered brain activity was found. These results confirm the restorative power of connecting with nature and support the hypothesis of the Theory of Attention Restoration. However, the results also suggest that there are individual differences between people and that nature is not equally beneficial to everyone. These differences may also lead to differences in NR. Nature relatedness may develop in people who experience stress relief in nature and not in people who do not feel the benefits of nature as much. Several studies have found a link between stress reduction (in the term of decreasing cortisol) and high levels of nature relatedness. Also there is some evidence that people who are more connected to nature may be physiologically more sensitive to their environment. However, in a significant proportion of measurements, no association between connectedness to nature and cortisol levels was found. These contradictory results are probably due to the huge methodological heterogeneity: There is considerable variation in the applied questionnaires, interventions, samples and experimental designs, which makes it almost impossible to compare the results. Another factor is that the majority of studies examined nature relatedness in combination with some type of activity whose benefits are well known (i.e. outdoor exercise). Most of the studies that have examined cardiovascular variables have not addressed the role of nature relatedness. However, where this link has been investigated, no association between changes in HRV and connectedness with nature has been found. One explanation could be the idea, often mentioned in György Ádám's studies, that humans are unable to accurately perceive their internal physiological state (Ádám, 2009). It is also possible that, among the physiological markers of stress, cortisol levels could be a more appropriate

measure of connection to nature and the effects of NR. This suggests that of the physiological markers associated with stress, cortisol levels may be a more appropriate measure to investigate the effects of exposure to nature and nature relatedness. Besides measuring cortisol, measurements of brain function are also promising of the three studies identified, all three found detectable results for NR-related changes in brain function. Higher connectedness to nature was associated with lower frontal beta amplitude and stronger theta activity during natural interventions and reduced amygdala activity during social stress task. These findings all suggest that nature relatedness might play an important role in the Stress Reduction Theory of nature exposure. Furthermore, because frontal beta activity is associated with rumination and attentional processes, and NR seems to reduce these, it also fits with the idea of Attentional Restoration Theory.

Eye-tracking studies have confirmed that this measurement method can be used to investigate nature relatedness at physiological level, which could be a useful complement to self-report questionnaires in future studies.

In terms of exercise-related measurements, two studies have confirmed that a stronger connection to nature goes hand in hand with more physical activity in nature. This relationship has been described in survey studies with children and young men (Molina-Cando et al. 2021; Puhakka et al. 2018) but has so far been poorly investigated by objective measurement. The promotion of nature relatedness can lead to chronic health improvements, since if someone spends time exercising in the natural environment then a deeper connection with nature can develop, which increases the desire for subsequent green exercises. Studies investigating nature relatedness as state-like characteristics have shown that being exposed to nature increased the level of connection to nature. This supports Nisbet and Zelenski's hypothesis (2011) that positive emotions from exposure to nature lead to a deeper connection to nature.

## Implications for future biology

In line with *Biologia Futura's* aim to “provide new avenues for future research in biology”, we have summarized below the biological aspects of the paper that are worthy of further study and/or may have practical implications.

In addition, our finding that among physiological markers of stress, changes in cortisol levels appear to be more appropriate than cardiovascular markers in order to examine the relationship between stress and nature raises important questions. Further studies would be needed to explore causal relationships.

It seems promising to include eye tracking in NR studies. This is a less explored area, but from what we have

seen so far, it could be an important addition to self-report questionnaires.

Another interesting issue is the question of individual differences. It would be interesting to examine whether different levels of NR also mean that exposure to nature does not have the same beneficial effects on individuals.

The article presents many studies that combine exposure to nature with exercise in nature. As the latter has been shown to have a positive effect on mood and stress reduction, it would be interesting to look at the positive effects of NR in isolation.

Although one of the studies we reviewed (Gidlow 2016) compared two different natural environments (blue, green) in terms of stress reduction, no significant difference was found. Nevertheless, it would be interesting to further investigate what kind of natural environment is most beneficial for humans.

Overall, there have been few studies on nature relatedness using physiological measures, and there is considerable heterogeneity in their methodologies. However, the results are promising and there is a strong need for further replication studies using rigorous methodologies to confirm the results so far and to explore causal relationships.

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## Declarations

**Conflict of interest** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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