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Efficacy of a multicomponent nature-based intervention on well-being and environmental engagement: A randomized clinical trial

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ABSTRACT

Background: Nature-based interventions (NBIs) benefit human well-being, but clinical trials comparing different NBIs in various natural environments are scarce.
Objective: To evaluate the efficacy of a multicomponent nature-based intervention (MNBI) in comparison to control group (classical forest bathing). Primary outcome: well-being; Secondary outcomes: vitality, happiness, connection, and engagement with nature across urban, *peri*-urban, and rural areas.
Methods: Randomized clinical trial with 486 participants between October/2022 and June/2023, from five natural areas in Southeast and Southern/Brazil. Well-being was assessed immediately before the activity and 30 days after, and secondary outcomes immediately before, immediately after and 30 days after. The data analyses considered a 95 % confidence interval and p-values < 0.05.

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Results: The main hypothesis was confirmed, well-being levels of MNBI group were significantly improved, especially in *peri*-urban areas ($p = 0.036$). Both groups increased vitality ($p < 0.001$), but MNBI was more effective overall ($p = 0.038$), especially in urban areas ($p = 0.020$). Happiness increased in both groups ($p = 0.001$), but MNBI participants maintained higher levels 30 days post-intervention ($p = 0.010$). Nature connection increased significantly in both groups ($p < 0.001$) but remained higher in MNBI after 30 days ($p = 0.021$), especially in *peri*-urban areas ($p = 0.034$). While both groups reported calm and relaxation, MNBI uniquely fostered learning, knowledge, and contemplation.
Conclusions: MNBI was more effective than classical forest bathing in improving well-being, nature connection and pro-environmental behaviors, particularly in *peri*-urban settings, expanding the potential of NBIs for well-being promotion. ClinicalTrials registration: NCT05486156.

1. Introduction

There is an increasing body of scientific literature highlighting the benefits of contact or connection with nature for health and well-being, including improvements in mental health, such as reductions in stress, anxiety, and depression (Chang et al., 2024), and positive effects on mood and enhanced interpersonal relationships (Marini et al., 2022). Additionally, positive impacts have been observed on cardiovascular health (Jimenez et al., 2021) and in the immune system (Lyu et al., 2019). Despite growing recognition of these benefits, there remains a scarcity of evidence from well-designed clinical trials that could establish guidelines for clinical practice (Oh et al., 2017).

Forest bathing is a popular nature-based intervention (NBI), defined as immersing oneself in the forest atmosphere or absorbing the forest through the senses (Kotera et al., 2022). There are various terminologies for forest bathing-like NBIs, and significant variability exists in how they have been applied. This ranges from mere exposure to the forest without further specification (Lyu et al., 2019) to residential programs lasting between one day and 10 weeks (Gál and Dömötör, 2023), including forest walks combined with activities such as meditation, yoga, therapeutic horticulture, music therapy, support group therapy, cognitive-behavioral therapy, and relaxation therapy (Jimenez et al., 2021; Marini et al., 2022). These variations complicate comparisons between studies and the understanding of the efficacy and limitations of each practice, posing challenges for training and implementing interventions in health services.

A review by Kotera and collaborators (2022) highlighted the importance of interventions promoting full sensory engagement. However, the included studies did not explore the relationship between the biodiversity (fauna-flora) and their impact on well-being. Our study advances the field by investigating not only human well-being but also the connection to nature and biodiversity conservation, aligned with the growing need for integrated approaches (van Heezik and Brymer, 2018).

The same researchers (van Heezik and Brymer, 2018) warn us about the risks of commodifying nature, especially if green spaces are designed, planned, and managed solely for human health benefits, with little concern for supporting biodiversity or ecosystem services. This one-sided approach focusing only on human interests, may threaten biodiversity and ecosystem integrity (Barragan-Jason et al., 2023), potentially undermining therapeutic opportunities associated with the contact with biodiversity. Simply being in nature does not necessarily lead to a deeper connection with it, nor does it always result in desirable behaviors of care and conservation. Such interactions might be based solely on an outdated perception of humans as a dominant species, and valuing nature for its utility only.

Despite the benefits reported in the literature, the implementation of NBIs, particularly in public health, has been limited because it remains unclear which elements of nature and types of participant experiences are associated with mental health benefits, for instance (Barragan-Jason et al., 2023; Kotera et al., 2022).

It is also assumed that when humans perceive nature as beneficial, they will have reasons to preserve it (Stoll-Kleemann, 2001). However, this appears to be more of an inference, as the scientific reproducibility and specific design of nature-based interventions for this purpose remain unknown.

This study focuses not only on human well-being but also on biodiversity conservation and the relationship between these variables. This approach aligns with a Planetary Health perspective, integrating actions beneficial to human health with positive outcomes for ecosystems to promote pro-environmental behavior (van Heezik and Brymer, 2018). We evaluate a multicomponent nature-based intervention (MNBI) that includes nature walks focused on sensory awareness (the classic version of forest bathing) and other cognitive-behavioral elements to promote well-being of both humans and non-humans. The evaluated MNBI is detailed in a model of nature-based health interventions titled “A Time with e-Nature” (Leão et al., 2023) and involves activities related to four types of experiences: 1) the experience of knowledge (by providing content on the relationship between nature and health); 2) the aesthetic/emotional experience (represented by contemplation and the practice of appreciative observation); 3) the integrated multisensory experience (through directed activities to perceive nature through the senses); and 4) the active experience proposed a set of activities to be undertaken in support of nature for a duration of thirty days following the intervention. Taking the classical approach as a control measure which takes into account two dimensions, sensory and aesthetics experience, we can compare a model of four dimensions better than opting for a no dimension comparison or using a highly urbanized landscape as a control group.

This study, therefore, aims to evaluate the efficacy of the MNBI in comparison to the control group (activity involving immersion in the natural environment through the senses − forest bathing).

The primary outcome was well-being, with secondary outcomes including vitality, happiness, connection, and engagement with nature. The participant’s perception of the single-word experience of the NBIs was also assessed.

To the best of our knowledge, this is the first randomized clinical trial (National Library of Medicine-US, 2024) in the Southern hemisphere to evaluate a specific MNBI protocol that considers reciprocal well-being for both humans and nature. The MNBI is based on a structuring model developed from the perspective of complex adaptive systems, considering activities related to different types of nature experiences. This approach yields better outcomes for both human and environmental well-being and conservation. Therefore, positive health outcomes are assessed in relation to different natural settings, as well as levels of connection and engagement with nature.

2. Methods

2.1. Study design and research field

The parallel, randomized clinical trial, without crossover, was conducted in five sites (Table 1 and Fig. 1).

The target population consisted of individuals who visited these natural areas and were invited to voluntarily participate in the study. Inclusion criteria were: (a) adults aged 18 years or older, (b) those with access to digital platforms to complete the pre- and post-intervention

Table 1
Characterization, social profile, biodiversity, and attractions of natural areas.*.

Natural area	Characterization	Social profile	Biodiversity and attractions
Horto Oswaldo Cruz at Butantan Institute (Urban Park)	Located in the western zone of São Paulo, about 15 km from the city center, covering an area of 75 ha. It features vegetation typical of the Atlantic Forest and Cerrado biomes. São Paulo HDI**: 0.805, classified as very high; and the Gini index***: 0.504. Free access area.	It receives 300,000 annual visitors, predominantly female (55 %) and adults aged 20 to 59 years (85 %). The region is characterized by a mix of social classes, with neighborhoods ranging from low to high income. It is heavily influenced by academic and cultural institutions, particularly due to its proximity to the University of São Paulo and other scientific research centers.	It is home to well-known species of fauna and flora that have been inventoried and are continuously monitored. Established in 1916 to cultivate medicinal plants and support medical research, the Horto has been revitalized and now features a variety of attractions, two hiking trails, and other activities related to biodiversity and environmental education for visitors.
Cantareira State Park – Núcleo Cabuçu (Peri-Urban Protected Natural Area)	The area covers 8,000 ha within the São Paulo Green Belt Biosphere Reserve, which primarily includes the city of São Paulo, in the northern zone, about 27 km from the city center. São Paulo HDI: 0.805, classified as very high; and the Gini Index stands at 0.504. Paid access area.	The visitor profile consists mainly of local residents, particularly from the city of Guarulhos and neighboring municipalities, who seek leisure and relaxation in contact with nature. There is no specific data on the annual number of visitors to Núcleo Cabuçu. However, according to 2021 data, Cantareira State Park, which includes Núcleo Cabuçu, received approximately 90,100 visitors in 2019.	It protects the largest urban green area in Brazil, consisting of remnants of the Atlantic Forest with various well-studied endemic species of fauna and flora and numerous water courses. The main activities include hiking, ecological trails, nature contemplation, sports practice, and picnicking.
Varginha Natural City Park (Peri-Urban Natural Area)	It covers approximately 486 ha. Located in the southern zone of São Paulo city, in a peripheral neighborhood, 30 km from the city center. São Paulo HDI: 0.805, classified as very high; and the Gini index: 0.504. Free access area.	As a naturalized park, it is particularly popular among families, with playgrounds and green spaces designed for children. Seniors also frequent the park due to its accessible infrastructure, including an outdoor gym specifically designed for their needs.	Consists of fragments of Atlantic Forest, riparian forests, pine reforestation areas, and wetlands, as well as endemic species of fauna. The park's emphasis on recreational activities like cycling and hiking draws active individuals, especially mountain biking enthusiasts.
Salto Morato Private Natural Heritage Reserve (Rural Natural Area)	Located in the city of Guaraqueçaba, on the northern coast of the state of Paraná, Brazil, it covers 2,253 ha. The HDI of Guaraqueçaba is 0.587, classified as medium. The Gini index stands at 0.490. Paid access area.	By December 2024, the reserve had welcomed approximately 162,000 visitors, averaging around 5,400 visitors annually. Visitors to Salto Morato tend to be older compared to other natural reserves, with higher levels of education and socioeconomic status.	Established in 1994 and recognized as a Private Natural Heritage Reserve (RPPN), this place is recognized by UNESCO as a World Natural Heritage site, the reserve is part of the largest continuous remnant of the Atlantic Forest in Brazil and shelters endemic and endangered species of fauna and flora. The main activities include hiking trails, birdwatching, river swimming, and camping.
Neblinas Park (Rural Natural Area)	Located in the municipality of Mogi das Cruzes (state of São Paulo), specifically in the eastern sub-region, about 115 km from the city center, it covers 7,000 ha. The municipality HDI is 0,783, classified as high; and the Gini index stands at 0,540. Paid access area.	In 2023, the number of visitors increased to 7,100, marking a 61 % growth compared to 2019, when it was 4,400. The visitors were predominantly adults aged between 25 and 45 years. 90 % of visitors chose the park to connect with nature, including activities such as interacting with local fauna and flora, hiking, waterfall bathing, and other ecotourism practices.	It is also within the largest continuous remnant of the Atlantic Forest in Brazil, with over 500 springs and 1,330 identified species of fauna and flora, 41 of which are endangered. The park offers a variety of ecotourism activities, such as self-guided and guided trails, canoeing, cycling, and camping areas, catering to different visitor profiles seeking experiences in natural environments.

* Public data source.

** **HDI**: The Human Development Index is a composite measure of a region's socioeconomic development. It evaluates health (life expectancy), education (average years of schooling and expected years of schooling), and income (gross national income per capita). Scores range from 0 to 1, with higher values indicating better development.

*** **Gini Index**: The Gini Index is a measure of income inequality within a population, ranging from 0 to 1. A value of 0 represents perfect equality (where everyone has the same income), while a value of 1 represents maximum inequality (where one individual has all the income). Unlike the HDI, there is no universally adopted official classification for the Gini Index.

study questionnaires, or those available to complete the questionnaires with the assistance of a researcher at the study site, and (c) those able to understand and consent to participate in the study. Exclusion criteria were: (a) exhibiting mobility difficulties, (b) reporting a phobia related to any component of the natural world, and (c) having a history of allergies when in contact with nature.

2.2. Recruitment, Screening, randomization and masking

2.2.1. Recruitment

The recruitment consisted of the study's promotion on social media and dissemination by the managers of the natural areas to visitors and the surrounding public through their social networks. Visitors to the area were also directly approached by the research team on the data

collection day in the field. Regarding retention strategies, three friendly reminder emails were sent to ensure participants responded to the questionnaires 30 days after data collection for both the experimental and control interventions. The research team implemented no additional strategies to maintain contact with participants.

No incentives for participation in accordance with Brazilian legislation regulating research with human subjects was adopted. We recruited individuals already present in the natural areas, and only a snack was offered at the end of their participation.

The selection of different natural areas indirectly aimed to promote the inclusion of diverse groups of visitors by considering their location, the social characteristics (HDI and Gini Index) of the surrounding population, and the availability of both paid and free access.

2.2.2. Screening

The eligibility criteria informed at recruitment were reviewed by the research team before applying the consent form.

2.2.3. Randomization

In this study, randomization was conducted independently of the recruitment site (urban, *peri*-urban, or rural), with direct allocation to either the experimental or control group. A predefined randomization list was used to include participants, considering a 5 % increase over the calculated sample size (480 participants) to account for dropout rate. Four hundred and eighty-six participants were randomly assigned in a 1:1 ratio using Randomizer® software to either the experimental group (Nature-Based Multicomponent Intervention, MNBI) or the control group (classical forest bathing).

The randomization process was designed to ensure balance between study groups. The randomization sequence was generated prior to the trial's initiation to guarantee a random and sequential distribution of participants as they consented to join, regardless of the timing or location of recruitment. The sequence was pre-generated globally for the entire sample, while allocation occurred progressively as participants were enrolled throughout the study period.

2.2.4. Masking

Given the characteristics of the interventions, masking was limited to the professional responsible for statistical analysis.

2.3. Ethical aspects

The study protocol was approved by the Institutional Review Board (CAAE No. 36882720.6.0000.0071), in compliance with Brazilian legislation for research involving human subjects and the Helsinki Declaration. All participants provided a written informed consent form (ICF) before randomization. This study is registered at ClinicalTrials.gov (NCT 05486156) with Completed status.

2.4. Data collection

Data collection took place from October 2022 to June 2023, exclusively in the morning, over 19 non-consecutive days. A total of 95 nature-based single sessions were conducted, with 51 sessions in the control group and 44 sessions in the experimental group. Each group averaged five participants, with sessions averaging 100 min. All the research team members were pre-trained and followed specific protocols for both groups. During the 30-days follow-up period, participants did not receive field interventions. This analysis was conducted to assess whether there were long-term effects post-intervention on the studied outcomes.

2.4.1. Nature-based intervention protocols

The NBI applied to the control group aligns with the classical concept of forest bathing, defined as absorbing the forest through the senses (Kotera et al., 2020). This approach was chosen for the control group because it is the most frequently discussed intervention in the literature and is widely regarded as a classic example.

The experimental intervention is based on a recently proposed MNBI, "A Time with e-Nature" (Leão et al., 2023), developed from the hypothesis that forest bathing has a documented potential to promote well-being. Traditional forest bathing lacks well-defined activities to enhance

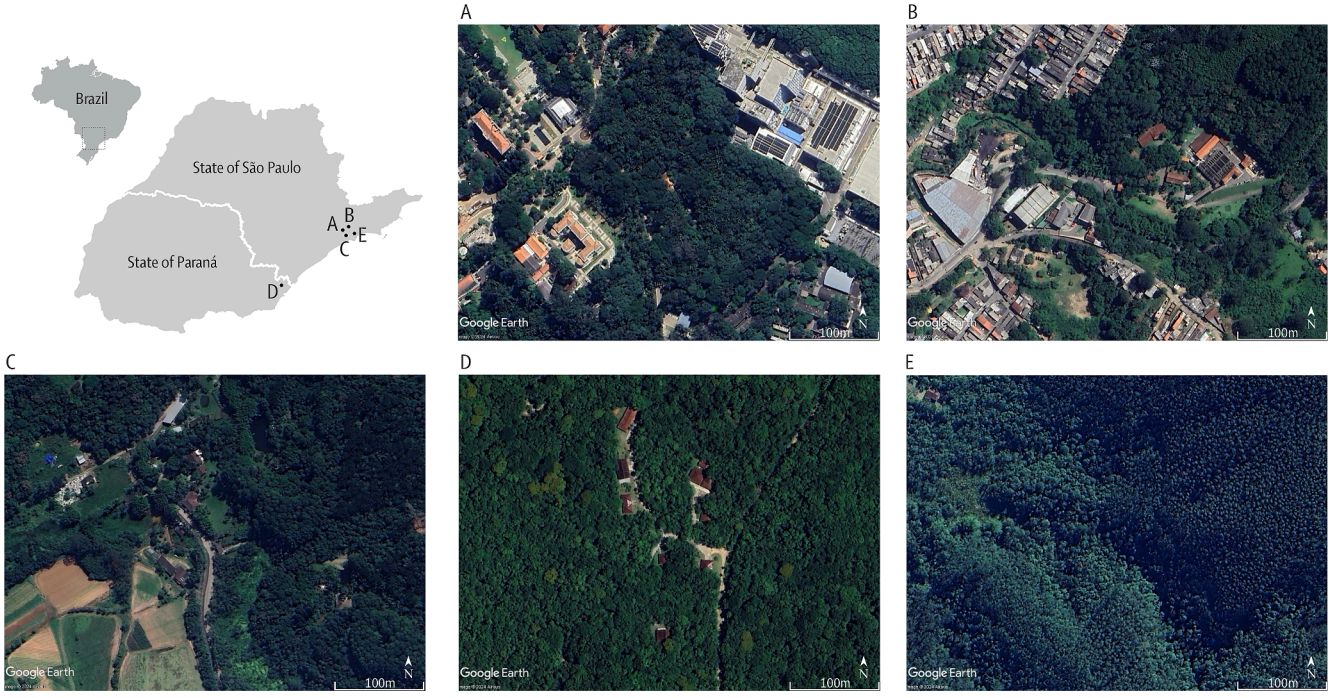


Fig. 1. The five different sites where the clinical trial was conducted, located in southwest Brazil, in the states of São Paulo and Paraná. The Horto Oswaldo Cruz at Butantan Institute is an urban natural area (A); Cantareira State Park – Nucleo Cabuçu (B) and Varginha Natural City Park (C) are *peri*-urban natural areas; and Salto Morato Private Natural Heritage Reserve (D) and Neblinas Park (E) are rural natural areas.

the individual's experience beyond an aesthetic and sensory experience. In contrast, "A Time with e-Nature" aims to provide a more knowledge-driven and engaging experience (an aspect not yet explored in the literature in an integrated manner).

Literature suggests that comparing interventions conducted in natural versus urban environments may not be meaningful (Beute et al., 2023; Silva et al., 2023), as these environments differ significantly and could introduce biases related to the environment itself, rather than the effectiveness of the intervention being evaluated. Likewise, comparisons with other interventions replicating the aesthetic and sensory aspects of forest bathing did not align with the study's objectives. Even immersive virtual reality was not considered, as it would contrast a direct nature-based intervention with an indirect one, whereas this study specifically aimed to evaluate direct nature-based interventions. Thus, comparing the experimental group, characterized by its four dimensions, with a control group that received forest bathing was considered appropriate.

To minimize the risk of contamination between the experimental and control groups, the interventions were conducted on the same days at different times with intervals between sessions. This ensured that participants from one group did not encounter participants from the other group, either on the natural trail or in the facilities where the pre- and post-intervention questionnaires were completed.

The detailed protocol for the experimental MNBI, "A Time with e-Nature" (Leão et al., 2023), is presented below.

Departure for the activity

(Guide's instructions to the participants): We will walk a short distance in silence, after which we will begin our activities.

(The total duration will be approximately 20 min).

Stop 1 – Emotional check-In

(Guide's instructions to the participants): Look around you, observe the environment, and mentally note what you see. (Brief pause).

For a moment, close your eyes, and pay attention to how you are feeling. (Brief pause) Now, we will take a short walk in silence.

Stop 2 – Grounding and focus on the senses

(Guide's instructions to the participants): Let's gather here (in a circle, if possible) and engage in an exercise that utilizes our senses to absorb the atmosphere of the surrounding nature.

If you feel comfortable, close your eyes and take three deep breaths. Bring your awareness to the present moment.

Notice the weight of your body distributed through your legs down to your feet.

Feel your feet touching your shoes and how they connect with the ground. Try to sense the ground you are walking on, staying well-supported. You may slightly bend your knees and observe the stability of this contact.

Keep your eyes closed (if you wish) and focus on the sounds you hear, both near and distant.

Now, open your eyes and observe the nature around you. Notice what you find beautiful and engage in an appreciative gaze. Take your time to enjoy.

Concentrate on the sensations on your skin, your hands, and your face. How do you perceive the temperature? Do you feel any breeze touching you?

Select a few elements from your surroundings that you can touch.

Take a deep breath again and see if you can detect any natural scents. Is there a particular smell that stands out?

Now consider your sense of taste. Do you perceive any taste in your mouth?

(Emotional Check-in) Now, turn your attention back to yourself. How do you feel at this moment? Do you notice any difference compared to your initial self-assessment?

From this point onward, we will take a gentle walk, guided by the biologist, to observe and learn more about nature.

Stop 3 – Nature around us

This stop lasts approximately 40 min and is conducted by the biologist. Playback resources may be used to attract birds along the way. It highlights the surrounding nature, focuses on flora and avifauna, and provides information to the participants.

Step 1: Begin with one minute of silence to listen to the birds. Ask participants to close their eyes and focus on how many (not which) bird species they can identify by sound. After participants open their eyes, the guide reveals the number of species he or she heard vocalizing (a number which will likely be higher than the number most participants, without prior birdwatching experience, would have noted). Based on this experience, the guide should prompt two reflections:

Observing is not synonymous with seeing; observing means paying attention, and in birdwatching and nature observation, listening can be as important as, or even more important than, seeing.

When we do not know the names of the birds, we have difficulty retaining the information. Knowing the names of things in nature helps us learn more about them and care more about nature.

Step 2: Stop at one of the tallest trees along the path, preferably a native species, and identify the species if possible. Point out that trees grow not only in height but also in diameter. The guide should measure the tree's diameter at breast height (1.3 m) using a measuring tape. Considering that tropical trees Grow approximately 1.5 mm per year, estimate the age of the tree. Prompt some reflections on what this tree may have "witnessed" over its lifetime.

Step 3: Find a lichen and explain what it is, emphasizing that it represents a symbiotic association between two species, neither of which can exist without this partnership. Due to this association, lichens are able to colonize substrates that are extremely hostile to other organisms. Lichens do not constitute a taxonomic group (distinct organisms) but rather a biological group (small ecosystems). Highlight the broader importance of cooperation in nature, using the features of lichens as an example.

Lichens are a symbiotic association between algae (phycobionts) and fungi (mycobionts), forming a single organism. Typically, the algae assist in photosynthesis, while the fungi provide moisture and contribute to the nutrition of the algae. Lichens inhabit environments ranging from polar to desert regions and grow on various substrates such as rocks, soil, tree trunks, posts, and leaves. They are also referred to as epiphytes (similar to many species of bromeliads, orchids, ferns, and bryophytes) because they use the substrate solely for attachment and development without harming their host (in this case, trees). Lichens are pioneering organisms in colonizing new environments. On rocky surfaces, the acids present in lichens contribute to the weathering of these materials, which facilitates the colonization of other organisms, such as bryophytes and ferns. Lichens also play a role in supporting various animal species. Birds use them for nest construction; insects rely on them for camouflage, helping them hide from or deceive predators; and other animals feed on them. Some lichen species with blue-green algae (cyanobacteria) contribute to nutrient cycling in the environment through nitrogen fixation, underscoring their ecological importance.

Step 4: Find a fallen tree or branch on the ground, lift it to reveal any insects, fungi, or other creatures, and highlight that even something "dead" in nature is often teeming with life.

Step 5: Locate a wild edible plant (PANC) and inform participants that they may sample it if they feel comfortable (do not encourage, as there is a possibility of adverse reactions or allergies, which could be problematic in a research context). Then, prompt reflection on the fact that everything we eat is derived from living organisms. Given this, and considering that the Atlantic Forest is one of the most biodiverse ecosystems on the planet, it is also one of the richest sources of food.

Stop 4 – Bird inventory and interpretation

This stop is conducted by the biologist, who reviews the list of observed species with the participants. This may include the use of the eBird repository (Cornell University, 2021).

Check-out (closure)

(Guide's instructions to the participants): To conclude, let's gather here (in a circle, if possible).

Take one last look around. Notice if anything has changed since the beginning of the activity.

Close your eyes (if you wish) and observe how you feel. Pay attention to any changes compared to the start of the activity.

Open your eyes and, if you'd like, share in just one word the experience you had today.

The team records the words and then guides participants to the support area to complete the post-intervention questionnaires.

Participants receive a lunch box, pencil, button, and an Eco-Challenges Guide (accompanied by explanations from the team) containing 21 simple nature-based activities that can be incorporated into their daily routines to foster engagement and connection with nature (Supplementary Material 1).

The detailed protocol for the control group, traditional forest bathing, is described below.

Departure for the activity

(Guide's instructions to the participants): We will walk a short distance in silence, where we will begin our activity.

Stop 1 – Emotional check-in

(Guide's instructions to the participants): Look around you, observe the environment, and mentally note what you see. (brief pause)

Close your eyes for a moment and pay attention to how you feel. (brief pause)

Now, we will take a silent walk. During this time, focus on your senses and immerse yourself in the atmosphere of the surrounding nature.

This activity will be accompanied by two members of the project team: one leading the trail and another closing it. The activity should not exceed one hour but should accommodate the participants' pace. The team members record the time, in minutes, taken by the first and last participants to complete the walk.

Check-out (Closure)

(Guide's instructions to the participants): To conclude, let's gather here (in a circle, if possible).

Take one last look around. Notice if anything has changed since the beginning of the activity.

Close your eyes (if you wish) and observe how you feel. Pay attention to any changes compared to the start of the activity.

Open your eyes and, if you'd like, share in just one word the experience you had today.

The team records the words and then guides participants to the support area to complete the post-intervention questionnaires. Participants receive a lunch box, pencil, and button (do not receive the Eco-Challenges Guide, which is supplied only to the MNBI group).

2.4.2. Assessment tools

The variables of interest in the study were evaluated according to their specificity at three moments: pre-intervention (T1), immediate post-intervention (T2) and 30-days after intervention (T3).

2.4.2.1. Sociodemographic and environmental assessment tools.

- *Sociodemographic characteristics (T1)*: Gender, age, nationality, profession, marital status, education level, household income, race/ethnicity, whether they were born and predominantly lived in urban or rural areas, frequency of contact with nature, distance from their residence to a natural area, and whether they currently or previously owned a pet, and which type.

- *Environmental characteristics (T1)*: A recent review (Silva et al., 2023) highlighted the lack of study site characterization as a notable shortcoming, emphasizing the importance of addressing this gap. We followed the guidelines recommended by Machado (Machado, 2004) and included temperature, humidity, weather conditions, vegetation cover, biodiversity richness, structural elements, and non-natural elements. We also utilized the normalized difference vegetation index (NDVI) to estimate the greenness of each natural area in the period of the respective data collection (Damasceno da Silva et al., 2024). To estimate the NDVI indices of the sites where the activities were conducted, we utilized data supplied by the Terra Moderate Resolution Imaging Spectroradiometer (MODIS) – product MOD13A1, and Aqua MODIS – product MYD13A1, with spatial resolutions of 250 m, 500 m, and 1000 m (Didan, 2021), during the month of the respective activity. We employed the Application for Extracting and Exploring Analysis Ready Samples (AppEEARS Team, 2024) to obtain the NDVI values for the geographic coordinates corresponding to the centers of the sites depicted in Fig. 1.

2.5. Outcomes

2.5.1. Primary outcome

- *Well-Being (T1 and T3)*: Measured by the WHO-5 Well-Being Index, where a percentage value is used to monitor possible changes in well-being, with a 10 % variation indicating a significant change (de Souza and Hidalgo, 2012). The WHO well-being index recommends at least two-week interval between assessments, as stated in the instrument's guidelines (WHO, 2024).

2.5.2. Secondary outcomes

- *Subjective Vitality (T1, T2, and T3)*: Assessed using a 7-point Likert scale identified as a positive feeling and a marker of well-being (Ryan and Frederick, 1997).
- *Self-Perception of Happiness (T1, T2, and T3)*: Assessed by a single question about happiness ("In general, do you feel happy?"), with responses ranging from 0 (extremely unhappy) to 10 (extremely happy) (Abdel-Khalek, 2006).
- *Connection with Nature (T1, T2, and T3)*: Assessed using the Nature Connection Scale adapted for Brazil (Pessoa et al., 2016).
- *Nature Engagement Questionnaire (T1 and T3)*: A nature engagement questionnaire was developed by the researchers, based on a survey conducted in the United Kingdom (Natural England, 2020) that provided evidence of how people can engage with the environment to determine pro-environmental and pro-conservation values and actions.
- *Assessment of Experience in Nature (T2)*: Participants were asked to summarize their experience in one word at the end of the intervention.

All questionnaires were hosted on the institutional Research Electronic Data Capture (REDCap) platform. Due to REDCap's specific safety features, there was no need for a data safety monitoring board. The REDCap is a widely used platform for data collection and management in academic and clinical research. It provides multiple layers of security to ensure data confidentiality, integrity, and availability. Additionally, aiming for quality and safety data all interventional studies are audited by the organization's Office of Scientific Integrity to assess compliance with Good Clinical Research Practices.

During field data collection, participants completed the instruments on tablets provided by the researchers. For the T3 assessment, participants received a link via email for digital access.

2.6. Statistical analysis

Qualitative data were described by absolute and relative frequencies, and quantitative data were described by medians, 1st and 3rd quartiles, in addition to minimum and maximum. The choice of the median and quartiles was due to the asymmetric characteristic of the quantitative data evaluated.

The hypothesis tested in the study was that individuals who

underwent experimental group showed improvement in the parameters investigated over time, compared to individuals in a control group. To evaluate the hypothesis, we investigated the effects of time (T1, T2 and T3, or T1 and T3 for the primary outcome), group (experimental or control) and interaction between group and control as explanatory variables in generalized estimating equation models, allowing for a flexible approach to the hierarchical structure of the data and the dependence inherent to the measurements of the same individual over time. We also specified the distributions for the outcomes in each model, namely: Gamma for the primary outcome and measures of Well-Being, Self-Perception of Happiness, Subjective Vitality and Nature Connection Scale and Binomial for the engagement items with nature.

The results of the models were presented as estimated means of outcomes in each group and moment, and respective 95 % confidence intervals, in addition to p-values for comparisons between groups at each moment and between moments within each group. These p-values were corrected using the sequential Bonferroni method to control type I error. The models were also stratified by type of area (urban, *peri*-urban, rural) to explore possible variations in the effects of the intervention in different environmental contexts. Analyzes were performed using R (version 4.4.1) and SPSS (version 29.0), following the intention-to-treat principle and considering a significance level of 5 %.

The minimum sample size estimate was based on comparisons between control and experimental groups. Aiming to detect a moderate effect size (0.5), assuming 80 % power and 5 % significance level, we estimated 64 individuals in each group and natural area (urban, *peri*-urban and rural). Anticipating a 20 % dropout rate, the goal was to include 80 individuals in each group and area, or 480 participants in total. Calculations were performed using the R (version 4.4.1) and pwr (version 1.3–0) package.

3. Results

A total of 486 participants took part in the study, as represented in the CONSORT diagram in Fig. 2, drawn from the five local natural areas under study.

In the control group, there were eight exclusions: withdrew from participation for personal reasons (n = 4), and excluded from analysis due to incorrect contact information, which prevented the delivery of the 30-day follow-up questionnaire (n = 4). Thus, the final control group were analysed 249 individuals immediate post intervention distributed in the sites as follows: 96 people at Horto Oswaldo Cruz, Butantan Institute; 21 at Cantareira State Park – Núcleo Cabuçu; 51 at Varginha Natural City Park; 28 at Salto Morato Private Natural Heritage Reserve; and 53 at Neblinas Park.

In the experimental (MNBI) group there were eight exclusions: withdrew from participation for personal reasons (n = 3), and excluded from analysis due to incorrect contact information, which prevented the delivery of the 30-day follow-up questionnaire (n = 5). Thus, the final experimental group were analysed 237 participants immediate post intervention, distributed by the study areas as follows: 86 at Horto Oswaldo Cruz, Butantan Institute; 15 at Cantareira State Park – Núcleo

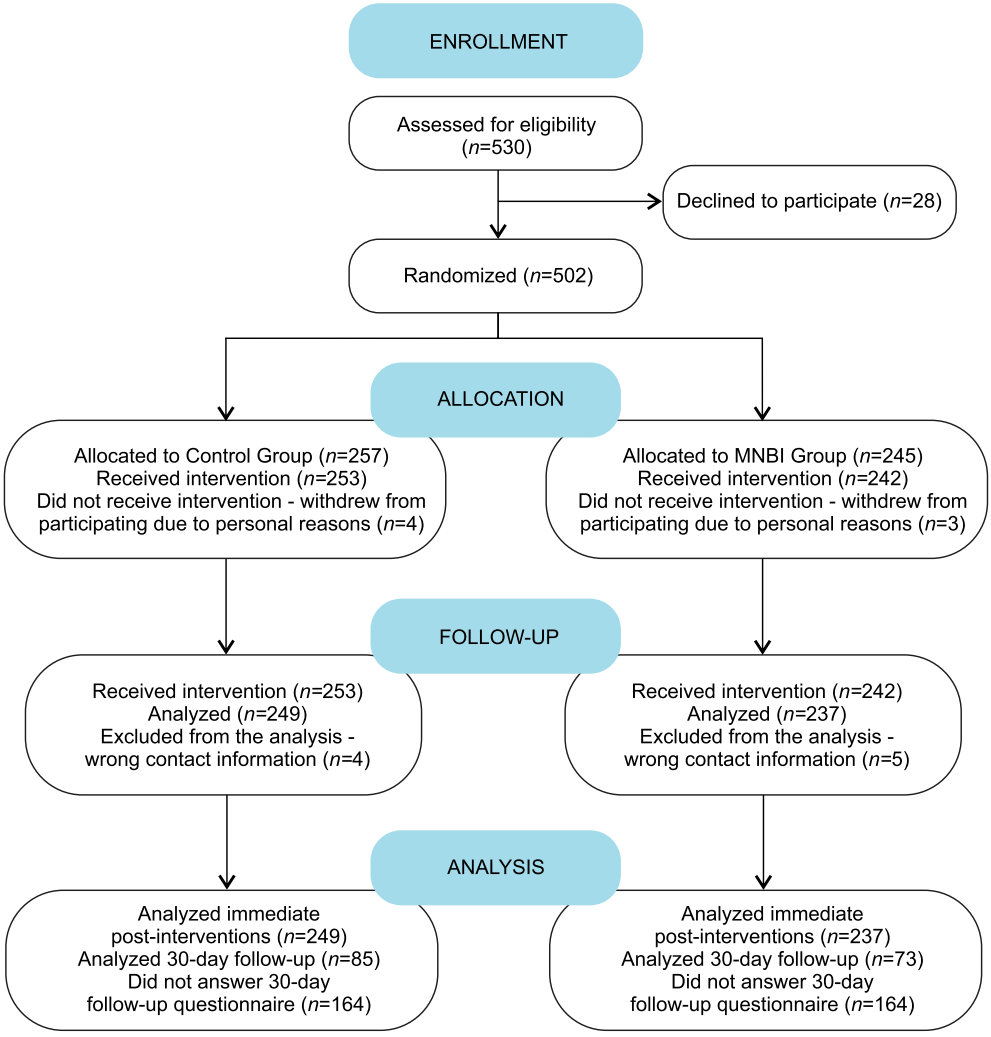


Fig. 2. CONSORT Flow Diagram.

Cabuçu; 46 at Varginha Natural City Park; 30 at Salto Morato Private Natural Heritage Reserve; and 60 at Neblinas Park.

The majority of the participants identified themselves as white, female, born and raised predominantly in urban areas, with a median age between 41 and 43 years. For questions about gender and race, we consider the Brazilian Institute of Geography and Statistics (IBGE) classification and insert a "Prefer not to inform" option. A complete description of participants' characteristics (including contact with nature/animals) is provided in Supplementary Material 2.

Environmental characterization revealed that all areas had a high diversity of vegetation, with at least ten species and different vegetation strata (herbaceous, shrub, and tree). Only rural areas featured predominantly native vegetation. All areas had exotic vegetation species and displayed artificial elements like boardwalks and bridges. The weather conditions were assessed on all 95 occasions. We found a median temperature of 24 °C (75·2°F), variations between 15 °C-30 °C (59°F-86°F), median humidity 64 % (42 %-88 %), median wind speed 12 km/h (7·5mph), variations between 4 km/h-31 km/h (2·5mph-19·3mph).

For each spatial resolution and site, we averaged the highest quality NDVI values from both Terra and Aqua MODIS products during the month of the respective activity. Fig. 3 highlights the NDVI values among study areas, so that rural areas have higher values than *peri*-urban areas, which have higher values than the urban area.

Table 2 presents the values for the Well-Being Index, Subjective Vitality, Self-Perception of Happiness, and Nature Connection Scale across the different natural areas and groups at distinct time points, along with comparisons.

The primary outcome of this study was overall well-being, measured by the WHO-5. Overall, no significant differences were observed in the WHO-5 between the control and experimental groups in urban and rural natural areas. However, in the *peri*-urban setting, the experimental group experienced a moderate increase in T2 ($p = 0.048$) and a significant increase in T3 ($p = 0.036$) with an estimated increase of 1·6 points on the scale for the experimental group. The 95 % CI for the increase ranged from 0·1 to 3·2, confirming a meaningful effect.

Both groups showed a significant increase ($p < 0.001$) in subjective vitality in T2 and a significant decrease ($p < 0.001$) in T3. In the *peri*-urban area, the experimental group was more effective in sustaining subjective vitality because, although it decreased in T3, it remained higher than the baseline.

Self-perception of happiness increased significantly in both groups between T1 and T2 ($p < 0·001$). Notably, in the *peri*-urban area, the experimental group maintained a higher level of happiness in T3 compared to the control group, indicating a more lasting effect ($p < 0·001$ for the experimental group; $p = 0·041$ for the control group).

Connection to nature significantly increased in both groups ($p < 0·001$) in T2, but only the experimental group maintained a higher level of connection in T3 ($p = 0·021$). Specifically, in the *peri*-urban area, the experimental group showed a sustained connection to nature in T3 ($p = 0·035$), while the control group did not exhibit the same effect.

Participants' experiences in the natural environment, summarized in a single word in T2, are depicted in the word clouds in Supplementary Material 3. In both word clouds, terms such as "Relaxing," "Life," "Calm," "Energizing," and "Lightness" are prominently featured, indicating that participants in both groups experienced feelings of relaxation, calm, and revitalization during the interventions. Terms related to emotional well-being, such as "Peace," "Tranquility," "Gratefulness," "Joy," and "Happiness," also appear in both clouds, demonstrating that both interventions effectively promoted feelings of peace and satisfaction. The experimental group (MNBI) emphasized "Knowledge" more than the control group.".

In the nature conservation engagement questionnaire, motivation most frequently mentioned by participants of both groups, in T1 and T3 were: "Getting fresh air and/or enjoying pleasant weather" (T1: 76·5% and T3: 82·3% follow-up); "Finding peace and tranquility" and "Relaxing" (T1:74·7% and T3: 76·6%). "Enjoying the scenery" was the third most cited reason for the control group at both moments (T1: 63·5% and T3: 65·9%) while "Physical exercise" was for the experimental group (T1: 66·2% and T3: 68·5%). Fig. 4 presents the proportions of pro-environmental values, household actions, and conservation actions for the control and experimental (MNBI) groups at T1 and T3 time points, for the urban, rural, and *peri*-urban areas.

Across all areas, both groups demonstrated strong pro-environmental values, with little variation in T3. The experimental group showed greater engagement in domestic and conservation actions, particularly in *peri*-urban and rural areas. This effect was more pronounced in the *peri*-urban area, where the experimental group managed to sustain or increase their engagement in T3, while the control group showed a reduction.

4. Discussion

This study compared the effects of the MNBI with the control group (forest bathing) on various outcomes, including well-being, subjective vitality, happiness, connection to nature, engagement in pro-environmental activities, and emotional experience. These were evaluated in urban, *peri*-urban, and rural settings.

The principal finding of this study is that the MNBI was significantly more effective in enhancing well-being, vitality, and connection to nature than the forest bathing control group, particularly in *peri*-urban settings. While both groups showed immediate increases in subjective vitality and happiness perception, the MNBI group maintained higher levels of well-being, nature connection, and engagement in conservation

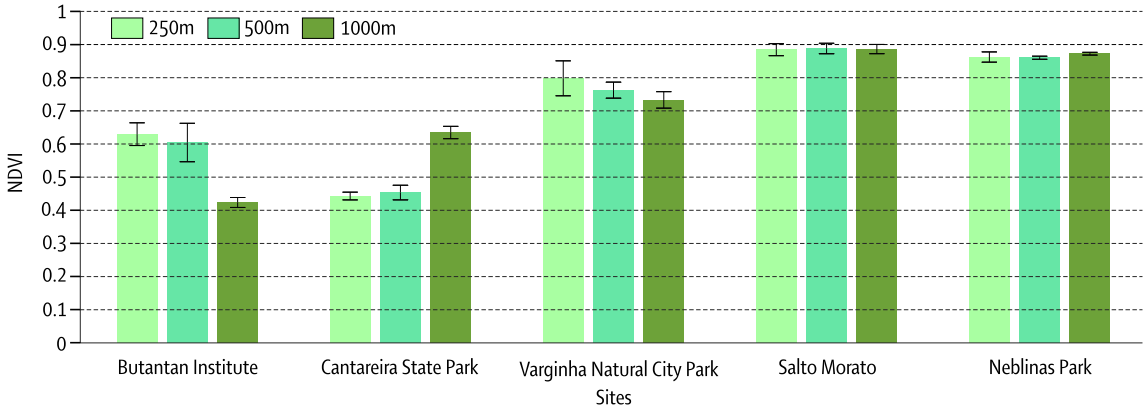


Fig. 3. The NDVI indices of the five sites where the clinical trial was conducted. The NDVI values were estimated from the samples collected from the Terra MODIS and Aqua MODIS instruments, using the AppEEARS, at spatial resolutions of 250 m, 500 m, and 1000 m, during the month of the respective activity.

Table 2
WHO-5 Well-Being Index, Subjective Vitality, Self-Perception of Happiness, Nature Connection Scale – estimated means and comparisons between areas types, groups, and time points.

	T1	T2	T3		p-value moment	
	Mean (IC)	Mean (IC)	Mean (IC)	T2 X T1 (n = 486)	T3 X T1 (n = 158)	T3 X T2 (n = 158)
WHO-5 Well-Being Index						
All areas						
Control	15.3 (14.8; 16.0)	NE	15.5 (14.6; 16.4)	NE	0.758	NE
MNBI	14.9 (14.3; 15.5)	NE	15.7 (14.9; 16.6)	NE	0.054	NE
Group p-value	0.260	NE	0.726	NA	NA	NA
Peri-urban area						
Control	14.7 (13.6; 15.9)	NE	16.0 (14.7; 17.5)	NE	0.061	NE
MNBI	13.8 (12.8; 14.9)	NE	15.4 (14.0; 17.0)	NE	**0.036**	NE
Group p-value	0.224	NE	0.571	NA	NA	NA
Rural area						
Control	16.6 (15.5; 17.7)	NE	15.9 (14.2; 17.8)	NE	0.432	NE
MNBI	16.0 (15.1; 17.0)	NE	16.2 (14.8; 17.7)	NE	0.778	NE
Group p-value	0.423	NE	0.785	NA	NA	NA
Urban area						
Control	14.7 (13.9; 15.6)	NE	14.6 (13.3; 16.0)	NE	0.822	NE
MNBI	14.5 (13.6; 15.5)	NE	15.2 (13.8; 16.6)	NE	0.288	NE
Group p-value	0.696	NE	0.555	NA	NA	NA
Subjective Vitality						
All areas						
Control	5.3 (5.2; 5.5)	6.0 (5.8; 6.1)	5.2 (4.9; 5.4)	**<0.001**	0.109	**<0.001**
MNBI	5.3 (5.1; 5.5)	6.1 (6.0; 6.3)	5.3 (5.1; 5.5)	**<0.001**	0.954	**<0.001**
Group p-value	0.859	**0.038**	0.348	NA	NA	NA
Peri-urban area						
Control	5.4 (5.1; 5.7)	5.9 (5.7; 6.2)	5.4 (5.0; 5.8)	**<0.001**	0.918	**0.016**
MNBI	5.2 (4.9; 5.5)	5.9 (5.6; 6.2)	5.3 (5.0; 5.7)	**<0.001**	0.331	**<0.001**
Group p-value	0.370	0.980	0.931	NA	NA	NA
Rural area						
Control	5.7 (5.4; 5.9)	6.2 (6.0; 6.4)	5.3 (4.8; 5.8)	**<0.001**	0.091	**<0.001**
MNBI	5.6 (5.3; 5.9)	6.3 (6.2; 6.5)	5.4 (5.2; 5.7)	**<0.001**	0.270	**<0.001**
Group p-value	0.743	0.354	0.625	NA	NA	NA
Urban area						
Control	5.0 (4.8; 5.3)	5.8 (5.6; 6.0)	4.9 (4.5; 5.2)	**<0.001**	0.790	**<0.001**
MNBI	5.1 (4.8; 5.4)	6.1 (5.9; 6.3)	5.1 (4.8; 5.5)	**<0.001**	0.869	**<0.001**
Group p-value	0.595	**0.020**	0.312	NA	NA	NA
Self-perception of Happiness						
All areas						
Control	7.6 (7.4; 7.9)	8.9 (8.7; 9.0)	7.7 (7.4; 8.0)	**<0.001**	0.533	**<0.001**
MNBI	7.6 (7.4; 7.8)	9.0 (8.9; 9.2)	8.0 (7.7; 8.3)	**<0.001**	**0.010**	**<0.001**
Group p-value	0.690	0.159	0.244	NA	NA	NA
Peri-urban area						
Control	7.5 (7.1; 7.9)	8.7 (8.4; 9.0)	7.9 (7.5; 8.3)	**<0.001**	**0.041**	**<0.001**
MNBI	7.1 (6.7; 7.6)	8.7 (8.4; 9.1)	8.1 (7.6; 8.7)	**<0.001**	**<0.001**	**0.031**
Group p-value	0.197	0.911	0.515	NA	NA	NA
Rural area						
Control	8.1 (7.7; 8.5)	9.2 (8.9; 9.5)	7.9 (7.3; 8.6)	**<0.001**	0.528	**<0.001**
MNBI	8.0 (7.7; 8.4)	9.2 (9.0; 9.4)	8.1 (7.6; 8.6)	**<0.001**	0.879	**<0.001**
Group p-value	0.809	0.814	0.723	NA	NA	NA
Urban area						
Control	7.3 (7.0; 7.7)	8.7 (8.5; 9.0)	7.3 (6.9; 7.8)	**<0.001**	>0.999	**<0.001**
MNBI	7.4 (7.1; 7.7)	9.0 (8.8; 9.3)	7.6 (7.1; 8.1)	**<0.001**	0.386	**<0.001**
Group p-value	0.717	0.095	0.414	NA	NA	NA
Nature Connection Scale						
All areas						
Control	55.5 (54.7; 56.4)	57.2 (56.4; 58.0)	55.9 (54.8; 57.0)	**<0.001**	0.416	**<0.001**
MNBI	54.4 (53.5; 55.4)	57.8 (57.0; 58.5)	55.8 (54.6; 57.0)	**<0.001**	**0.021**	**<0.001**
Group p-value	0.089	0.309	0.875	NA	NA	NA
Peri-urban area						
Control	56.2 (54.4; 58.0)	56.7 (55.1; 58.3)	56.8 (55.1; 58.6)	>0.999	>0.999	>0.999
MNBI	54.2 (52.0; 56.4)	58.2 (56.7; 59.8)	56.5 (54.4; 58.7)	**<0.001**	**0.034**	**0.035**

(continued on next page)

Table 2 (*continued*)

	T1	T2	T3		p-value moment	
	Mean (IC)	Mean (IC)	Mean (IC)	T2 X T1 (n = 486)	T3 X T1 (n = 158)	T3 X T2 (n = 158)
Group p-value	0.163	0.181	0.849	NA	NA	NA
Rural area						
Control	55.6 (54.3; 57.0)	57.4 (56.1; 58.7)	54.6 (52.4; 57.0)	**0.001**	0.275	**0.014**
MNBI	55.1 (53.7; 56.5)	57.8 (56.5; 59.0)	55.3 (53.5; 57.2)	**<0.001**	0.801	**0.009**
Group p-value	0.592	0.664	0.649	NA	NA	NA
Urban area						
Control	55.0 (53.7; 56.3)	57.2 (56.0; 58.4)	55.6 (54.1; 57.3)	**<0.001**	0.361	0.071
MNBI	53.9 (52.4; 55.5)	57.5 (56.3; 58.8)	55.2 (53.2; 57.4)	**<0.001**	0.184	**0.025**
Group p-value	0.300	0.696	0.762	NA	NA	NA

T1: Pre-intervention; T2: Post-intervention; T3: 30-days follow-up.
Mean (CI): Model-estimated mean and 95% confidence interval.
Group p-value: p-value for the comparison between groups, separated by time point and by area.
p-value moment: p-value for the comparison within groups, separated by group and by area.
p-values highlighted in bold indicate cases with significant differences.
NE: Not Evaluated.
NA: Not Applicable.

activities 30 days post-intervention. The most notable improvements were observed in *peri*-urban areas, where participants in the MNBI group demonstrated a sustained increase in well-being and environmental engagement.

Considering that all the areas in the study are in the Atlantic Forest biome, they all had a high diversity of vegetation and a predominance of green color tones. However, when we evaluate vegetation density using NDVI, the differences between the areas become clear. The better results obtained in the *peri*-urban areas in terms of well-being and connection with nature may be associated with this density.

Urban natural areas may be unable to provide well-being and connection with nature after a 30-day follow-up period, while rural areas characteristic of the Atlantic Forest may promote feelings of fear and suffocation, as they are denser and more enclosed. These results corroborate other evidence that medium density vegetation is the most beneficial for human health (Beute et al., 2023; Chiang et al., 2017).

Our sample group predominantly consisted of women in their 40 s, mostly white, with educational backgrounds in social sciences. More than 85 % of participants were born and lived most of their lives in urban areas. This demographic profile is significant as the literature suggests that individuals who grew up in rural areas or have more frequent contact with nature tend to exhibit a stronger connection thanks to regular access and outdoor activities (Rosa et al., 2018). This outcome could be explained by a sample bias, as participants, despite being urban dwellers, might have an affinity with nature that motivated them to volunteer for a study with this focus. This affinity could have been developed in childhood through various natural world experiences (Rosa et al., 2018), such as holidays, or even due to a shift in perception following the COVID-19 pandemic, where nature was used as a strategy for mental health, leading to greater appreciation and awareness, even in urban areas (Kanelli et al., 2023).

It is noteworthy that, given the socioeconomic context surrounding each natural area, a more diverse sample in terms of race and education level was expected, but this was not observed. Brazilian researchers have highlighted that the lack of access to urban green spaces among vulnerable or marginalized populations is not due to the absence of such areas but rather the lack of policies promoting social interaction, landscape appreciation, leisure, and cultural activities to attract a more diverse population. The mere presence of green spaces is insufficient to ensure their use by different demographic groups (SIlva et al., 2023b). This ends up depriving part of the population of the benefits that nature can provide for health. Factors such as racial discrimination and social exclusion affect the perception of belonging in green areas. These spaces are often perceived as exclusive or unfriendly to disadvantaged ethnic and socioeconomic minorities (Haycox, et al., 2024), which may explain the sample profile found among visitors.

There were no significant changes in the WHO-5 between the control and experimental group, except in the *peri*-urban area, where the experimental group showed a significant improvement in well-being. Forest bathing and walks in natural environments have demonstrated potential for enhancing well-being by increasing vitality and life satisfaction following such activities (Pichler et al., 2022).

A point for discussion is the understanding of well-being in health, considered a multidimensional concept encompassing physical, mental, emotional, and social aspects of a person's life, and this perception may vary (Ryan and Frederick, 1997). The literature presents different constructs, and beyond what the WHO-5 assesses, various aspects of the human-nature relationship can be considered as hedonic well-being, which is why different assessment tools exist. Vitality, happiness, and life satisfaction are sometimes analyzed individually and sometimes under the umbrella of well-being, complicating comparisons between studies.

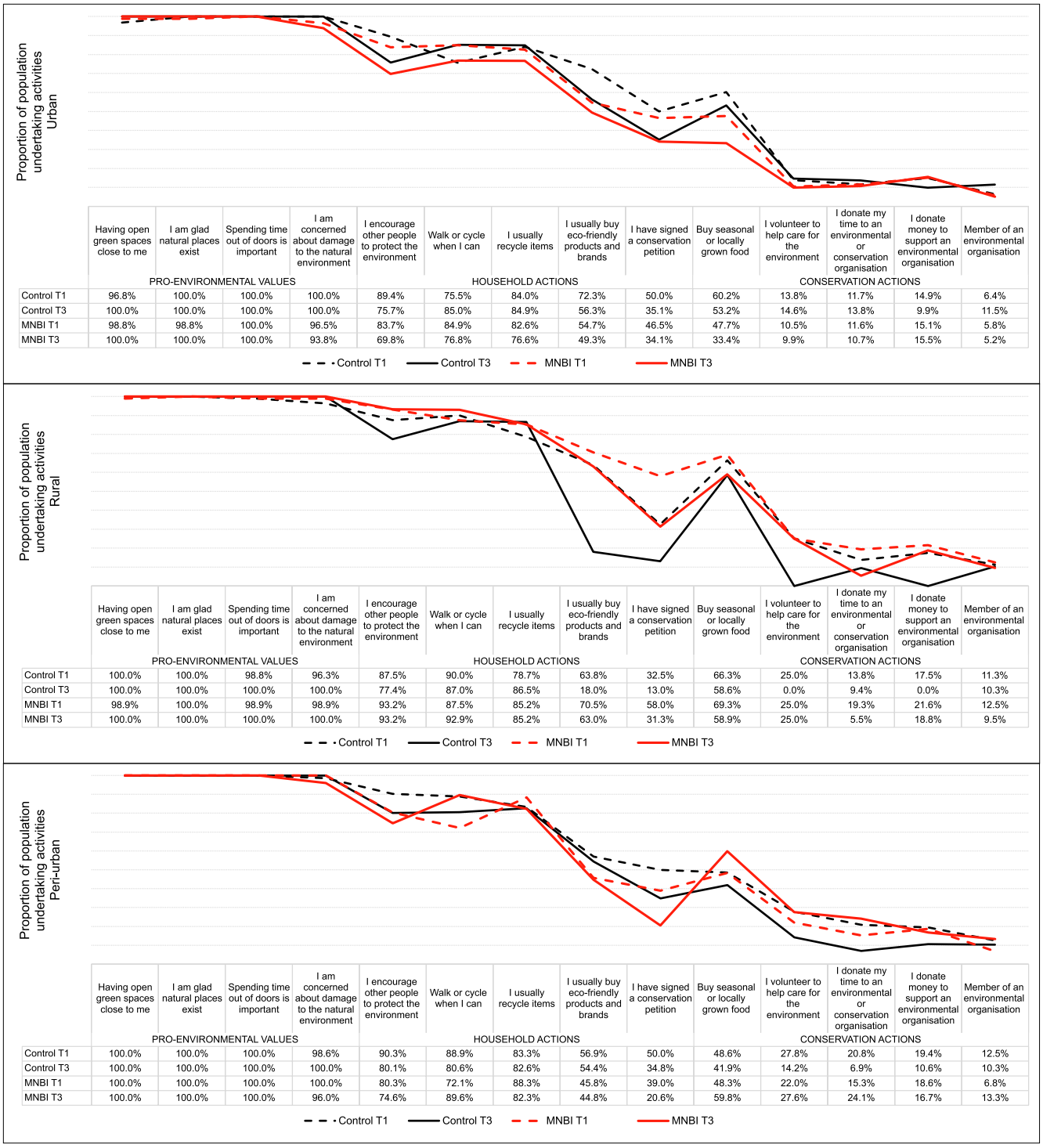
While both groups showed an immediate positive impact on vitality, MNBI was significantly more effective in enhancing it, particularly in urban areas. Most of the positive effects decreased after 30 days follow-up, suggesting that the benefits of the intervention may be transient, highlighting the need for ongoing practices to maintain vitality gains.

Researchers point out that connection with nature enhances the perception of vitality. There is a positive relationship between connection with nature and various domains of well-being, including emotional, psychological, and social well-being. Individuals with a stronger connection to nature tend to experience more positive affect, vitality, and life satisfaction (Jones, 2022), as well as greater happiness, underscoring the positive impact of nature on human life (Capaldi et al., 2014).

Both groups experienced immediate and similar increases in happiness, suggesting that exposure to the natural environment enhances happiness, regardless of the specific intervention. Regarding the connection with nature, both groups showed an immediate increase. The experimental group demonstrated significant increases in nature connection across all areas, with effects slightly more sustained over time compared to the control group, particularly in the *peri*-urban area. Researchers have demonstrated that exposure to nature increases connection and improves both physiological and mental health measures (Gál and Dömötör, 2023).

Both control and experimental groups maintained strong pro-environmental values over time. Practices such as recycling and transportation by bicycle use remained high in both groups and across all areas. However, the experimental group showed a more significant increase in purchasing eco-friendly products and environmentally-friendly brands after 30 days, especially in *peri*-urban and rural areas, indicating that the intervention effectively reinforced conscious consumption practices.

Greater engagement in conservation actions, such as volunteering and donations to environmental organizations, was also observed in the experimental group compared to the control group. This effect was more pronounced in the *peri*-urban area, where the experimental group managed to sustain or increase their engagement after 30 days follow-up, unlike the control group, which showed a reduction. A similar



Urban

	Having open green spaces close to me	I am glad natural places exist	Spending time out of doors is important	I am concerned about damage to the natural environment	I encourage other people to protect the environment	Walk or cycle when I can	I usually recycle items	I usually buy eco-friendly products and brands	I have signed a conservation petition	Buy seasonal or locally grown food	I volunteer to help care for the environment	I donate my time to an environmental or conservation organisation	I donate money to support an environmental organisation	Member of an environmental organisation
	PRO-ENVIRONMENTAL VALUES				HOUSEHOLD ACTIONS						CONSERVATION ACTIONS			
Control T1	96.8%	100.0%	100.0%	100.0%	89.4%	75.5%	84.0%	72.3%	50.0%	60.2%	13.8%	11.7%	14.9%	6.4%
Control T3	100.0%	100.0%	100.0%	100.0%	75.7%	85.0%	84.9%	56.3%	35.1%	53.2%	14.6%	13.8%	9.9%	11.5%
MNBI T1	98.8%	98.8%	100.0%	96.5%	83.7%	84.9%	82.6%	54.7%	46.5%	47.7%	10.5%	11.6%	15.1%	5.8%
MNBI T3	100.0%	100.0%	100.0%	93.8%	69.8%	76.8%	76.6%	49.3%	34.1%	33.4%	9.9%	10.7%	15.5%	5.2%

Rural

	Having open green spaces close to me	I am glad natural places exist	Spending time out of doors is important	I am concerned about damage to the natural environment	I encourage other people to protect the environment	Walk or cycle when I can	I usually recycle items	I usually buy eco-friendly products and brands	I have signed a conservation petition	Buy seasonal or locally grown food	I volunteer to help care for the environment	I donate my time to an environmental or conservation organisation	I donate money to support an environmental organisation	Member of an environmental organisation
	PRO-ENVIRONMENTAL VALUES				HOUSEHOLD ACTIONS						CONSERVATION ACTIONS			
Control T1	100.0%	100.0%	98.8%	96.3%	87.5%	90.0%	78.7%	63.8%	32.5%	66.3%	25.0%	13.8%	17.5%	11.3%
Control T3	100.0%	100.0%	100.0%	100.0%	77.4%	87.0%	86.5%	18.0%	13.0%	58.6%	0.0%	9.4%	0.0%	10.3%
MNBI T1	98.9%	100.0%	98.9%	98.9%	93.2%	87.5%	85.2%	70.5%	58.0%	69.3%	25.0%	19.3%	21.6%	12.5%
MNBI T3	100.0%	100.0%	100.0%	100.0%	93.2%	92.9%	85.2%	63.0%	31.3%	58.9%	25.0%	5.5%	18.8%	9.5%

Peri-urban

	Having open green spaces close to me	I am glad natural places exist	Spending time out of doors is important	I am concerned about damage to the natural environment	I encourage other people to protect the environment	Walk or cycle when I can	I usually recycle items	I usually buy eco-friendly products and brands	I have signed a conservation petition	Buy seasonal or locally grown food	I volunteer to help care for the environment	I donate my time to an environmental or conservation organisation	I donate money to support an environmental organisation	Member of an environmental organisation
	PRO-ENVIRONMENTAL VALUES				HOUSEHOLD ACTIONS						CONSERVATION ACTIONS			
Control T1	100.0%	100.0%	100.0%	98.6%	90.3%	88.9%	83.3%	56.9%	50.0%	48.6%	27.8%	20.8%	19.4%	12.5%
Control T3	100.0%	100.0%	100.0%	100.0%	80.1%	80.6%	82.6%	54.4%	34.8%	41.9%	14.2%	6.9%	10.6%	10.3%
MNBI T1	100.0%	100.0%	100.0%	100.0%	80.3%	72.1%	88.3%	45.8%	39.0%	48.3%	22.0%	15.3%	18.6%	6.8%
MNBI T3	100.0%	100.0%	100.0%	96.0%	74.6%	89.6%	82.3%	44.8%	20.6%	59.8%	27.6%	24.1%	16.7%	13.3%

Fig. 4. Proportions of pro-environmental values and actions for the control and experimental (MNBI) groups at different time points. T1 is pre-intervention and T2 immediate post-intervention.

trend was observed regarding signing petitions and participating in environmental organizations.

Pro-environmental values were more prevalent than direct conservation activities, which is expected. Despite understanding the importance of nature, active conservation behaviors often remain uncommon. For instance, selective waste collection, while widespread in our study, is not yet a universal practice. However, our experimental group in *peri*-urban areas demonstrated a significant increase in conservation engagement after 30-day follow-up.

The increased connection with nature and sense of belonging observed in this study positively impact conservation. This can influence public policies related to urban green spaces and protected areas (Barragan-Jason et al., 2023; Rosa et al., 2018), contributing to the health of both humans and non-humans, as demonstrated by Barragan-Jason and colleagues (Barragan-Jason et al., 2023).

In this sense, the greater engagement observed in the MNBI speaks in favor of the model on which the protocol was based, as unlike forest bathing, which emphasizes sensory experience, the "A Time with e-

Nature" model (Leão et al., 2023) emphasizes cognitive aspects characterized by an experience of knowledge and engagement as key factors for developing pro-environmental behaviors.

It does not, however, forgo the aesthetic and emotional experience and the sensory integration with nature in the proposed activities. This was made quite clear in the words the participants chose to characterize their experience. In the MNBI group, words such as knowledge, learning, and contemplation stood out, reinforcing that, in addition to scientifically clear and reproducible protocols for nature-based interventions, theoretical models that align with and rationally support such interventions are also necessary.

Although nature is recognized as beneficial to humans, the reverse is generally not true, as most human activities can cause significant negative impacts on the environment and other species, including disruptions to genetic diversity (Almeida-Rocha et al., 2020). Knowing the diversity and uniqueness of plants and animals that make up the various ecosystems can lead to a better understanding of why they need to be protected (Barragan-Jason et al., 2023; Stoll-Kleemann, 2001).

This is a necessary stance for expanding environmental education and awareness of the importance of biodiversity and ecosystems, enabling the creation of mitigation strategies, increased engagement, and public participation in conservation activities, which culminate in public policies that guide practices in nature with sustainable management aligned with Planetary Health. Although both groups experienced positive feelings such as relaxation and calm, the control group focused more on emotional and connection aspects, while the experimental group offered a more diverse experience, incorporating learning and contemplation, which are more favorably aligned to extend benefits beyond humans.

When analyzing each group separately across the three types of areas, the *peri*-urban natural area, in association with the MNBI, stood out positively among the other areas in some of the outcomes analyzed. The experimental group maintained higher levels of happiness compared to the control group, showed a significant increase in well-being, sustained connection to nature over time, as well as greater engagement in pro-environmental behaviors.

Researchers have pointed out the difficulty of analyzing different natural areas and their impact on health and well-being outcomes (Beute et al., 2023), as they depend on both the individuals and the characteristics of the areas. Engagement with natural beauty, self-reflection, and mindful attention can explain differences in individuals' responses to natural environments, but also through affect regulation, explained by the functional evolutionary model, which demonstrates the physiological bases that allow understanding the benefits of nature for mental well-being (Chang et al., 2024).

Vegetation density has been identified as one of the factors influencing this perception. Moderately dense green spaces have been preferred (Chiang et al., 2017), while more densely vegetated spaces may result in lower perceptions of safety due to the obstruction of the field of vision by vegetation. However, other elements can interfere with this perception, such as familiarity with the location, a sense of belonging, and nearby gray infrastructure (Santo-Tomás Muro et al., 2020).

Perhaps this is why the *peri*-urban area, which is not too urban and therefore may present fewer anthropogenic interferences, and not too rural (where there may be more animals considered dangerous, such as snakes and spiders), to the point of causing biophobia, presented better results. Besides being more accessible in terms of time and resources to enjoy it, it may combine characteristics that make the experience more pleasant and safe. In future studies, the characterization of green spaces should consider form, pattern, networks, and both objective and perceived qualities (Nguyen et al., 2021).

On the other hand, the experimental group in the urban area only showed a significant improvement in vitality perception immediately after the activity, which may also be linked to the fact of living in a highly anthropogenic environment, with noise and visual pollution that increase fatigue. Contact with a natural environment amid an urban jungle might have resulted in an immediately perceived restorative effect as a sense of greater vitality.

In summary, the results demonstrated that both groups, control and intervention, experienced significant increases in happiness and subjective vitality immediately after the activities. However, these positive effects tend to diminish over time, with a significant reduction in happiness and vitality levels 30 days after the intervention. Despite this decrease, the experimental group maintained slightly higher levels of happiness and subjective vitality compared to the control group, particularly in the *peri*-urban area, suggesting that the intervention may have a more sustained effect in certain contexts.

Although some differences between the groups were not statistically significant, the MNBI showed some additional efficacy in terms of maintaining positive effects. On the other hand, the immediate analysis of participants' experience perception left no doubt that both the MNBI protocol and the model that underpinned its construction fostered a less utilitarian relationship with nature, favoring a more reciprocal two-way street for mutual benefits.

5. Strengths and Limitations

The study presents some limitations. The 30-day follow-up limits the ability to understand the long-term effects of the interventions. The sample characteristics do not represent the diversity of populations that may be substantially different in the global and even in the Global South or Brazilian scenarios. Black and other racial groups, as well as non-binary genders, were underrepresented in the volunteer group studied. Therefore, these findings may not be generalizable to other regions or populations with different cultural, socioeconomic, and environmental characteristics. However, this is the first robust clinical trial conducted not just in Brazil, but in the Southern Hemisphere to investigate the relationship between human exposure to different natural settings and well-being outcomes, considering its benefits to nature.

Some response bias may have occurred, as outcomes such as well-being, happiness, and connection with nature were assessed based on participants' self-perception, and with individuals who were already in natural areas or chose to go there for the study. Regarding the sample, participants may report what they believe is the "correct" answer or what they think the researchers expect to hear. In fact, after 30 days, the observed effects tended to decrease, not just due to a lack of exposure, but also because participants might have been more truthful in their responses when answering in their own environments and without the presence of researchers. This situation may overestimate or underestimate the actual effects of the interventions. Additional physiological measures could also be considered in future studies, as we only analyzed subjective data.

6. Conclusion

The efficacy of the interventions seems to vary depending on the environmental context, being more pronounced in *peri*-urban areas. This suggests that interventions customized for different contexts can maximize benefits for participants and deserve further exploration. Future studies should also investigate strategies to prolong the benefits of these interventions. Moreover, the impact of prolonged engagement in pro-environmental behaviors and the role of knowledge, learning, and contemplation as central elements for nature-based interventions should be considered.

7. Data sharing

De-identified participant data, the generated data dictionary, and the statistical code stored on the institutional REDCap platform can be shared upon request from the investigators and will be made available after approval by the investigators and the Institutional Review Board of

the Albert Einstein Teaching and Research Center.

CRediT authorship contribution statement

Eliseth Ribeiro Leão: Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Roberta Maria Savieto:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Gustavo Benvenutti Borba:** Writing – review & editing, Visualization, Methodology, Conceptualization. **Elivane da Silva Victor:** Visualization, Formal analysis, Data curation. **Sabrina Bortolossi Bomfim:** Writing – review & editing, Supervision, Resources, Investigation, Formal analysis, Data curation. **Erika Hingst-Zaher:** Writing – review & editing, Resources, Methodology, Conceptualization. **Luciano Moreira Lima:** Writing – review & editing, Investigation, Conceptualization. **Luccas Guilherme Rodrigues Longo:** Writing – review & editing, Resources, Investigation, Conceptualization. **Leticia Bernardes de Oliveira:** Writing – review & editing, Resources, Investigation. **Denise Tiemi Noguchi:** Writing – review & editing, Investigation. **Lucas Pires Garcia Oliveira:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Rafael Facure Moredo:** Writing – review & editing, Investigation. **Clarissa de Oliveira Santos:** Writing – review & editing, Investigation. **André Menini:** Writing – review & editing, Investigation. **Lital Moro Bass:** Writing – review & editing, Investigation. **Karina Pavão Patrício:** Writing – review & editing, Investigation, Conceptualization. **Giulia Catissi:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation. **João Marcos Rosa:** Writing – review & editing, Investigation. **Emerson Barão Rodrigues Soldado:** Writing – review & editing, Investigation. **Floriana Bertini:** Writing – review & editing, Investigation. **Claudia Garcia de Barros:** Writing – review & editing, Conceptualization. **Edgard Joseph Kiriyama:** Writing – review & editing, Investigation.

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: [Eliseth Ribeiro Leao reports financial support, article publishing charges, and travel were provided by Boticário Group Foundation for Nature Protection. Eliseth Ribeiro Leao reports a relationship with National Council for Scientific and Technological Development that includes: funding grants. If there are other authors, they 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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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2025.109286.

Data availability

Data will be made available on request.

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Glossary

Nature-Based Interventions: Interventions that use contact with nature to promote human health and well-being. It involves activities in natural environments such as parks, squares, or nature reserves, and can be conducted in green (forested) or blue (coastal) environments (Jimenez et al., 2021; Marini et al., 2022).

Multicomponent Nature-Based Intervention: The nature-based intervention proposed in this study, which includes components of aesthetic and emotional experience, multisensory integration, knowledge, and engagement. It involves sensory, cognitive, and behavioral activities aimed at promoting both human well-being and environmental engagement to develop and strengthen pro-environmental behaviors (Leão et al., 2023).

Forest Bathing: Also known as *"Shinrin-yoku"*, developed in Japan in the mid-1980 s, it is a practice that combines relaxation therapy and connection with nature, promoting immersion and engagement in the forest atmosphere through the senses, thus providing mental and physical well-being (Kotera et al., 2020).

Well-being: The overall state of a person's physical, mental, emotional, and social health. It encompasses multiple dimensions, including life satisfaction, emotional balance, physical health, and the quality of social relationships. Well-being is a broad concept that includes both vitality and happiness (de Souza and Hidalgo, 2012).

Vitality: The feeling of energy, enthusiasm, and physical and mental readiness to perform activities (Ryan and Frederick, 1997).

Happiness: Linked to the emotional state of satisfaction and joy, focusing on the emotional dimension and pleasure (Abdel-Khalek, 2006).

Connection with Nature: A deep emotional bond with the natural environment, aligned with a sense of belonging, identity, and appreciation of its benefits. Connection with nature is an important component for the promotion of pro-environmental behaviors (Pessoa et al., 2016).

Engagement with Nature: A more active and participatory level of involvement with the ecosystem, involving concrete actions and contributions to the conservation and protection of nature (Natural England, 2020).

Pro-environmental Behaviors: Actions aimed at protecting and preserving the environment, such as recycling, using sustainable transportation, or participating in conservation activities, for example (van Heezik and Brymer, 2018).

Planetary Health: An integrative approach that considers the interaction between natural and human systems. It involves actions that benefit both human health and the preservation of the environment (van Heezik and Brymer, 2018).

Urban Areas: Densely populated regions with developed infrastructure, such as buildings, roads, public transportation, and services like hospitals, schools, and commerce. They are characterized by economic and social activities centered around industry, commerce, and services (IBGE, 2023).

Peri-Urban Areas: Areas located in the transitional zones between urban and rural environments, often characterized by the presence of natural vegetation, agricultural activities, and lower levels of urbanization and population density (IBGE, 2023).

Rural Areas: Regions with lower population density, where activities related to the countryside, such as agriculture, livestock farming, and forestry, predominate. These areas typically have less urban infrastructure and limited access to public services compared to urban areas, in addition to large natural or cultivated spaces (IBGE, 2023).

Randomized Clinical Trial: A type of experimental study in which participants are randomly assigned to intervention or control groups to evaluate the effect of a specific intervention, ensuring methodological rigor and scientific quality (National Library of Medicine (US), 2024).