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Effects of an afforestation activity on thermal and mechanical pain mechanisms: A clinical trial

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ABSTRACT

Sensory stimulation has shown the capacity to modulate pain mechanisms. Yet, the optimal methods of sensory stimulation remain uncertain. Afforestation activities stand out as a potential stimulation method, as they allow individuals to interact with multisensory stimuli produced in green environments. Exposure to natural multisensory stimuli has been shown to induce neurobiological activations in pain-related brain areas in healthy populations. However, the possible impact of the natural multisensory stimuli on the pain mechanisms themselves is yet to be explored. This study aimed to investigate the potential effects of sensory stimulation experienced during participation in an afforestation program on thermal and mechanical pain mechanisms. A single-group, pretest-posttest clinical trial was used. Forty-seven healthy adults performed an afforestation activity for 90 minutes. Measurements included cold pain detection and tolerance thresholds via the Cold Pressor Test, wind-up and mechanical pain sensitivity through a pinprick stimulator, and pressure pain detection and tolerance thresholds utilizing pressure algometry. For both thermal and mechanical pain thresholds, pain intensity was assessed using the 101-point Numeric Rating Scale. The results showed significant reductions in the cold pain intensity at the moment of detection ($p = .046$), mechanical pain sensitivity ($p \leq .014$), and increases in the thresholds of pressure pain detection ($p = .005$) and tolerance ($p \leq .046$). Therefore, the interaction with natural multisensory stimuli could be a possible therapeutic strategy to positively modulate mechanical pain sensitivity and pressure pain thresholds.

1. Introduction

Therapeutic approaches concerning the functional recovery of the central nervous system can be classified into two main perspectives: “*top-down*” and “*bottom-up*” approaches (Pelletier et al., 2015; Tiemann et al., 2015). The term “top-down” often stands for the subject-driven psychogenic effects, while “bottom-up” refers to the stimulus-driven somatic modulations on neurobiological processes (Hauck et al., 2015). These processes are integral to pain perception, particularly in the activation of sensory receptors and transmission of nerve impulses through sensory fibers. When evaluating the impact of somatic modulations on these processes, thermal and mechanical pain thresholds serve as key indicators (Cruz-Almeida & Fillingim, 2014). The pain intensity experienced at these thresholds provides further insights into the functioning of these processes (Kelly et al., 2005). Additionally, the wind-up phenomenon holds particular significance, as an amplified wind-up response is considered to be a potential contributing factor to aberrant pain perceptions, such as those observed in chronic pain conditions (Hackett et al., 2020). Although current evidence supports the effect of top-down and bottom-up approaches in modulating pain perception, the bottom-up approach is gaining prominence as a potential therapeutic strategy due to its demonstrated ability to induce neuroplastic changes (Arendsen et al., 2020; Cardini & Longo, 2016; Gossrau et al., 2020; H. Kim et al., 2020).

Literature shows that the mechanisms of pain can be modulated using different bottom-up intervention strategies (Bi et al., 2017; Félix et al., 2017). Wrist-ankle acupuncture appears to have an analgesic effect on pressure-induced pain in pain-free adults. This positive effect was observed both in the corresponding regions of the needling point and in the secondary ones (Bi et al., 2017). Bowen therapy resulted in immediate effects on pressure pain thresholds in healthy university students. The results showed significant increases in two areas of the body after receiving this bodywork compared to a sham group (Félix et al., 2017). These are examples of how different bottom-up stimulation

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methods—invasive and non-invasive—can influence pain mechanisms in populations without pain complaints. Other stimulus-driven strategies may have the potential to positively modulate pain perception through activation of various neurobiological processes. Therefore, using bottom-up stimulation methods may contribute to a more profound understanding of how to address aberrant pain perception in patients with chronic pain conditions.

Afforestation activities serve as an environmental strategy to transform barren landscapes into thriving forest ecosystems (Food and Agriculture Organization of the United Nations, 2018). This strategy involves human-led interventions such as planting, intentional seeding, and encouraging natural seed sources within a designated timeframe. Among the possible afforestation activities, planting is the most direct form and implies the manual insertion of tree saplings into the soil. Planting is particularly effective in urban areas as it offers immediate landscape transformation, controlled growth conditions, and strategic spatial planning. The species of trees selected for planting are usually native to the area and based on their adaptability to local soil and climatic conditions. Afforestation initiatives have increased significantly worldwide, since the United Nations incorporated them into their Sustainable Development Goals (United Nations Economic & Social Council, 2017). Although primarily driven by environmental concerns, these activities may also have the potential to enhance the health of humans as they engage in them (Jones, 2021; Jones & Goodkind, 2019).

Tree planting may have particular relevance for pain modulation as a potential bottom-up approach, since these activities provide immediate sensory inputs, activating corresponding sensory receptors in humans upon exposure (Gungormus et al., 2023; Han et al., 2016; Serrat et al., 2020; Verra et al., 2012). Indirect pain mechanisms are based on a range of physiological and psychological functions, such as pro-inflammatory cytokines (Geiss et al., 2012), cortisol levels (Boakye et al., 2016), autonomic nervous activity (Hohenschurz-Schmidt et al., 2020), depression (Du et al., 2020), stress (Crettaz et al., 2013), and anxiety (Michaelides & Zis, 2019). Recent meta-analyses and systematic reviews have highlighted the potential influence of specific multisensory stimuli produced in natural environments on these indirect pain mechanisms (Antonelli et al., 2019; Gagliardi & Piccinini, 2019; Jo, Song, & Miyazaki, 2019; Nicholas et al., 2019; Soga et al., 2017). For example, nature-based activities have been found to positively affect the functioning of the HPA axis, a major physiological regulator of the stress response. A recent meta-analysis by Antonelli et al. (2019) reported significant decreases in cortisol levels after forest bathing (*shinrin-yoku*). Since stress is a factor influencing pain sensitivity (Choi et al., 2012), it is possible to hypothesize that tree planting may play a role in modulating this indirect pain mechanism. On the other hand, the reception of sensory stimuli produced in green environments has been shown to induce neurobiological activations in pain-related brain areas (Chang et al., 2008; Igarashi et al., 2015; Ikei et al., 2017; Jo, Song, Ikei, et al., 2019; Joung et al., 2015; Kim, Jeong, Kim, et al., 2010; Kim, Jeong, Kim, et al., 2010; Lee, 2017; Oh et al., 2019; Park et al., 2007; Park et al., 2016; Song et al., 2017). Given these findings, afforestation activities appear to be promising as a bottom-up approach in the context of pain modulation.

Despite these potential benefits of active engagement in afforestation activities, the current body of research remains limited. The majority of the existing literature employs cross-sectional methodologies, primarily examining the health correlations associated with the presence of green spaces or the adverse effects of deforestation on different health parameters. These investigations primarily focus on passive interactions with nature, resulting in a limited scope of nature-based investigations (Jones & Goodkind, 2019). In contrast, participating in afforestation activities offers a more dynamic and active form of engagement with nature, involving multiple bodily systems and functions (World Health Organization, 2001). This active participation may enable the self-regulation of multisensory inputs from visual, auditory, tactile, and olfactory pathways (Dunn, 1997). In light of this context, the current study aims to investigate the potential effects of active engagement in afforestation activities on thermal and mechanical pain thresholds and intensities, as well as the wind-up phenomenon. It is hypothesized that actively participating in a tree-planting program has a modulating effect on the thresholds of thermal and mechanical pain, along with their pain intensities and the wind-up phenomenon.

2. Methods

2.1. Design

The study was conducted as a single-group, pretest-posttest clinical trial with a quasi-experimental design. All data collection and exposure were executed in a 4324 m^2 area in Parque Tecnológico de la Salud (Granada, Spain) between 16 and 24 May 2022. The protocol was approved by the Ethics Committee for Provincial Research of Granada (CEI-Granada) with reference number 2744-N-21. This study was prospectively registered on ClinicalTrials.gov (reference number: NCT05364034).

2.2. Participants

A total of forty-seven healthy university students enrolled in the study. Prior to recruitment, the participants were thoroughly informed about the objectives and procedures of the study, and their written consent was obtained.

The selection process adhered to the following inclusion criteria: (i) any sex and gender; (ii) adults aged 18–65 years; and (iii) no complaints of pain in the hands, cheeks, lower back, wrists, and trapezius muscles in the previous three months, registered by a healthcare professional.

The participants were filtered based on the following exclusion criteria: (i) intake of any analgesic or psychotropic medication; (ii) severe or unstable medical conditions that may interfere with participation (e.g., cancer, airborne and direct contact diseases, asthma); (iii) severe cognitive impairment (Mini-Mental State Examination score < 17 out of 30 points) (Tombaugh & McIntyre, 1992); (iv) diagnosis of severe intellectual disability; (v) severe mental disorders in the symptomatic phase; (vi) behavioral disturbances that may interfere with their participation (e.g., anger expression); and (vii) pregnant or lactating.

2.3. Afforestation program

An afforestation activity in a single session of 90 min was implemented by all the participants. The interventions were performed at the same time of the day (Aviram et al., 2013). A health professional with 10 years of experience, two biologists (research assistants), and three gardeners supervised the individual performance of each participant throughout the intervention. The presence and incidence of adverse effects were registered throughout the whole recruitment phase by the supervising health professional (Peryer et al., 2019). These assessments were performed by observations and inquiries focused on any signs of adverse effects that might be related to the intervention. Feasibility and tolerability were assessed via rates of dropout. Safety and tolerability were assessed using discontinuation rates, treatment-emergent adverse events, and serious adverse events. Serious adverse events were defined as those that either pose a life-threatening risk, result in permanent disability, lead to severe incapacitation, necessitate an extended inpatient hospital stay, or are fatal in nature. No adverse effects or risks were expected. During the recruitment period, the average temperature was 28.7 °C, humidity was 28.6%, wind speed was 13.7 km/h, and atmospheric pressure was 938 hPa.

The intervention comprised tillage and transplantation activities—-from pot to ground—at several locations in the campus green space. A therapist guided the participants and directed their attention to the multisensory features of the plants and surrounding environment, considering the preestablished parameters of horticultural therapy (Im et al., 2018). Each participant planted three trees (3.33 ± 1.08) for a total of 141 plants. Every participant dug a hole in the disturbed soil, ensuring it was large enough to accommodate the root ball. To avoid physical exhaustion, the participants were permitted to have rest periods during the intervention. Plants native to this Mediterranean region were selected because they thrive well and withstand higher temperatures and longer periods of drought, including the following species: gall oaks (*Quercus faginea*), wild cherry trees (*Prunus avium*), carob trees (*Ceratonia siliqua*), dog rose (*Rosa canina*), and holm oaks (*Quercus ilex*). The arrangement of the trees was different depending on the characteristics of each area. On some slopes, shrubs were planted according to the quincunx system, about 2 m apart. The rest were planted in rows along the existing linden trees (*Tilia* × *europaea*) and fences of the campus, about 6 m apart from each other. Irrigation was performed by either drip irrigation or sprinkler systems.

2.4. Evaluation system

Sociodemographic, anthropometric, and clinical data were collected from each study participant to provide a comprehensive description of the sample. An evaluation protocol of pain based on the consensus of the International Association for the Study of Pain was followed (Rolke, Magerl, et al., 2006). Primary outcomes were cold pain detection threshold, cold pain tolerance threshold, cold pain intensities, wind-up ratio, mechanical pain sensitivity, pressure pain detection threshold, pressure pain tolerance threshold, and pressure pain intensities. An assessment protocol was implemented just before and after the afforestation activity, following a chronological order from least to most painful measurement (Table 1) (Avellanal et al., 2020). Room temperature and humidity were not measured, as they have been shown to not affect thermal (Koenig et al., 2014) and mechanical (Strigo et al., 2000) pain mechanisms in healthy populations.

The evaluator had prior experience in quantitative sensory testing. One-min resting periods were given between each pain mechanism evaluation. Although some evaluations are performed manually, an utmost effort was made to standardize the duration and intervals between stimuli.

Table 1
Chronological order of the measurement procedure.

Measurement		Application Site
1.	Cold pain detection threshold	Non-dominant hand
2.	Cold pain detection intensity	Non-dominant hand
3.	Cold pain tolerance threshold	Non-dominant hand
4.	Cold pain tolerance intensity	Non-dominant hand
5.	Wind-up ratio	L2–L5 paraspinal muscles on the non-dominant side
6.	Mechanical pain sensitivity	Cheek on the dominant side
7.	Mechanical pain sensitivity	Cheek on the non-dominant side
8.	Pressure pain detection threshold	Tibialis anterior on the dominant side
9.	Pressure pain detection threshold	Mid-dorsal aspect of the wrist on the dominant side
10.	Pressure pain intensity (294 kPa)	Nail of the dominant thumb
11.	Pressure pain intensity (490 kPa)	Nail of the dominant thumb
12.	Pressure pain tolerance threshold	Midpoint of the upper border of the trapezius on the non-dominant side
13.	Pressure pain tolerance threshold	Nail cuticle of the ring finger on the non-dominant side

2.4.1. Cold pain detection threshold

The Cold Pressor Test was used with the ascending method of limits, which is defined as the first report of the pain evoked by the gradually intensifying experimental stimulus (Mitchell et al., 2004). A 15-L plastic container filled with ice water was prepared to evoke tonic cold pain in the non-dominant hand (Pud et al., 2009). A separating mesh kept the ice away from the hand. The water temperature was maintained at 3 ± 1 °C and continuously controlled with a digital thermometer. Heat formations around the hand were prevented by utilizing a circulator pump. Before starting, the participants held their corresponding hands up to the wrist in a 32 ± 1 °C tepid water bath for 3 min to standardize the baseline temperature. Then, they were instructed to submerge their hand in the cold water without touching the surfaces of the container. The participants were asked to report the initial feeling of pain without withdrawing their hand. The elapsed time in seconds was defined as the cold pain detection threshold. The cut-off time was determined to be 4 min, as numbness has been reported to occur thereafter (Dufton et al., 2008). If no pain was reported, the cut-off value was registered. This test is a valid method with good test-retest reliability (ICC = .79) (Koenig et al., 2014). A longer pain detection time indicates a higher cold pain detection threshold.

2.4.2. Cold pain tolerance threshold

As part of the Cold Pressor Test, the participants were asked to keep their hand immersed under the ice water for as long as they could endure. Once the cold pain became unbearable, the participants took their hands from the ice water. Then, the elapsed time in seconds was registered as the cold pain tolerance threshold. If the hand was not withdrawn, the cut-off value was again set at 4 min. In both parts of the test, the participants were not informed about the time limit to prevent procedural misconceptions and minimize the potential risk of "competition" regarding immersion time. This method shows excellent test-retest reliability (ICC = .92) (Koenig et al., 2014). A longer period between the immersion and removal of the hand indicates a higher cold pain tolerance threshold.

2.4.3. Cold pain intensity

Upon reaching the detection and tolerance thresholds, the participants were asked to rate perceived pain intensity on the 101-point Numeric Rating Scale. The limits of zero and 100 on the scale represented "*no pain*" and "*the worst pain imaginable*," respectively. A lower rating indicates lower cold pain sensitivity (Kelly et al., 2005).

2.4.4. Wind-up ratio

The wind-up phenomenon is a central modulation mechanism of nociceptive signals. This frequency-dependent increase in excitability of dorsal horn neurons after induction of uniform noxious stimuli is considered to cause a perceptual manifestation of the temporal summation of pain in humans (Herrero, 2000). A mechanical psychophysical test was performed by utilizing a pinprick mechanical stimulator (256 mN). A single stimulus was applied to the L2–L5 paraspinal muscles on the non-dominant side, and the participants were asked to rate perceived pain intensity on the 101-point Numeric Rating Scale. After 10 seconds, a series of 10 stimuli were applied to the same area with an average cadence of two stimuli per second (Herrero, 2000). Then, the participants were asked to rate the overall intensity of pain evoked by the stimuli series. The pain rating of the stimuli series was divided by that of the single punctuation and defined as the wind-up ratio. This method shows moderate test-retest reliability (ICC = .52) (Nothnagel et al., 2017). A lower value in the wind-up ratio is interpreted as a reduction in facilitatory modulation of ascending noxious stimuli, resulting in a less summation effect of pain perception (Mackey et al., 2017).

2.4.5. Mechanical pain sensitivity

Mechanical pain sensitivity of superficial soft tissue was assessed in the facial region by using the same pinprick stimulator as for the wind-up ratio (Rolke, Magerl, et al., 2006). A 2-s pinprick stimulus was applied three times to each cheek, with an interstimulus interval of 10 seconds. Following each stimulus, the participants were asked to rate perceived pain intensity on the 101-point Numeric Rating Scale. The mean value of the three measurements was defined as the index of mechanical pain sensitivity. This method shows excellent test-retest reliability (r = .90) (Geber et al., 2011). A lower score indicates lower mechanical pain sensitivity.

2.4.6. Pressure pain detection threshold

The pressure pain detection threshold is defined as the least amount of pressure force that induces pain (Walk et al., 2009). To measure it in deep soft tissue, a hand-held dial pressure algometer (0.5 cm^2 circular flat probe; Baseline Push Pull Force Gauge Model 12-0304; Fabrication Enterprises Inc., USA) was utilized. Pressure algometry is a valid tool commonly used with the method of limits (Fischer, 1987). Application sites were the muscle belly of the tibialis anterior and the mid-dorsal aspect of the wrist joint line on the dominant side of the body, in sequence. These areas were selected to cover both muscle and connective tissues. The evaluator placed the rubber tip of the algometer perpendicularly to the skin and gradually increased the pressure at 50 kPa/s (Rolke, Baron, et al., 2006). The patients were asked to report initial pain sensation; whereupon the evaluator stopped and recorded the value in kg. For safety reasons, the maximum force applied was limited to 1000 kPa. A total of three consecutive measurements were obtained at a single site before proceeding to the other. Data from the first measurements were excluded because they have been shown to reduce reliability (Lacourt et al., 2012). The average of the second and third measurements was defined as the pressure pain detection threshold. This method shows excellent reliability in the tibialis anterior (intra-rater ICC = .94; test-retest ICC = .79) (Walton et al., 2011) and dorsal aspect of the wrist (intra-rater ICC = .90; test-retest ICC = .93) (Mailloux et al., 2021; Waller et al., 2015). A higher value indicates a higher pressure pain detection threshold.

2.4.7. Pressure pain intensities

Two separate moderate-intensity pressure stimuli (pre-established in human pain research; 294 and 490 kPa) were applied to the nail of the dominant thumb (Lacourt et al., 2012). Upon reaching the target levels, the pressure was maintained for 2 s. Then, participants were asked to rate the evoked pain sensation on the 101-point Numeric Rating Scale. Those who were unable to tolerate the pressure before reaching these levels were excluded from the analysis and managed as missing data. This procedure was repeated three times. The average of the second and third measurements was defined as the pressure pain intensity. A lower rating score indicates lower pressure pain sensitivity.

2.4.8. Pressure pain tolerance threshold

The pressure pain tolerance threshold is defined as the maximum pressure at which an individual considers ongoing pressure pain to be unbearable. A procedure similar to the detection thresholds was adopted and applied to the midpoint of the upper border of the trapezius muscle and the nail cuticle of the ring finger on the non-dominant side (Tham et al., 2016). These body sites were selected to cover one of the most common pain regions and a less likely one. The average of the second and third measurements was defined as the pressure pain tolerance threshold. A higher value indicates a higher pressure pain tolerance threshold.

2.5. Sample size

The sample size was calculated a priori using G*Power 3.1.9.7 software. For each primary outcome, recruiting 44 participants would give 90% power to adequately detect a pre-post difference of 0.5 in effect size using a paired t-test with a two-sided type I error rate of 0.05. Assuming a possible 5% missing data, a total of 47 participants needs to be recruited.

2.6. Statistical methods

Statistical analyses were performed in SPSS v26.0 for Windows (SPSS Inc., Chicago, IL, USA). To provide an overview of the data, descriptive analyses were conducted, with continuous variables reported as mean ± standard deviation and categorical variables as absolute counts and percentages. A within-group comparison was performed using a paired Student t-test. Effect sizes were estimated by Cohen's d_z, categorized as "small" (≥ 0.2), "medium" (≥ 0.5), and "large" (≥ 0.8) (Lakens, 2013). A p-value below .05 was considered a significant difference.

3. Results

3.1. Sociodemographic, anthropometric, and clinical data

Forty-seven adults met all the eligibility criteria. The participants' ages ranged from 25 to 65 years, with an average of 21.00 years (SD = 3.54). The sex distribution of the sample was predominantly female, with 40 individuals accounting for 85.1% of the sample. No adverse effects were reported. The sociodemographic, anthropometric, and clinical characteristics of the study sample are shown in Table 2.

3.2. Effect of tree planting on cold pain thresholds and intensities

The cold pain detection and tolerance thresholds showed no significant differences (p = .116 and p = .941, respectively). The cold pain detection intensity was significantly reduced (t = 2.049, p = .046), with

Table 2
The sociodemographic, anthropometric, and clinical characteristics of the study sample (N = 47).

Characteristic	$M \pm SD$ or n (%)
Handedness, right	41 (87.2)
Height, cm	164.45 ± 7.28
Weight, kg	60.27 ± 10.28
Body mass index, kg/m^2	22.25 ± 3.29
Underweight	2 (4.3)
Normal weight	37 (78.7)
Overweight	7 (14.9)
Obese	1 (2.1)
Marital status	
Single	46 (97.9)
Married	0 (0)
Divorced	0 (0)
Widowed	0 (0)
Employment status	
Employed	11 (23.4)
Unemployed	36 (76.6)
Economic status	
Independent	2 (4.3)
Dependent	45 (95.7)
Self-perceived health	
Excellent	11 (23.4)
Very good	14 (29.8)
Good	15 (31.9)
Fair	5 (10.6)
Menstrual cycle	
Menstruation	10 (21.3)
Follicular phase	9 (19.1)
Ovulation	6 (12.8)
Luteal phase	15 (31.9)
Hours of sleep per night	6.88 ± 1.06
Time spent walking, hours per week	11.27 ± 11.96
Time spent exercising, hours per week	3.15 ± 2.92
Number of smokers	10 (21.3)
Average units per day	3.70 ± 2.62
Number of caffeine consumers on the intervention day	11 (23.4)
Medication users	12 (25.5)

a small effect size ($d_z = 0.274$). However, the tolerance intensity showed no significant changes ($p = .195$). The pre- and post-intervention values for cold pain thresholds and intensities are shown in Table 3.

3.3. Effect of tree planting on mechanical pain sensitivity

There were significant reductions in the mechanical pain intensities (dominant side $t = 3.128$, $p = .003$; non-dominant side $t = 2.551$, $p = .014$). The corresponding effect sizes were moderate for both the dominant side ($d_z = 0.628$) and the non-dominant side ($d_z = 0.668$). The pre- and post-intervention values for mechanical pain sensitivity are given in Table 3.

3.4. Effect of tree planting on pressure pain thresholds and intensities

The pressure detection thresholds exhibited a significant increase in the wrist ($t = -3.043$, $p = .005$), but not in the tibialis anterior ($p = .190$). The effect size of this increase was large ($d_z = 1.031$). The pressure tolerance thresholds increased significantly in the trapezius ($t = -4.079$, $p < .001$) and the nail cuticle of the ring finger ($t = -2.084$, $p = .046$). The effect sizes were moderate for the trapezius ($d_z = 0.570$) and small for the nail cuticle of the ring finger ($d_z = 0.311$). The pain intensities showed no significant differences (290 kPa $p = .500$; 490 kPa $p = .118$). Table 3 shows the pre- and post-intervention values for pressure pain thresholds and intensities.

4. Discussion

The objective of the present study was to evaluate the effects of active participation in a 90-min afforestation program on the thermal and mechanical pain mechanisms. The results showed: (i) a small reduction in the cold pain detection intensity, (ii) a medium reduction in the mechanical pain sensitivity, (iii) a large increase in the pressure pain detection thresholds, and (iv) both medium and small increases in the pressure pain tolerance thresholds. As a result, the sensory stimulation method through performing an afforestation activity achieved the expected statistical power for the mechanical pain sensitivity, as well as pressure pain detection and tolerance thresholds.

From the findings of cold pain, various interpretations can be derived. The perceived intensity is a crucial aspect of the multifaceted nature of the pain phenomenon, since thresholds alone may not necessarily represent the entire pain experience (Kelly et al., 2005). As an example, elevated thresholds might delay pain onset but do not preclude the possibility of experiencing intensified pain. The observed reduction in cold pain detection intensity after tree planting may suggest a decrease in neural activity. Specifically, external cold stimuli might have evoked fewer action potentials at high-threshold receptors, which detect thermal pain and trigger signal transmission through C-fibers. This reduction in the intensity of thermal pain, while tissue damage is still absent, could indicate positive regulation of the protective nociceptive system. This result is in line with prior neuroimaging studies reporting that nature-based sensory stimulation (Kim, Jeong, Kim, et al., 2010; Kim, Jeong, Kim, et al., 2010) may increase cerebral activity in areas where more activity relates to less cold pain perception (Shao et al., 2012). Therefore, this type of stimulation might help counteract the cold pain sensation, potentially reducing its intensity or perception. In the context of dysregulated pain mechanisms in chronic pain populations, an elevated intensity upon detecting pain can be an indicator of a symptom named hyperalgesia (Sandkühler, 2009). Thus, tree planting could be used for alleviating this painful hyperarousal symptom.

Mechanical pain thresholds showed significant improvements in both cutaneous and deep tissue after tree planting. It is possible that mechanoreceptors (mechanical pain) might be more prone to benefit from the sensory stimulation through afforestation activity than thermoreceptors (cold pain). Likewise, the A-β fibers, mainly responsible for mechanical signals, might share this predisposition to benefit more than A-δ fibers that are responsible for cold pain signal transmission. Another alternative explanation is that this afforestation activity played a regulatory role in an unpredicted “pressure hypersensitivity” in the study sample (Neziril et al., 2011). Compared to previous normative data, the current sample showed lower baseline values for the tolerance thresholds in the upper trapezius (6.34 vs. 5.44 kg) and in the nail cuticle of the ring finger (7.92 vs. 4 kg) (Tham et al., 2016). The lower thresholds observed could be due to that the present sample consisted of university students, who tend to face more potential daily stressors (Yu et al., 2022). These thresholds increased significantly post-intervention as hypothesized in this study, approaching the normative values. This hypoalgesic effect was observed to be more pronounced in the muscular region. This can be attributed to the stress-relieving effects of exposure to natural environments (Yao et al., 2021). Complaints of pain in the upper trapezius are often associated with mental distress (Luijcks et al., 2016). Likewise, muscle tissue compared to cutaneous one exhibits greater odds of glutamate release, an excitatory substance that increases under stressful conditions (Musazzi et al., 2015).

The literature on the modulation of pain perception using nature-based sensory stimulation strategies, to the authors’ knowledge, is thus far limited. Yet, the existing literature is concordant with the results of the present study. A recent investigation (Li et al., 2021) involving 24 healthy adults compared the effects of visiting a residential green space to those of viewing an image of the same area, using a control group for reference. Outcome measures included electrical pain detection and tolerance thresholds. The group that visited the green space exhibited increased detection and tolerance thresholds in response to the experimental pain stimuli, compared to both the image-viewing group and the control scenario. It can be argued that being present in the green space had a more pronounced influence on pain outcomes, given that it encompasses multiple sensory stimuli beyond the visual alone. As possible contributors to these positive results in pain modulation, the authors

Table 3
The pre- and post-intervention values for each outcome ($N = 47$).

Outcome Measure	Area		Pre $M \pm SD$	Post $M \pm SD$	t	d_z	p	95% CI
Cold pain detection threshold	Hand	D	18.87 ± 11.64	22.47 ± 20.51	−1.604	0.269	.116	[−8.11, 0.92]
Cold pain detection rating	Hand	D	45.32 ± 18.63	40.36 ± 17.50	2.049	0.274	.046*	[0.09, 9.83]
Cold pain tolerance threshold	Hand	D	53.51 ± 50.68	53.00 ± 46.13	0.074	0.026	.941	[−13.47, 14.50]
Cold pain tolerance rating	Hand	D	75.68 ± 13.47	73.48 ± 14.52	1.316	0.157	.195	[−1.17, 5.58]
Wind-up ratio	L2–L5 paraspinal muscles	N	2.33 ± 1.81	2.52 ± 2.05	−0.531	0.100	.598	[−0.88, 0.51]
Mechanical pain sensitivity	Cheek	D	11.89 ± 8.02	9.15 ± 9.83	3.128	0.628	.003**	[0.97, 4.52]
		N	13.84 ± 9.69	10.67 ± 10.89	2.551	0.668	.014*	[0.66, 5.69]
Pressure pain detection threshold	Tibialis anterior	D	5.46 ± 1.83	5.85 ± 1.75	−1.342	0.335	.190	[−0.97, 0.20]
	Wrist	D	3.91 ± 1.33	4.46 ± 1.45	−3.043	1.031	.005**	[−0.92, −0.18]
Pressure pain intensity rating (294 kPa)	Nail of thumb	D	31.24 ± 24.41	29.42 ± 23.11	0.682	0.077	.500	[−3.63, 7.28]
Pressure pain intensity rating (490 kPa)	Nail of thumb	D	62.98 ± 26.39	54.88 ± 27.97	1.616	0.298	.118	[−2.18, 18.40]
Pressure pain tolerance threshold	Trapezius	N	5.44 ± 1.67	6.51 ± 2.03	−4.079	0.570	<.001***	[−1.60, −0.53]
	Nail of ring finger	N	4.00 ± 1.19	4.35 ± 1.05	−2.084	0.311	.046*	[−0.68, −0.01]

Note. D = dominant side; N = non-dominant side. *$p < .05$, **$p < .01$, ***$p < .001$.

suggested environmental microbiota, phytoncides, and negative air ions from plants. These therapeutic aspects of green spaces on underlying mechanisms of pain modulation have also been proposed by other authors (Stanhope et al., 2020). In the context of an active interaction with green spaces as tree planting, while the physical activity inherent to this activity can lead to a state of hypoalgesia (Wewege & Jones, 2021), the study of Li et al. (2021) suggests that the sensory stimuli from the environment per se can trigger these pain-relieving effects.

The present study offers several potential theoretical and practical implications from both healthcare and environmental areas. From a theoretical perspective, the findings not only suggest that the act of planting trees itself may serve as a pain modulation strategy. This adds a new dimension to the existing literature, which has primarily focused on passive interactions with nature, such as simply being in a natural environment. The difference between the active and passive nature of the activity interaction might lead to different therapeutic outcomes. Therefore, the study suggests that there is room to diversify and expand the methods used in nature-based therapies. Moreover, regarding the pain modulation, while the exact neurobiological pathways remain to be explored, these findings provide further directions for research into how natural multisensory stimuli interact with the nervous system to modulate pain perception. On the other hand, from a practical standpoint, afforestation activities could be introduced as a complementary therapy alongside conventional treatments, potentially enhancing their efficacy in individuals with pain complaints. Given the task-oriented nature of the tree planting activity, it may foster patient engagement and adherence to therapy compared to passive counterparts. On a broader scale, public health policies could be developed in collaboration with environmental agencies, ensuring that both health and environmental benefits are maximized. Governments could launch educational campaigns highlighting the dual benefits of afforestation and leading to increased public participation.

5. Limitations

This study has several limitations to consider when interpreting the results. First, this clinical trial had an uncontrolled quasi-experimental design; therefore, it is not possible to fully attribute the results to the afforestation activity. Second, the sample was not balanced for sex, a potential determinant of pain thresholds (Bartley & Fillingim, 2013). Third, the implemented cold pain assessment protocol may exhibit some inherent limitations despite all possible contingency strategies taken in this study to avoid potential biases in its assessment. Even the smallest changes in water temperature during the Cold Pressure Test have shown to reduce the reliability of the data obtained (Birnie et al., 2016). All the possible contingency strategies conducted in the study were based on previous evidence on cold pain assessment (Mitchell et al., 2004). Fourth, the study sample showed higher baseline cold pain tolerance thresholds compared to normative data (53.51 vs. 48.1 seconds, respectively) (Tham et al., 2016). These higher baseline thresholds can decrease the probability of registering small changes after the implementation of the stimulation, since these individuals took a longer time to detect painful stimuli. This may be a possible reason why the thermal detection threshold only showed marginal variation after the stimulation. Lastly, the sequence in which the pain tests were administered might have caused an "*order effect*," which is an unintended consequence of implementing the measurements in a particular order. As an example, the evaluation of cold pain first may cause a lower baseline mechanical thresholds (Gröne et al., 2012); however, it should be noted that this study implemented an evaluation protocol based on the consensus of the International Association for the Study of Pain.

6. Future research

The present investigation delineates multiple trajectories for future research, each aimed at deepening our understanding of the therapeutic potential of afforestation activities in pain modulation. Experimental designs employing control groups and randomization could yield stronger evidence regarding the efficacy of afforestation programs. Longitudinal studies with subsequent follow-up assessments may provide insights into the potential accumulation and sustainability of the observed pain-reducing effects. To enhance the external validity of these findings, future studies may aim to diversify the sociodemographic profile of participants. This could include a sex-balanced cohort or a broader age range. Such diversification would allow determining whether the benefits of afforestation activities are equally beneficial to the general population or particularly effective for specific subgroups. Lastly, further research could also explore the specific components of afforestation activities that contribute to these outcomes. Parameters such as the duration of the activity, the type of natural setting involved, and the species and number of trees planted could be influential factors.

7. Conclusions

The hypothesis of this study was that active participation in a 90-min afforestation program would modulate the pain thresholds and intensities and wind-up ratio in a sample of healthy adults. The results support this hypothesis, demonstrating significant reductions in cold pain detection intensity and mechanical pain sensitivity, along with increases in pressure pain detection and tolerance thresholds. The present study underscores the therapeutic potential of active participation in afforestation activities, specifically in modulating pain thresholds and intensities, thereby enriching the field of nature-based therapies which has traditionally emphasized passive interactions with nature. The potential dual benefits of afforestation activities in health and environmental areas position them as a holistic strategy, aligning them with public health and global sustainability goals.

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Data availability statement

The raw data that support the findings of this study are available upon reasonable request from the corresponding author.

CRediT authorship contribution statement

Dogukan Baran Gungormus: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Laura Sánchez-Bermejo:** Investigation, Writing – review & editing. **José Manuel Pérez-Mármol:** Conceptualization, Methodology, Formal analysis, Writing – review & editing, Supervision.

Declaration of competing 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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