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Acute and Delayed Psychophysiological Responses to a Guided Forest Therapy Session: A Wearable HRV and Self-Report Study

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Abbreviations

ANS – autonomic nervous system

ART – Attention Restoration Theory

BP – blood pressure

HHP – Human Health Passport

CD-RISC-10 – Connor-Davidson Resilience Scale, 10-item version

CNS – central nervous system

ECG – electrocardiography

EEG – electroencephalography

fMRI – functional magnetic resonance imaging

fNIRS – functional near-infrared spectroscopy

HF – high-frequency component of HRV

HPA axis – hypothalamic-pituitary-adrenal axis

HR – heart rate

HRV – heart rate variability

lnRMSSD – natural logarithm of RMSSD

NBI – nature-based intervention

NN intervals – normal-to-normal interbeat intervals

PANAS – Positive and Negative Affect Schedule

PPG – photoplethysmography

RMSSD – root mean square of successive differences of NN intervals

SRT – Stress Recovery Theory

STAI-S – State-Trait Anxiety Inventory, State version

STAI-T – State-Trait Anxiety Inventory, Trait version

WHOQOL-BREF – World Health Organization Quality of Life, Brief version

Introduction

Urbanization and modern lifestyle have increasingly distanced people from regular contact with natural environments. As individuals spend more time in built, urban settings, rates of psychological stress and stress-related disorders have risen (World Health Organization, 2022). Globally, more than one billion people are currently living with mental health disorders, including anxiety and depression. Those conditions impose substantial personal, social, and economic burdens. In response to this growing mental health crisis, preventive, non-pharmacological approaches are becoming increasingly important.

One such approach is forest therapy, commonly known as forest bathing (shinrin-yoku), which involves immersive engagement with forest environments to promote sensory awareness and relaxation (Li, Takayama, Katsumata, et al., 2025). Originally introduced in Japan during the 1980s as a public health strategy, forest bathing has since become an established practice for stress management and health promotion (Park et al., 2010). The theoretical foundation of forest therapy can be described by Attention Restoration Theory (ART) and Stress Reduction Theory (SRT). ART proposes that exposure to natural environments replenishes depleted attentional resources (Kaplan & Kaplan, 1989), and Stress Reduction Theory (SRT) suggests that natural sensory stimuli - such as greenery, fresh air, and natural soundscapes - activate parasympathetic responses and reduce physiological stress *(Ulrich et al., 1991)*.

Beyond psychological restoration, the relevance of forest exposure can be understood through stress physiology. Chronic stress is associated with dysregulation of autonomic and neuroendocrine systems, impaired affect regulation, reduced physiological flexibility, and sleep disturbance (da Estrela et al., 2021; McEwen, 1993). Lower heart rate variability (HRV), particularly lower RMSSD, is often interpreted as reduced cardiac vagal modulation and lower autonomic flexibility. However, HRV is also strongly influenced by breathing, posture, physical movement, time of day, sleep quality, and signal quality, which makes careful methodological control essential (Laborde et al., 2017; Quintana & Heathers, 2014).

Recent environmental neuroscience research further supports the biological plausibility of nature-based restoration. A scoping review integrating EEG, fMRI/MRI, and fNIRS studies reported that nature exposure is associated with reduced neural signatures of stress, enhanced attentional control, and improved emotional regulation, with effects often stronger in real-world natural environments than in simulated nature settings (Baquedano et al., 2026). These findings support the value of ecological, real-world studies that combine subjective psychological measures with physiological monitoring.

Systematic reviews and meta-analyses indicate that time spent in forests or participation in forest therapy may reduce anxiety, depressive symptoms, and negative affect (Corazon et al., 2019; Siah et al., 2023; Yeon et al., 2021). Nevertheless, physiological findings are more mixed. Existing studies differ in intervention structure, duration, environmental context, control conditions, and HRV processing methods. Many also rely on short pre-post comparisons without delayed follow-up. Therefore, there remains a need for naturalistic studies that examine not only immediate psychological change, but also how physiological and psychological recovery develops over time.

Problem statement

Although there is growing research on forest therapy, its usefulness for real-world application is limited by several common research issues. Evidence shows three main limitations in the current literature. First, there is considerable variation in how forest therapy interventions are conducted, including differences in duration, level of guidance, physical activity intensity, and characteristics of the forest environment. Second, many studies rely on small sample sizes and simple pre–post designs, often without robust control or comparison groups. Third, relatively few studies include follow-up measurements beyond the immediate or same-day effects, which limits conclusions about longer-term outcomes (Corazon et al., 2019; Yeon et al., 2021).

Another important issue concerns HRV measurement. HRV is a useful marker of autonomic regulation, but it is not a direct or context-free measure of relaxation. It can be affected by movement, posture, breathing patterns, sleep stage, caffeine, alcohol, illness, and sensor quality. Because of this, researchers need to use clear, standardized methods for collecting and analyzing HRV data to ensure their findings are valid. This is especially relevant for wrist-worn PPG devices, which are practical for longitudinal field research but more vulnerable to motion and signal artifacts than laboratory ECG (Electrophysiology, 1996; Laborde et al., 2017; Quintana & Heathers, 2014; Schäfer & Vagedes, 2013).

The present study therefore focused on a realistic, field-based guided forest therapy session and combined wearable-derived physiological monitoring with self-report questionnaires. The main analysis emphasized nocturnal confirmed-sleep RMSSD as a more controlled HRV outcome, while immediate daytime physiology during the forest therapy session was treated as exploratory.

Aim, objectives, research questions, and hypotheses

The aim of this study was to evaluate acute and delayed psychophysiological recovery following forest therapy using wearable-based physiological monitoring and self-report questionnaires.

Objectives:

1. To assess changes in nocturnal wearable-derived HRV, primarily RMSSD, from the pre-session period to the acute post-session night and post-session period.
2. To assess changes in nocturnal heart rate and sleep window duration across the same periods.
3. To evaluate acute psychological change in state anxiety and affect immediately before and after the forest therapy session.
4. To evaluate delayed changes in selected questionnaire outcomes, including physical quality of life, depressive symptoms, resilience, anxiety, and affect.
5. To explore whether individual physiological changes were associated with psychological changes.

Research questions:

1. Does a guided forest therapy session produce acute improvements in state anxiety and affect?
2. Are delayed changes observed in nocturnal HRV, heart rate, sleep window duration, and questionnaire outcomes after forest therapy?
3. Do immediate session-level physiological dynamics suggest short-term autonomic modulation during forest therapy?
4. Are physiological changes associated with psychological changes at the individual level?

Hypotheses:

1. Nocturnal RMSSD would increase after forest therapy compared with the pre-session period.
2. State anxiety and negative affect would decrease after forest therapy, while positive affect would increase.
3. Some questionnaire improvements would remain visible at final assessment.
4. Larger increases in RMSSD would be associated with larger reductions in state anxiety.

1. Literature review

1.1. Forest therapy, stress recovery, and psychological outcomes

Forest therapy and forest bathing (shinrin-yoku) are typically described as immersion in forests with the intention to facilitate restoration and stress reduction through multisensory engagement and low-demand activity patterns (Li, Takayama, Katsumata, et al., 2025; Song et al., 2016). In practice, interventions vary widely: some involve guided sensory attention and breathing exercises, while others resemble walking in nature with minimal guidance. This variability contributes to heterogeneity in estimated effects and complicates the identification of active ingredients (Corazon et al., 2019; Farrow & Washburn, 2019).

Forest therapy is often discussed inside the broader umbrella of nature-based interventions (NBIs), which also include park-based walking, horticultural therapy, wilderness or adventure therapy, and virtual nature exposures used in laboratory paradigms. The existing evidence on nature-based interventions (NBIs) shows more consistent improvements in psychological outcomes than in physiological ones. Physiological findings tend to be less reliable, often due to limitations in study design, inconsistent measurement methods, and insufficient control of confounding factors (Corazon et al., 2019).

Theoretical frameworks of restoration and stress recovery

Two major theoretical frameworks have guided scientific understanding and research on how exposure to nature influences human health and well-being.

Stress Recovery Theory. Ulrich's Stress Recovery Theory suggests that safe, non-threatening natural environments can quickly improve mood and help the body return to a calmer physiological state after experiencing stress, especially compared to typical urban settings. Studies based on this theory have shown that people recover more effectively - both in terms of emotional state and physiological markers - when they are exposed to natural scenes rather than urban environments following a stressor (Ulrich et al., 1991).

Attention Restoration Theory. ART proposes that natural environments support recovery of directed attention through "soft fascination," reducing cognitive fatigue and restoring executive resources (Kaplan & Kaplan, 1989). Contemporary neurocognitive studies extend this logic by examining neural signals associated with attentional demand and restoration during and after nature experiences (Grassini et al., 2022; McDonnell & Strayer, 2024).

These frameworks are complementary in forest therapy research: stress recovery predicts changes in autonomic and endocrine stress systems, while ART motivates outcomes related to affect, executive attention, and brain activity.

Recent environmental neuroscience has begun to connect these theoretical models with specific neurobiological pathways. A recent scoping review proposed that nature exposure may engage a multilevel restorative cascade involving sensory coherence, limbic–autonomic regulation, attentional restoration, and self–affective integration. Within this model, natural environments may reduce stress-system activation while simultaneously supporting effortless attention and emotional regulation (Baquedano et al., 2026).

Psychological outcomes: anxiety, mood and depressive symptoms

Meta-analyses suggest that forest therapy can help reduce symptoms of depression and anxiety, although the size of these effects differs depending on the study design and participant group. For instance, Yeon et al. (2021) reviewed both randomized and quasi-experimental studies and found overall improvements in depression and anxiety. However, they also noted that results varied across studies and that many studies had methodological limitations that affected their quality.

Larger reviews of forest bathing research suggest that psychological benefits are some of the most consistent findings - especially immediate reductions in negative emotions like anxiety, and boosts in positive mood (Siah et al., 2023).

In a field study of a forest therapy program in middle-aged females, participants showed reductions in salivary cortisol alongside improved psychological indices (Ochiai et al., 2015). Similarly, a three-day forest therapy workshop study reported improvements in emotional state. In addition, the study found increased creativity, suggesting that forest exposure may influence higher-level cognitive and affective processes beyond immediate stress relief (Yu & Hsieh, 2020).

One major limitation in the psychological research on forest bathing is that most studies only assess short-term effects. Although some rare trials include longer follow-ups - such as a UK study that compared forest bathing with compassionate mind training over a three-month period (McEwan et al., 2021). This lack of longer-term data highlights the very gap that this study aims to address.

1.2. Autonomic mechanisms and HRV outcomes

Forest therapy is thought to increase parasympathetic activity in the autonomic nervous system, supporting a “rest and recovery” state. This effect is often shown by a slower heart rate and higher heart rate variability (HRV). This fits with how HRV is commonly understood: as an indicator of vagal (parasympathetic) control over the heart. It also aligns with broader theories in psychophysiology that link strong vagal regulation to emotional balance and better self-regulation (Electrophysiology, 1996; Laborde et al., 2017; Shaffer & Ginsberg, 2017).

Heart rate variability can be measured using both electrocardiography (ECG) and optical wearable sensors. While ECG remains the gold standard for detecting cardiac interbeat intervals, recent advances in wearable technology allow HRV estimation using photoplethysmography (PPG) sensors integrated into wrist-worn devices. Photoplethysmography is a non-invasive optical technique that detects changes in blood volume in peripheral microvascular tissue using light-emitting diodes and photodetectors. During each cardiac cycle, changes in blood flow alter how much light is absorbed or reflected by the tissue, allowing pulse waves corresponding to heartbeats to be detected (Allen, 2007). From these pulse signals, pulse-to-pulse intervals can be derived and used to estimate heart rate variability metrics. Under resting conditions, pulse rate variability derived from PPG signals has been shown to correspond closely with HRV obtained from ECG recordings (Schäfer & Vagedes, 2013). Wearable PPG devices therefore enable continuous physiological monitoring outside laboratory settings and are increasingly used in ecological studies examining physiological responses to environmental exposures (Castaneda et al., 2018).

However, reviews focusing on physiological measures report variable and sometimes inconsistent findings. These differences are often linked to methodological factors such as recording duration, artifact handling, posture, and time of day. Additional sources of variability include inconsistent control conditions (e.g., differences in noise, air pollution, crowding, and activity patterns between forest and urban environments) as well as participant self-selection (Corazon et al., 2019; Farrow & Washburn, 2019).

This study's longitudinal design, including baseline monitoring, a guided forest therapy session, and follow-up assessments, addresses a key limitation in existing research: the reliance on immediate pre–post measurements of autonomic changes. Such short-term assessments may overlook delayed effects and fail to capture how physiological recovery develops and diminishes over time.

1.3. Broader physiological and neurocognitive mechanisms

Cortisol is a widely used biomarker of HPA-axis activity and stress physiology. Antonelli et al. (2019), in a systematic review and meta-analysis, reported overall reductions in cortisol following forest bathing, while emphasizing substantial heterogeneity and the importance of methodological rigor (e.g., timing of sampling relative to circadian cycles and expectancy effects).

Additional evidence from individual experimental studies further supports these findings. For instance, Ochiai et al. (2015) found that participants who took part in a structured forest therapy program showed a significant reduction in salivary cortisol, a key stress hormone. Specifically, average cortisol concentrations decreased by approximately 13.4% after the intervention compared to baseline levels. This reduction indicates a meaningful physiological shift toward stress recovery, reflecting increased parasympathetic activity and reduced hypothalamic–pituitary–adrenal (HPA) axis activation. These hormonal changes complement findings on heart rate and blood pressure, further supporting the role of forest therapy as a stress-reducing intervention.

Cardiovascular outcomes: blood pressure most consistently supported

Among physiological outcomes, blood pressure shows relatively strong meta-analytic support. Ideno et al. (2017), in a systematic review and meta-analysis, concluded that exposure to forest environments is associated with lower systolic and diastolic blood pressure compared with non-forest environments in experimental studies.

The observed effects on heart rate variability (HRV) and sleep quality can be interpreted within well-established cardiovascular prevention frameworks. Increased HRV reflects enhanced parasympathetic (vagal) activity and autonomic balance, which are associated with reduced cardiovascular risk. At the same time, improved sleep is known to support cardiovascular regulation by lowering nighttime sympathetic activity and allowing for blood pressure recovery.

Together, these changes suggest that forest therapy may contribute to long-term blood pressure control and reduced cardiovascular strain. It is a potentially valuable tool in preventive cardiovascular health (Li et al., 2022).

Neural and cognitive markers: EEG and neurocognitive restoration

A recent scoping review synthesizing 108 neuroimaging studies reported that exposure to natural environments modulates brain activity across several neural systems. Reported changes include increases in alpha and theta oscillations, stronger connectivity in attention-related networks, and reduced activity in brain regions associated with rumination and stress (Baquedano et al., 2026). These findings suggest that nature exposure may trigger a coordinated neurobiological process linking perception, autonomic regulation, cognition, and emotional experience. Across neuroimaging modalities, nature exposure has been associated with increased alpha–theta activity, reduced activation in stress-related regions such as the amygdala and subgenual prefrontal cortex, and lower prefrontal metabolic load, suggesting a general shift toward calmer and more self-regulated brain states.

A growing body of research focuses on brain-based markers of cognitive and emotional restoration following nature exposure. For instance, randomized trials comparing walks in natural and urban environments have identified differences in frontal midline theta activity, a neural index associated with executive attention demand. These changes were accompanied by greater increases in positive affect following nature exposure (McDonnell & Strayer, 2024). In controlled laboratory settings, viewing nature scenes – such as through videos – has been linked to increased EEG alpha power, particularly over central brain regions, together with higher subjective relaxation ratings (Grassini et al., 2022). These findings suggest that even simulated nature exposure can engage neural processes associated with restorative experiences. These findings lend empirical support to mechanisms outlined in Attention Restoration Theory (ART), reinforcing the idea that nature exposure influences not only affective states but also neurocognitive regulation.

However, many neural studies rely on brief exposures and artificial laboratory conditions, limiting their ecological validity when applied to real-world forest therapy. In contrast, wearable-based longitudinal designs offer a valuable complement by enabling naturalistic monitoring of brain–body dynamics over time. This approach focuses on tracking recovery patterns in real-life settings rather than isolated neural responses, making the findings more relevant for practical use. Importantly, these findings are consistent with evidence that natural environments influence autonomic nervous system regulation, including changes in heart rate variability. Recent synthesis work also indicates that real-world natural environments, with their multisensory complexity and unpredictability, tend to produce stronger and more persistent restorative effects than artificial or simulated nature exposure. In addition, individual differences may moderate these responses. For example, trait nature connectedness has been identified as a potential factor influencing restorative outcomes, with individuals who feel more psychologically connected to nature often showing stronger neural and subjective responses during nature exposure (Baquedano et al., 2026).

1.4. Methodological limitations and research gap

Across both systematic reviews and individual studies, several common methodological issues tend to repeat:

1. **Poor consistency in control conditions:** Studies often use urban settings as comparison environments, but these differ from forest environments in many ways- not just in the presence of nature. Factors like air pollution, noise, temperature, crowding, and even how safe or comfortable people feel can all vary. This makes it difficult to determine whether observed benefits are due to nature itself or to other environmental factors (Corazon et al., 2019; Mavros et al., 2022).
2. **Inconsistent intervention formats:** There is a wide range in how forest therapy is delivered - from short walks to full weekend retreats. Some include guided mindfulness or breathing exercises, while others do not. Because of this variation, it’s hard to tell whether the benefits come mainly from being in nature, from the mindfulness activities, or from a combination of both (Farrow & Washburn, 2019).
3. **Too many outcomes without clear focus:** Many studies measure a large number of psychological and physiological outcomes without specifying in advance which are the most important. This raises the risk of reporting only the most favorable results. It’s a particular issue in HRV research, where multiple types of measures (like time-domain or frequency-

domain indices) may be reported without defining a primary marker beforehand (Laborde et al., 2017).

4. **Lack of follow-up data:** While many studies measure immediate effects after forest therapy, relatively few follow up with participants days or weeks later. This makes it hard to know whether any benefits last over time (Yeon et al., 2021).
5. **Limited multimodal and ecologically grounded designs:** Recent reviews in environmental neuroscience emphasize that many studies remain confined to short laboratory exposures and single measurement modalities. There is still a shortage of longitudinal, real-world studies that integrate neural, physiological, behavioral, and environmental data within the same individuals over time.

Research gaps motivating the present study

This thesis addressed two key gaps in the forest therapy literature:

1. **Time-course gap:** Many existing studies focus only on immediate effects, with limited use of delayed follow-up or longitudinal wearable monitoring to track how recovery unfolds over time (Yeon et al., 2021).
2. **Integration gap:** There is often a lack of within-person analysis linking physiological changes - such as heart rate variability (HRV) - with psychological outcomes like anxiety or mood. This is despite strong theoretical models suggesting that autonomic regulation and emotional recovery should move together (Electrophysiology, 1996; Laborde et al., 2017).

By combining longitudinal HRV and sleep data with validated self-report measures, this study seeks to create a clear, ecologically valid profile of recovery. It estimated both short-term and delayed effects using prespecified outcomes and standardized procedures for HRV data collection and analysis.

1.5. Rationale and Lithuanian context

Taken together, previous research suggests that forest therapy is most consistently associated with acute psychological benefits, particularly reduced negative affect, anxiety, and perceived stress. Physiological effects are plausible and supported by several studies, but they are less consistent and more sensitive to methodological decisions. HRV outcomes are especially complex because they depend not only on autonomic regulation, but also on movement, posture, breathing, sleep stage, signal quality, and participant context.

This thesis therefore used a conservative physiological strategy. Nocturnal RMSSD during confirmed sleep was treated as the main HRV outcome because it is less affected by daytime activity than free-living daytime HRV. In parallel, an immediate 5-minute session physiology was analyzed exploratorily to describe the dynamic pattern during forest therapy. This two-level strategy helped separate the main, more reliable results from the more exploratory physiological findings collected during the forest therapy session.

Additional methodological rationale for HRV in real-world forest therapy

A central challenge in forest therapy research is that the intervention is intentionally ecological and embodied, while many physiological markers require strict control to be interpreted confidently. HRV is a good example of this tension. On the one hand, HRV is attractive because it gives a non-invasive index of autonomic regulation and can be measured repeatedly with modern wearable devices. On the other hand, HRV is sensitive to posture, respiration, speech, movement, temperature, and the emotional meaning of the situation. In a laboratory, these factors can be controlled. In a forest, they are part of the intervention itself.

This creates a methodological choice. If researchers make the forest session too controlled, it may no longer resemble actual forest therapy. If they allow the session to remain naturalistic, physiological data become harder to interpret. The present thesis accepted this trade-off rather than ignoring it. For this reason, confirmed-sleep RMSSD was treated as the main HRV outcome, while immediate daytime RMSSD during the session was treated as exploratory. This distinction is important because it prevents the study from making stronger physiological claims than the data can support.

The decision to focus on RMSSD rather than multiple HRV indices also reflects good HRV reporting practice. HRV research can easily become overloaded with many correlated metrics, such as SDNN, RMSSD, HF power, LF power, LF/HF ratio, and nonlinear indices. In a small master's thesis sample, testing many HRV metrics would increase the risk of selective interpretation. RMSSD was therefore selected because it is widely used in short-term HRV research, is less complex to interpret than frequency-domain indices in uncontrolled field settings, and is closely associated with parasympathetic modulation.

At the same time, RMSSD should not be interpreted in a simple way as a direct measure of calmness. A higher RMSSD can reflect stronger vagal modulation, but it can also be influenced by breathing depth, breathing frequency, measurement context, and signal processing. In this thesis, RMSSD was therefore interpreted as an indicator of autonomic regulation and was considered alongside heart rate, wearable stress scores, and psychological outcomes, rather than treated as direct proof of relaxation on its own. This more cautious interpretation is especially important when using consumer-grade wrist-based PPG data.

Why the present study used both delayed and immediate physiological windows

Forest therapy may influence stress recovery at different time scales. Some effects may be immediate and subjective: a person may feel calmer, safer, or more connected immediately after the session. Other effects may be physiological and delayed: sleep, nocturnal heart rate, and nocturnal HRV might change later in the day or during the following night. Still other effects may require repeated exposure over weeks rather than a single session. A single measurement window cannot capture all of these possibilities.

For this reason, the thesis separated acute psychological effects, delayed nocturnal physiological effects, delayed questionnaire outcomes, and immediate session physiology. This structure made it possible to identify different layers of response. The acute questionnaire results addressed the participant's conscious experience of the session. The nocturnal RMSSD results addressed whether this experience translated into a measurable night-time autonomic change. The delayed questionnaires addressed broader changes over the study period. Finally, the exploratory 5-minute RMSSD analysis described how physiology may have shifted during the actual forest therapy process.

This layered approach is one of the most important strengths of the thesis. It avoids reducing forest therapy to a single outcome and instead treats recovery as a process. In real life, psychological relief, autonomic regulation, sleep, and self-perceived well-being may move together, but they may also diverge. Understanding this divergence is scientifically valuable because it helps clarify what forest therapy can and cannot be expected to change after one guided session.

Relevance to the Lithuanian context

Although forest bathing originated in Japan, the idea of using forests for restoration is highly relevant in Lithuania. Forests are culturally, emotionally, and ecologically important in Lithuanian society. At the same time, modern urban life, academic stress, information overload, and reduced daily contact with natural environments create a context in which structured nature-based recovery practices may be useful. Studying forest therapy in a Lithuanian peri-urban forest setting therefore adds local relevance to the international literature.

The Dvarčionių šaltinis area is not a remote wilderness location. It is a real peri-urban forest setting near Vilnius. This is important because many people do not have access to remote therapeutic forests, but they may have access to local forest patches, springs, trails, and urban-edge green spaces. If such environments can support acute psychological recovery, they may have practical value for public health and community well-being.

This local context is also important because forest areas are increasingly exposed to pressures such as urban expansion, infrastructure development, fragmentation, and intensive forestry. From a public-health perspective, forests should not be understood only as ecological or economic resources, but also as environments that may support psychological restoration and stress recovery.

Scientific evidence on the psychophysiological benefits of forest exposure can therefore strengthen the argument for protecting accessible, high-quality forest environments.

This thesis therefore has two levels of relevance. Scientifically, it contributes to the discussion about how forest therapy affects psychological and physiological markers. Practically, it asks whether a relatively accessible forest setting near a city can support stress recovery in real participants under real field conditions.

2. Materials and methods

2.1. Study design and setting

This study used a prospective, within-subject, real-life field design. Participants were monitored before and after a guided forest therapy session using wearable physiological-device data and self-report questionnaires. The design was not randomized and did not include a separate control group; therefore, the results were interpreted as within-person changes over time rather than definitive causal evidence.

The wearable monitoring period covered approximately two weeks. Participants received Garmin vívosmart 5 devices at Vilnius University Life Sciences Center between April 13 and April 17, 2026, and returned the devices on April 30, 2026. They were instructed to wear the device continuously until the end of the project, with particular emphasis on night-time sleep wear. Participants were instructed to synchronize the device with the Fitrockr Sync application every morning.

Two guided forest therapy sessions took place during the monitoring period: one on April 25, 2026, and one on April 26, 2026. For the exploratory immediate-session HRV analysis, the April 25 session window was 13:20–16:00, and the April 26 session window was 15:10–17:35.

Setting

The forest therapy sessions were conducted in a peri-urban forest area near Dvarčionių šaltinis, Plytinės g., Vilnius, Lithuania. The meeting point was near Dvarčionių šaltinis, close to Nemenčinės plentas, with coordinates approximately 54.731678° N, 25.357919° E. The site was selected because it provided access to a forest environment while remaining logistically reachable for participants.

Weather conditions were recorded as contextual information. The April 25 session was pleasant and mostly sunny, with temperatures around 12-15°C. The April 26 session was partly cloudy and windy, with some episodes of snow. These differences are important because weather can influence comfort, movement patterns, perceived restoration, and physiological responses.

2.2. Participants and participant flow

Participants were recruited within the PsySoma-UA-LT project context through study communication channels, personal networks, and public invitation. The forest therapy component involved adults who agreed to take part in the wearable monitoring and forest therapy session. The study used anonymized participant labels (dn) for data processing and analysis.

The Fitrockr user export contained 30 PsySoma user accounts. Twenty-nine accounts had a Garmin vívosmart 5 assigned. The forest therapy tracking file listed 27 participants, of whom two were marked as not having participated in the forest therapy session. Thus, 25 participants were confirmed as forest therapy participants and were included in the main forest therapy analyses. Participants dn 19, 16, 8, 23, and 3 participated on April 26; all remaining confirmed participants participated on April 25.

Table 1. Participant flow and analysis samples

Step / analysis set	N	Description
Fitrockr/PsySoma user accounts	30	Total accounts in USERDATA export
Accounts with Garmin vívosmart 5 assigned	29	One account had no listed device
Listed in forest therapy tracking file	27	Participants recorded in the forest therapy tracking sheet
Marked as no participation	2	dn 7 and dn 26
Confirmed forest therapy participants	25	Main analytic sample for forest therapy
Acute psychological analysis	25	STAI-S and PANAS pre-post
Confirmed-sleep RMSSD: acute-night comparison	24	Participants with valid paired data
Confirmed-sleep RMSSD: post-period comparison	25	Participants with valid paired data
Immediate 5-min HRV analysis	25	Post-session 1 h phase had n = 24
Delayed questionnaire analysis	18-22	N varied by questionnaire/outcome

Note. Participant labels were pseudonymized. Personal identifying information was not used in analysis tables.

Participant characteristics

Among the 25 confirmed forest therapy participants, gender information from Fitrockr indicated 20 females and 5 males. Age, height, and weight were available for 23 participants because two participants had missing demographic entries in the USERDATA. For participants with available data, mean age was 38.3 ± 13.5 years, with a range from 19 to 59 years. Mean height was 169.4 ± 9.4 cm and mean weight was 67.1 ± 11.2 kg.

Because the study was conducted in a real-world project context, detailed medical screening information was limited. Medication use, cardiac arrhythmia, acute illness, and other physiological confounders were considered potential limitations when interpreting HRV outcomes.

Table 2. Demographic characteristics of confirmed forest therapy participants

Characteristic	Value
Analytic sample	N = 25
Gender	20 female, 5 male
Age, mean ± SD	38.3 ± 13.5 years
Age range	19-59 years
Height, mean ± SD	169.4 ± 9.4 cm
Weight, mean ± SD	67.1 ± 11.2 kg

Note. Age, height, and weight were calculated only for participants with available USERDATA entries.

Inclusion and exclusion criteria

Inclusion criteria were adult age, voluntary participation in the PsySoma-UA-LT monitoring project, provision of written informed consent, willingness to wear the Garmin vívosmart 5 device during the monitoring period, willingness to complete the required questionnaires, and ability to participate in a low-intensity guided outdoor forest therapy session. Participants were instructed to wear the device continuously until the end of the project, especially during night sleep, and to synchronize data with the Fitrockr application every morning.

For the main forest therapy analyses, participants were excluded if they did not attend a forest therapy session. For each physiological or questionnaire analysis, participants were included only if the necessary paired data were available for the specific outcome and analysis window. Because the study was conducted as a naturalistic observational sub-study rather than a controlled clinical trial, detailed medical screening was limited. Therefore, possible unrecorded cardiovascular conditions, psychological conditions, medication use, acute illness, sleep disturbance, or other factors that could influence HRV were treated as methodological limitations when interpreting the results.

2.3. Forest therapy session

The forest therapy session was delivered as a guided sensory forest therapy / forest bathing session. The guide was Jurgita Šikšnienė, a certified nature and forest therapy specialist and forest bathing practice guide. According to her professional information, she completed postgraduate studies in "Gamtos ir miško terapija" at the Lithuanian University of Health Sciences in 2024.

The session format followed the principles of forest bathing and nature therapy. Participants were invited to engage slowly and consciously with the forest environment using multiple senses. The protocol included sensory invitations, optional reflection circles, and a final tea circle. The session was not a hike; movement was low intensity and the overall walking distance was limited. The general forest therapy material used in the project described recommended sessions as lasting approximately 2.5-4 hours, with a distance not exceeding 2 km.

During the forest therapy session, participants wore the Garmin vívosmart 5 device throughout the practice. The participant instruction sheet described the forest therapy activities as sensory forest therapy practice, reflection, and a tea circle. Participants were advised to wear comfortable clothing and footwear, bring water or tea, and prepare for sitting outdoors.

2.4. Physiological and questionnaire measures

Physiological data were collected using Garmin vívosmart 5 wearable devices. The devices were worn on the wrist and used photoplethysmography (PPG) to estimate heart rate and HRV-related variables. Data were exported through the Fitrockr platform. Garmin vívosmart 5 was selected because it enabled repeated field-based monitoring over multiple days with minimal burden on participants.

The main physiological outcome was nocturnal RMSSD, expressed in milliseconds. RMSSD was selected as the primary HRV metric because it is a time-domain measure closely related to short-term vagal modulation and is commonly recommended in psychophysiological HRV research. Nocturnal heart rate and sleep/window duration were analyzed as secondary physiological outcomes. Daytime immediate-session RMSSD, heart rate, and Garmin stress score were analyzed exploratorily.

Questionnaire measures

Questionnaire data were collected at multiple time points. Long-form questionnaires were completed when participants received the device and again when they returned it. PANAS and STAI-S were also used around the forest therapy session to assess acute pre-post psychological change.

State and trait anxiety were assessed using the Spielberger State–Trait Anxiety Inventory (STAI) (Spielberger et al., 1983). The Lithuanian questionnaire source used in this study included 40 items: 20 items for state anxiety and 20 items for trait anxiety, with higher scores indicating higher anxiety (Puzinavičius, 2005).

Positive and negative affect were assessed using the Positive and Negative Affect Schedule (PANAS), which measures positive affect and negative affect as separate dimensions (Watson et al., 1988). Lithuanian affect terminology was supported by previous Lithuanian validation work on PANAS-X (Petraškaitė & Grigutytė, 2022).

Quality of life was assessed using WHOQOL-BREF. The instrument includes 26 items and produces four domain scores, with higher scores indicating better quality of life. The WHOQOL-BREF scoring document specifies reverse-scored items and transformation of raw scores to a 0-100 scale. In the final delayed questionnaire analysis, the physical health domain was used because it showed the clearest thesis-relevant change and avoided overloading the Results section.

The Human Health Passport (HHP; Lithuanian version 1.2) was used as a structured self-assessment tool for collecting health-related and functional information. The original HHP method was developed at the D. F. Chebotarev Institute of Gerontology of the National Academy of Medical Sciences of Ukraine. The Lithuanian version used in this thesis was adapted from the original Ukrainian version by Dr. Zoryna Boiarska and Prof. Osvaldas Rukšėnas. The HHP includes 21 binary scored items reflecting physical, functional, sensory, cognitive, social, mobility, balance, falls, and blood-pressure-related indicators (Poliakov et al., 2022). Each item is scored as 1 when the participant meets the predefined favourable health/functioning criterion and 0 when the criterion is not met. The total score ranges from 0 to 21, with higher values indicating a more favourable health and functional profile. In the present thesis, HHP total score was analysed as a secondary delayed health-functioning outcome. Detailed HHP scoring rules are provided in Appendix C.

Psychological resilience was assessed using the 10-item Connor-Davidson Resilience Scale (CD-RISC-10), scored from 0 to 40, with higher scores indicating greater resilience (Campbell-Sills & Stein, 2007).

Depressive symptoms were assessed using the Burns depression questionnaire total score, interpreted as a non-diagnostic research indicator of depressive symptom burden (Burns, 2013).

Questionnaire schedule

- Baseline / device pickup: participants completed long-form questionnaires and PANAS on the day they received the Garmin device.
- Forest therapy session: participants completed acute pre-session and post-session affect/state questionnaires, PANAS and STAI-S, according to study instructions.
- Final / device return: participants completed long-form questionnaires and PANAS again before returning the device on April 30, 2026.

Questionnaire scoring sources are summarized in Appendix B.

2.5. Wearable data processing

Nocturnal HRV processing

The main HRV analysis used confirmed-sleep 5-minute epochs from the detailed Fitrockr health-log data. Sleep windows were defined using device-confirmed sleep information. Within those sleep windows, 5-minute RMSSD epochs were extracted, and epochs corresponding to awake periods or invalid/zero-wear data were excluded. For each valid night, RMSSD was aggregated using the median across valid 5-minute epochs to reduce the influence of outliers and unstable epochs.

For each participant, pre-session RMSSD was calculated from valid confirmed-sleep nights before the forest therapy session. Acute-night RMSSD was calculated from the night immediately after the forest therapy session. Post-period RMSSD was calculated from valid confirmed-sleep nights after the forest therapy session. The same confirmed-sleep approach was used for nocturnal heart rate and sleep window duration, with small differences in available N depending on valid data availability.

This processing strategy was chosen because confirmed-sleep nocturnal HRV is less confounded by daytime movement, posture, conversation, and activity context than daytime HRV. It also aligns with the principle that HRV analyses should be reported with clear window definition, artifact handling, and aggregation rules.

Exploratory immediate-session physiology processing

In addition to the main nocturnal HRV analysis, an exploratory immediate-session analysis was performed to examine physiological dynamics during the forest therapy session. Five-minute RMSSD epochs were extracted around the session window. For each participant, RMSSD values were normalized to that participant's own 1-hour pre-session baseline. This produced a within-person RMSSD change score at each 5-minute epoch and within each session phase.

The following phases were used: 1 hour before the session, the first hour, the second hour, the final/closing segment, and 1 hour after the session. Statistical comparisons were performed at the participant-level phase summaries rather than individual 5-minute epochs, to avoid treating repeated measurements from the same participant as independent observations. Five-minute group means were used only for visualization of temporal dynamics.

Rationale for confirmed-sleep analysis

The thesis used confirmed-sleep epochs for the primary nocturnal HRV analysis because sleep provides a more standardized physiological context than daytime activity. During the day, participants may be walking, talking, eating, using phones, or changing posture. These contextual differences can strongly influence wrist-based HRV estimates. During confirmed sleep, movement and conscious behavioral variation are reduced, although sleep stage and sensor quality still remain relevant.

The confirmed-sleep approach was also conservative. Some nights may have shown apparent sleep-like patterns in RMSSD and step count, even when not labeled as sleep by the device. However, the main thesis analysis did not depend on manually reconstructed windows. This reduces the risk of subjective window selection.

The nightly RMSSD median was selected because 5-minute wearable HRV epochs can include occasional unstable values. A median is less affected by outliers than a mean and is therefore appropriate for summarizing multiple sleep epochs. This is especially useful in small samples where one or two extreme epochs can disproportionately influence a nightly average.

Rationale for limited main outcomes

The study collected many possible outcomes, including HRV, heart rate, sleep window duration, state anxiety, trait anxiety, positive and negative affect, quality of life, depressive symptoms, and resilience. However, presenting every possible scale and subscale as an equal outcome would make the thesis difficult to interpret and increase the risk of overemphasizing isolated findings. Therefore, the Results section focuses on outcomes most directly linked to the thesis questions.

Nocturnal RMSSD was treated as the primary physiological outcome. Acute STAI-S and PANAS were treated as the primary acute psychological outcomes. Delayed questionnaire results were presented concisely in a single table, highlighting the most relevant and interpretable outcomes. Other collected variables can be retained as supplementary information or used in future analyses.

Handling of missing data

Missing data were handled at the level of each analysis. Participants were included in a paired comparison only when both required values were available. This is why sample size differs across acute-night, post-period, and delayed questionnaire analyses. This approach avoids imputation in a small exploratory thesis sample and makes the number of observations transparent for each test.

For delayed questionnaire analyses, N varied by outcome because not every participant completed both baseline and final forms for every scale. The Results tables therefore report N separately for each outcome. This is important because interpreting the delayed findings requires awareness that the questionnaire sample was smaller than the acute psychological sample.

Detailed wearable preprocessing rules, session windows, and analysis-specific missing-data rules are provided in Appendix D.

2.6. Statistical analysis

Statistical analyses were performed using JASP 0.96 and Python-based preprocessing. Paired-samples t-tests were used for within-participant comparisons when the normality assumption for paired differences was acceptable. When normality was violated, Wilcoxon signed-rank tests were reported. Normality was evaluated using the Shapiro-Wilk test. The alpha level was set at .05.

Cohen’s d was reported as the effect size for paired t-tests. For Wilcoxon signed-rank tests, matched rank biserial correlation was reported when available. For questionnaire and physiological outcomes, the primary emphasis was placed on the direction, magnitude, and consistency of effects rather than p-values alone. Immediate-session physiological analyses and psychophysiological correlations were explicitly treated as exploratory because daytime wrist-based HRV can be influenced by movement, posture, breathing, and activity context.

2.7. Ethics, consent, and data management

The present thesis was conducted as an observational student sub-study within the approved PsySoma-UA-LT project, “PsySoma-UA-LT: Integruotas psichosomatinės sveikatos vertinimo modelis visuomenės krizės sąlygomis”. The main research protocol and instruments were approved by the Vilnius University Faculty of Medicine Research Ethics Committee on 20 February 2026, No. 1.5.60 E-150000-KT-8.

Written informed consent was obtained before participation. The participant information sheet described the PsySoma-UA-LT project, voluntary participation, the right to withdraw without negative consequences, pseudonymized and confidential data handling, aggregated reporting of results, and the non-diagnostic nature of the physiological and psychological information collected.

This thesis did not introduce a new investigator-assigned intervention. Forest therapy was not prescribed, randomized, or controlled by the thesis author. Instead, participation in the guided forest therapy session was treated as a participant-selected, non-randomized activity occurring during the two-week PsySoma monitoring period. The analysis focused on selected physiological and questionnaire data before, during, and after participation. The PANAS questionnaire was used as a brief additional self-report measure of affective state; it was non-invasive, involved minimal participant burden, and posed no physical or medical risk.

Data analysis was conducted using pseudonymized participant labels. Personal identifiers such as names, e-mail addresses, and telephone numbers were used only for practical coordination and were not included in analysis tables. The working analysis files used participant labels to link wearable data, questionnaire responses, and forest therapy attendance. Results are reported only at group level, and no individual physiological or psychological profile is interpreted diagnostically.

The practical data workflow required aligning several data sources: Fitrockr USERDATA, detailed health-log exports, sleep-window information, participant tracking sheets, and REDCap questionnaire exports. Because the study was conducted in a real-world project context, the data required cleaning before analysis. Participant-facing information, consent, and instruction materials are provided in Appendix A.

3. Results

3.1. Analysis samples and wearable data

Of the 25 confirmed forest therapy participants, all were included in the acute psychological analysis. For confirmed-sleep physiological analyses, valid data availability varied slightly across comparisons. 24 participants had valid paired data for the acute-night comparison, and 25 for the post-period comparison. Delayed questionnaire analyses had smaller, more variable sample sizes because not all participants completed both the baseline and final versions of every questionnaire.

The Results section is organized according to the study's main analytical logic: nocturnal physiological outcomes, acute psychological outcomes, delayed questionnaire outcomes, exploratory immediate-session physiology, and psychophysiological correlations.

3.2. Nocturnal physiological outcomes

Table 3. Paired-samples t-test results for nocturnal RMSSD

Comparison	N	Pre, ms	Post, ms	t	df	p	d
Pre vs acute	24	45.59	44.16	0.535	23	.598	0.109
Pre vs post	25	45.59	45.75	-0.211	24	.835	-0.042

Note. RMSSD values are based on confirmed-sleep 5-minute epochs aggregated at participant level. Values are reported in milliseconds.

No statistically significant change in nocturnal RMSSD was observed after the forest therapy session. Acute-night RMSSD did not differ significantly from pre-session RMSSD, $t(23) = 0.535$, $p = .598$, Cohen's $d = 0.109$. Similarly, post-period RMSSD did not differ significantly from pre-session RMSSD, $t(24) = - 0.211$, $p = .835$, Cohen's $d = -0.042$.

Thus, the main confirmed-sleep HRV analysis did not support a detectable acute-night or delayed increase in nocturnal RMSSD after forest therapy.

Table 4. Paired-samples test results for nocturnal heart rate

Comparison	N	Pre, bpm	Post, bpm	Test	df	p	ES
Pre vs acute	24	62.49	63.60	W = 137.0	-	.726	r = -0.087
Pre vs post	25	62.49	62.35	t = 0.270	24	.789	d = 0.054

Note. Wilcoxon is reported for the acute-night comparison because normality was violated. Student paired t-test is reported for the post-period comparison because normality was acceptable. W = Wilcoxon signed-rank statistic; r = matched rank biserial correlation; d = Cohen's d.

No statistically significant changes were observed in nocturnal heart rate. Acute-night heart rate was slightly higher than pre-session heart rate, but this difference was not significant. Because the normality assumption was violated for the acute comparison, the Wilcoxon signed-rank test was used, $W = 137.0$, $p = .726$. Post-period heart rate did not differ from pre-session heart rate, $t(24) = 0.270$, $p = .789$, Cohen's $d = 0.054$.

Table 5. Paired-samples t-test results for nocturnal sleep window duration

Comparison	N	Pre, h	Post, h	t	df	p	d
Pre vs acute	24	7.46	8.61	-2.198	23	.038	-0.449
Pre vs post	25	7.46	7.49	-0.110	24	.913	-0.022

Note. Student paired t-tests are reported because normality assumptions were acceptable. Wilcoxon signed-rank tests showed W = 85.0, p = .065 for the acute-night comparison and W = 151.0, p = .771 for the post-period comparison; therefore, the acute-night increase should be interpreted cautiously.

Nocturnal sleep window duration was longer on the acute post-session night compared with the pre-session period (7.46 ± 0.72 h vs. 8.61 ± 2.18 h). This difference reached statistical significance in the paired-samples t-test, t(23) = -2.198, p = .038, Cohen's d = -0.449. However, the Wilcoxon signed-rank test showed only a non-significant trend, W = 85.0, p = .065; therefore, this result should be interpreted cautiously.

No significant difference was observed for the overall post-session period, t(24) = -0.110, p = .913, Cohen's d = -0.022. This suggests a possible acute increase in sleep/window duration after forest therapy, but no sustained post-session change.

3.3. Acute psychological outcomes

Table 6. Paired-samples test results for acute psychological outcomes

Outcome	N	Pre M ± SD	Post M ± SD	Test	p	ES
STAI-S	25	36.36 ± 11.52	27.17 ± 8.23	W = 281.5	< .001	r = 0.877
PANAS PA	25	31.03 ± 6.07	35.08 ± 7.67	t(24) = -3.352	.003	d = -0.670
PANAS NA	25	15.68 ± 7.39	12.32 ± 5.07	W = 160.5	.009	r = 0.689

Note. STAI-S = State-Trait Anxiety Inventory, State version; PANAS PA = Positive Affect; PANAS NA = Negative Affect. Wilcoxon signed-rank tests are reported for STAI-S and PANAS NA because normality was violated. The paired-samples t-test is reported for PANAS PA because normality was acceptable. W = Wilcoxon signed-rank statistic; r = matched rank biserial correlation; d = Cohen's d.

Acute psychological responses changed significantly after the forest therapy session. State anxiety decreased from 36.36 ± 11.52 before the session to 27.17 ± 8.23 after the session. Because the normality assumption was violated, the Wilcoxon signed-rank test was used and showed a significant reduction in STAI-S score, W = 281.5, p < .001, r = 0.877.

Positive affect increased from 31.03 ± 6.07 to 35.08 ± 7.67, and this change was significant in the paired-samples t-test, t(24) = -3.352, p = .003, Cohen's d = -0.670. Negative affect decreased from 15.68 ± 7.39 to 12.32 ± 5.07. Because normality was violated, the Wilcoxon signed-rank test was used, which indicated a significant reduction, W = 160.5, p = .009, r = 0.689.

Overall, these results indicate clear acute psychological improvement after forest therapy, reflected by lower state anxiety, higher positive affect, and lower negative affect.

3.4. Delayed questionnaire outcomes

Table 7. Baseline-to-final changes in selected questionnaire outcomes

Outcome	N	Baseline M ± SD	Final M ± SD	Δ	Test	p	ES
WHOQOL physical	22	74.51 ± 13.56	83.60 ± 10.38	9.09	t(21) = -4.178	< .001	d = -0.891
HHP total score	21	16.38 ± 1.77	16.10 ± 2.81	-0.29	W = 95.5	.656	r = 0.117
Burns depression	21	29.48 ± 11.54	20.19 ± 11.47	-9.29	W = 192.5	.001	r = 0.833
Resilience	21	28.10 ± 5.98	30.76 ± 5.98	2.67	W = 20.0	.013	r = -0.706
STAI-S	20	35.20 ± 9.09	32.90 ± 9.27	-2.30	t(19) = 1.384	.183	d = 0.309
STAI-T	21	41.71 ± 9.30	38.24 ± 8.37	-3.48	W = 181.0	.022	r = 0.567
PANAS PA	18	32.89 ± 6.38	33.83 ± 5.86	0.94	t(17) = -0.761	.457	d = -0.179
PANAS NA	18	14.00 ± 3.27	13.06 ± 3.80	-0.94	t(17) = 1.302	.210	d = 0.307

Note. M = mean; SD = standard deviation; ES = effect size; d = Cohen's d; r = matched rank biserial correlation. Paired-samples t-tests are reported when normality was acceptable; Wilcoxon signed-rank tests are reported when paired differences were non-normal. HHP = Human Health Passport; RT = state/reactive anxiety; OT = trait anxiety; PANAS PA = positive affect; PANAS NA = negative affect. HHP total score ranges from 0 to 21, with higher values indicating a more favourable health-functioning profile. PANAS baseline–final analyses have lower N because fewer participants completed both forms. Questionnaire scoring details are summarized in Appendices B and C.

Delayed questionnaire outcomes showed partial improvement from baseline to final assessment. WHOQOL-BREF physical health increased significantly, while Burns depression symptoms decreased significantly and resilience increased. STAI state anxiety and PANAS positive and negative affect did not show significant sustained baseline-to-final changes.

HHP total score did not change significantly from baseline to final assessment, W = 95.5, p = .656, r = .117. Mean scores were 16.38 ± 1.77 at baseline and 16.10 ± 2.81 at final assessment, indicating no detectable change in broad self-rated health/functioning during the study period.

STAI trait anxiety also decreased significantly, but this finding should be interpreted cautiously because trait anxiety is generally considered a relatively stable construct. Overall, the strongest psychological response was acute, whereas delayed questionnaire data suggest broader improvements mainly in physical well-being, depressive symptoms, and resilience rather than sustained affective change.

3.5. Exploratory immediate-session RMSSD dynamics

To explore immediate physiological responses during forest therapy, 5-minute RMSSD values were normalized to each participant's 1-hour pre-session baseline. Group-level changes were examined across the first hour, second hour, final/closing segment, and the first hour after the session. This analysis was treated as exploratory because daytime wrist-based HRV can be affected by movement, posture, breathing, conversation, and activity context.

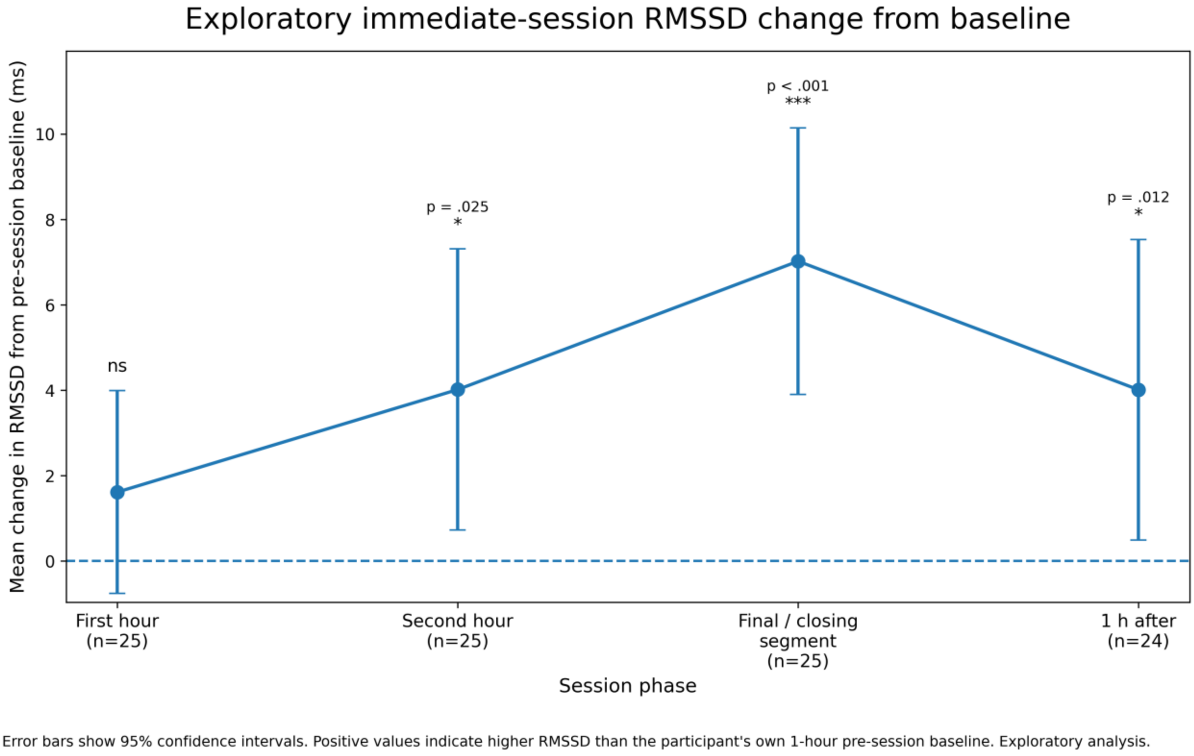

Figure 1. Exploratory immediate-session RMSSD change from pre-session baseline. Values represent participant-level mean RMSSD change relative to each participant's own 1-hour pre-session baseline. Error bars show 95% confidence intervals. Positive values indicate higher RMSSD compared with pre-session baseline. This analysis was considered exploratory because wrist PPG-derived HRV can be affected by movement, posture, breathing, and activity context.

Exploratory immediate-session analysis suggested a time-dependent increase in RMSSD during forest therapy. RMSSD change was small during the first hour, increased during the second hour, reached the highest level during the final/closing segment, and remained elevated during the first hour after the session. In parallel, heart rate and Garmin stress score decreased, especially during the final/closing segment.

These findings suggest a possible acute shift toward lower physiological arousal during and shortly after forest therapy. However, because the data were collected during daytime activity using a wrist-based wearable, the finding should be interpreted cautiously as supportive rather than confirmatory.

Table 8. Exploratory immediate-session RMSSD change from individual pre-session baseline

Phase	N	Mean RMSSD change, ms	Interpretation
First hour	25	+1.62	Small increase; not robust
Second hour	25	+4.02	Significant increase
Final/closing segment	25	+7.02	Largest increase
1 h after	24	+4.01	Elevation partly retained after session
Whole session	25	+3.81	Overall session increase

Note. Values are exploratory participant-level phase summaries normalized to each participant's own 1-hour pre-session baseline. Daytime wrist PPG-derived HRV can be influenced by movement, posture, breathing, speech, sensor contact, and activity context.

3.6. Psychophysiological correlations

Exploratory psychophysiological correlation analyses did not show robust associations between immediate RMSSD, heart-rate, or wearable stress-score changes and the magnitude of acute psychological improvement. In practical terms, participants who showed larger immediate physiological changes were not consistently the same participants who showed the largest improvements in state anxiety or affect.

This negative result should not be interpreted as evidence that psychological and physiological processes are unrelated. Instead, it suggests that within the current sample and measurement context, individual coupling between wearable-derived daytime physiology and acute self-report change was not sufficiently stable to support a strong conclusion.

3.7. Results summary

- Acute psychological improvement was clear and statistically significant.
- Nocturnal confirmed-sleep RMSSD did not show significant acute-night or delayed post-period change.
- Nocturnal heart rate did not change significantly.
- Sleep window duration showed a possible acute increase but no sustained change.
- Delayed questionnaires suggested improvement in physical quality of life, depressive symptoms, and resilience.
- Exploratory immediate-session physiology suggests a time-dependent increase in RMSSD during the session and reduced physiological arousal, but this result must be interpreted cautiously.

4. Discussion

4.1. Main findings

This thesis examined acute and delayed psychophysiological responses to a guided forest therapy session using wearable-derived physiological data and self-report questionnaires. The strongest and clearest finding was psychological: immediately after the forest therapy session, state anxiety decreased, positive affect increased, and negative affect decreased. These effects were substantial and consistent with the broader literature, which shows that forest therapy and forest bathing most reliably influence mood and perceived stress (Siah et al., 2023; Yeon et al., 2021).

In contrast, the main confirmed-sleep physiological outcome, nocturnal RMSSD, did not show significant acute-night or delayed post-period change. Nocturnal heart rate also remained stable. This means that the strongest conclusion of the study is not that forest therapy clearly changed delayed nocturnal autonomic regulation, but rather that it produced an acute psychological benefit and a more tentative immediate daytime physiological pattern during the session.

The exploratory immediate-session analysis added nuance to this interpretation. When 5-minute RMSSD values were normalized to each participant's own pre-session baseline, RMSSD increased mainly in the second hour and final/closing segment of the session, and remained somewhat elevated during the first hour after the session. Heart rate and wearable stress score decreased in parallel. This pattern is compatible with acute autonomic relaxation, but it is less methodologically controlled than nocturnal HRV and therefore should be treated as supportive results.

4.2. Psychological effects and delayed questionnaire changes

The acute psychological findings were the most robust part of the study. The decrease in STAI-S indicates that participants felt less state anxiety after the session. At the same time, PANAS results showed increases in positive affect and decreases in negative affect. Together, these changes suggest that forest therapy influenced not only one dimension of distress, but a broader emotional state: participants became less anxious, less negatively activated, and more positively engaged.

This pattern aligns well with Stress Recovery Theory, which proposes that safe natural environments can rapidly reduce stress-related emotional and physiological activation (*Ulrich et al., 1991*). It also fits Attention Restoration Theory, because a slow, low-demand forest environment may allow participants to disengage from directed attention and cognitive pressure (Kaplan & Kaplan, 1989). In other words, the session likely created a space where participants could stop performing, slow down, and reconnect with their body and surroundings. This subjective shift is exactly what many forest therapy practices are designed to facilitate.

The magnitude of acute psychological change is important because the study was conducted in a real-world setting rather than under tightly controlled laboratory conditions. Real-life interventions usually involve more noise: people arrive with different expectations, stress levels, sleep habits, physical conditions, and weather exposure. Despite this variability, acute questionnaire responses changed clearly. This suggests that guided forest therapy may have practical value as a low-intensity stress-recovery intervention.

Nocturnal HRV did not show delayed autonomic change

The absence of a significant change in nocturnal RMSSD is one of the most scientifically important results. It prevents an overclaim that forest therapy "increased HRV" in a general or sustained way. Instead, the confirmed-sleep analysis suggests that a single guided session was insufficient to produce a detectable change in nocturnal RMSSD in this sample, at least with the available wearable data and analysis windows.

There are several possible interpretations. First, the forest therapy session may have produced mainly acute psychological and daytime physiological changes rather than sustained night-time autonomic changes. Second, the dose may have been too small: one session may not be enough to modify nocturnal HRV, especially if participants returned to their usual stressors after the session. Third, wearable-derived RMSSD during sleep may be insufficiently sensitive to detect subtle changes in a small sample. Fourth, interindividual variability in sleep patterns, daily activity, caffeine, illness, and stress may have obscured small effects.

This finding should not be interpreted as a failure of the study. Non-significant physiological results are informative because they help define the limits of forest therapy effects. They also align with the broader literature, which shows that psychological outcomes are often more consistent than HRV outcomes. In this study, the main nocturnal HRV analysis did not support a delayed autonomic effect, whereas the immediate-session analysis suggested exploratory short-term physiological changes.

Delayed questionnaire improvements

The baseline-to-final questionnaire results showed a different kind of signal than the acute pre-post data. Physical health quality of life improved, depressive symptoms decreased, and resilience increased. These outcomes are broader and less momentary than PANAS affect or STAI-S state anxiety. They may reflect a combination of the forest therapy session, the wider PsySoma study context, self-monitoring, social participation, expectation, and general life changes over the two-week period.

The improvement in physical quality of life is particularly interesting because it may connect psychological restoration with bodily self-perception. Forest therapy is not only a cognitive or emotional intervention; it involves walking, breathing, sensory attention, outdoor temperature, social presence, and embodied contact with the environment. Participants may have experienced their bodies as more capable or less burdened after the session. However, without a control group, this interpretation must remain cautious.

The reduction in depressive symptoms and increase in resilience are also meaningful, but they should not be over-attributed to a single forest therapy session. Depression and resilience are influenced by many factors, and the study design cannot isolate forest therapy from expectancy, participation in a meaningful project, social connection, or repeated self-reflection through questionnaires. The observed improvement is therefore best described as delayed questionnaire improvement during the study period rather than direct proof of a sustained causal forest therapy effect.

In contrast, HHP total score remained stable from baseline to final assessment. This suggests that the broader health-functioning profile captured by the HHP did not detect measurable change over the two-week monitoring period. This is understandable because HHP is a broad screening-style instrument reflecting multiple functional and health-related domains, whereas the strongest effects in this study were observed in more state-sensitive psychological outcomes and selected well-being measures.

4.3. Immediate-session physiology

The immediate 5-minute analysis was included because it addresses an important question that the nocturnal analysis cannot answer: what happens to physiology during the actual forest therapy session? The results suggested that RMSSD did not increase strongly in the first hour, but did increase in the second hour and reached its highest value in the final/closing segment. Heart rate and Garmin stress score decreased during the same period. This temporal pattern is intuitively consistent with the structure of forest therapy: participants may need time to arrive, settle, and disengage from daily activation before a stronger relaxation response appears.

The use of baseline-normalized RMSSD was important. Raw RMSSD varies greatly between individuals; one participant may naturally have a low RMSSD and another a high RMSSD. By subtracting each participant's own pre-session baseline, the analysis focused on within-person change rather than group-level differences in absolute HRV. This makes the graph more meaningful for describing session dynamics.

Nevertheless, daytime wrist-derived HRV has clear limitations. Participants may have walked, stood, sat, spoken, changed posture, breathed differently, or had variable sensor contact. All of these can affect RMSSD independently of autonomic relaxation. For this reason, the immediate-session analysis should be described as exploratory and supportive. It suggests a possible acute autonomic relaxation pattern, but it should not replace the more conservative confirmed-sleep HRV analysis.

Psychophysiological coupling was not robust

One expectation of this thesis was that physiological improvement and psychological improvement might be coupled: for example, participants with larger RMSSD increases might also show larger decreases in state anxiety. The correlation analyses did not provide robust support for this idea. This means that, in this sample, autonomic change and subjective improvement did not clearly scale together at the individual level.

There are several possible reasons. Psychological questionnaires capture conscious experience, while HRV captures one aspect of physiological regulation. These systems are related, but not identical. A participant may feel much calmer without showing a large RMSSD increase, or may show physiological relaxation without reporting a strong psychological shift. In addition, measurement noise in daytime PPG-HRV, small sample size, and individual differences in baseline HRV may weaken correlations.

This result is important because it prevents an overly simple mind-body interpretation. The study supports the idea that forest therapy can improve subjective psychological state and may influence immediate physiology, but it does not demonstrate a strong individual-level coupling between the two in the present dataset.

Possible acute sleep window duration change

Sleep window duration increased on the acute night after forest therapy in the paired t-test, but the Wilcoxon test showed only a non-significant trend. This makes the result interesting but not definitive. A longer sleep or analysis window after forest therapy is plausible: participants may have been physically relaxed, emotionally calmer, or more tired after spending several hours outdoors. However, the variability was high and the result was not sustained across the whole post-period.

For this reason, the safest interpretation is that forest therapy may have been associated with a short-term change in sleep window duration on the night after the session, but the evidence is not strong enough to claim a stable sleep improvement. Future studies should combine wearable sleep estimates with sleep diaries and more controlled information about bedtime, wake time, naps, caffeine, alcohol, and evening activity.

4.4. Strengths, limitations, and future research

Methodological strengths

This thesis had several methodological strengths. First, it combined psychological and physiological outcomes rather than relying solely on questionnaires. Second, the main HRV analysis used confirmed-sleep 5-minute epochs, which is more controlled than uncontrolled daytime HRV. Third, the study included both acute and delayed outcomes, addressing a common limitation in forest therapy research. Fourth, the immediate-session analysis used participant-level baseline normalization, a more scientifically meaningful approach for examining dynamic physiological change.

Another strength is ecological validity. The session took place in a real forest setting with a trained guide and real participants, not in a laboratory simulation. This makes the findings relevant to actual forest therapy practice. Although this design reduced experimental control, it also allowed the study to examine forest therapy under realistic field conditions.

Limitations

- The study did not include a randomized control group. Therefore, changes cannot be attributed uniquely to forest therapy. Time, expectation, social contact, study participation, weather, and repeated self-reflection may also have contributed to the observed effects.
- The sample size was modest, especially for delayed questionnaire outcomes where N varied between outcomes. This limited statistical power and increased uncertainty around correlations.
- Wearable-derived HRV was collected using wrist-based PPG rather than ECG. Although PPG is useful for field monitoring, it is more sensitive to motion artifacts and peripheral circulation than ECG.
- Daytime immediate-session HRV was influenced by uncontrolled factors, including movement, posture, breathing, talking, and sensor contact. Therefore, immediate-session physiology was treated as an exploratory approach.
- Detailed confounder data such as caffeine, alcohol, medication use, menstrual cycle phase, illness, and daily stress were limited or not consistently available for all participants.

Practical implications and future research

The findings suggest that guided forest therapy may be a useful low-intensity practice for acute psychological stress. The clearest practical message is that even a single guided session may produce immediate reductions in anxiety and negative affect and increase positive affect. This is relevant for preventive mental health, student well-being, workplace stress recovery, and community-based health promotion.

Future research should use larger samples, randomized or matched control conditions, and clearer control of physical activity, weather, social interaction, and expectation. Repeated forest therapy sessions may be necessary to test sustained HRV or sleep effects. Future studies should also consider ECG-based validation in a subsample, continuous posture/activity tracking, ecological momentary assessment, and stronger environmental measurement such as noise, air temperature, humidity, and air quality.

For the specific question of psychophysiological coupling, future work should use analytical methods that can handle repeated measures more directly, such as mixed-effects models or time-series approaches. This would allow researchers to examine whether physiology and subjective experience converge within individuals over time, rather than relying only on broad pre-post difference scores.

4.5. Overall interpretation and contribution of the thesis

Forest therapy produced a clear acute psychological benefit. It did not produce a detectable confirmed-sleep nocturnal RMSSD change. Exploratory immediate-session physiology suggested that autonomic relaxation may have developed gradually during the session, especially in the second hour and final/closing segment. Delayed questionnaire outcomes suggested broader improvement in physical well-being, depressive symptoms, and resilience, but these findings cannot be attributed solely to forest therapy without a control group.

Taken together, these findings suggest that forest therapy may produce strong short-term psychological benefits, whereas physiological changes are more context-dependent. The study therefore provides a nuanced picture of forest therapy effects under naturalistic field conditions rather than evidence for a single uniform psychophysiological response.

Interpreting the mismatch between acute psychology and nocturnal HRV

One of the most interesting aspects of the thesis is the mismatch between strong acute psychological effects and non-significant nocturnal RMSSD changes. At first glance, this may seem disappointing. However, from a psychophysiological perspective, it is not surprising. Subjective state can change rapidly after a meaningful, calming, or socially supportive experience. Nocturnal HRV, in contrast, may reflect a broader physiological state shaped by many factors across the day and night.

A person can report feeling calmer immediately after forest therapy, yet show no measurable increase in RMSSD during sleep. This does not mean the person’s experience was not real. It means that conscious emotional recovery and night-time autonomic regulation are related but not identical systems. The nervous system may return to habitual patterns after the session, or the session may need to be repeated to affect sleep-related physiology.

The opposite is also possible in other contexts: physiology may change without strong conscious awareness. For this reason, forest therapy research should avoid assuming that subjective and physiological outcomes must always move together. The present thesis supports a more nuanced view: forest therapy can have a clear acute psychological impact while producing weaker or more context-dependent physiological effects.

Meaning of the final/closing segment response

The exploratory immediate RMSSD analysis showed the largest increase in the final/closing segment. This pattern is theoretically meaningful. Forest therapy is not simply exposure to trees. It is a structured process that often begins with arrival, orientation, slowing down, sensory invitations, reflection, and closing ritual. Participants may not enter a relaxed state immediately. The first part of the session may still involve adjustment, social awareness, and movement. A stronger response later in the session may reflect gradual settling into the practice.

The final tea and reflection circle may also have contributed to the observed pattern. Sitting still, sharing experience, drinking warm herbal tea, and completing the practice in a supportive group context could all reduce physiological arousal. This makes it difficult to separate the effect of forest exposure itself from the effect of guided ritual and social co-regulation. However, in actual forest therapy, these components are not necessarily separate; they are part of the session package.

For future studies, it would be useful to annotate the session more precisely: when participants walked, sat, stood, reflected, drank tea, or completed questionnaires. Combining HRV with event markers would allow researchers to test whether specific phases of forest therapy produce stronger physiological responses. This thesis provides a first step by showing that the response may be time-dependent rather than uniform across the session.

Role of weather and embodied experience

The two forest therapy dates differed in weather conditions. April 25 was pleasant and mostly sunny, while April 26 was windy, partly cloudy, and included episodes of snow. Weather can influence forest therapy in multiple ways. Pleasant sunlight may support comfort and positive mood, while wind and cold may increase bodily arousal or discomfort. At the same time, unusual weather such as snow may also intensify sensory awareness and make the experience more memorable.

This matters because forest therapy is embodied. Participants are not only cognitively evaluating the forest; they are feeling temperature, wind, ground texture, clothing comfort, fatigue, and safety. These factors can influence both psychological responses and wearable physiology. The current study was not designed to isolate weather effects, but acknowledging them makes the interpretation more honest and ecologically grounded.

In future work, weather should be treated not just as background information but as a measurable environmental variable. Temperature, wind, humidity, precipitation, sunlight, and perceived comfort could be collected systematically. This would help distinguish the restorative effect of forest therapy from the physiological demands of being outdoors in specific conditions.

The value and risk of wearable devices in this thesis

Wearable devices made this study possible. Without a wrist-worn device and Fitrockr export, it would have been difficult to collect repeated physiological data across two weeks in a naturalistic sample. Wearables reduce participant burden and allow data collection outside the laboratory. This is a major advantage for studies that aim to understand real-life stress recovery rather than artificial laboratory responses.

At the same time, wearable devices create interpretive risk. They can make data appear more objective than they really are. A number printed by a wearable platform is not automatically a clean physiological signal. It is the result of optical sensing, proprietary preprocessing, movement conditions, wearing behavior, and export rules. For this reason, the thesis used wearable data carefully and avoided overclaiming. The confirmed-sleep approach, participant-level aggregation, and exploratory labeling of daytime HRV were all attempts to respect these limitations.

This balance is important for future neuroscience and psychophysiology research. Wearables are likely to become increasingly common in ecological studies, but their scientific value depends on transparent preprocessing and cautious interpretation. This thesis demonstrates both the promise and the difficulty of using consumer wearable data in a master's-level field study.

Contribution of the thesis

The main contribution of this thesis is a structured psychophysiological assessment of forest therapy under real field conditions. Rather than demonstrating a single, uniform physiological effect, the study shows a more nuanced pattern: acute psychological improvement was clear, delayed nocturnal RMSSD did not change significantly, delayed questionnaire outcomes suggested partial, broader improvement, and immediate-session physiology indicated a possible exploratory pattern of autonomic relaxation.

This profile is useful because it shows both the potential and the limits of forest therapy effects. The findings support the view that forest therapy can produce short-term psychological relief, while also indicating that physiological responses are more dependent on measurement timing, context, and analytic approach. In this way, the thesis contributes a balanced and realistic account of forest therapy as a psychophysiological practice under naturalistic field conditions.

Conclusions

1. Forest therapy produced significant acute psychological improvement: state anxiety and negative affect decreased, while positive affect increased immediately after the session.
2. Nocturnal RMSSD did not change significantly on the acute night after forest therapy or during the post-session period, indicating no detectable delayed effect on nocturnal HRV in this sample. The primary HRV hypothesis was not supported.
3. Nocturnal heart rate did not change significantly after the session. Sleep window duration showed a possible acute-night increase, but this result was not robust across tests and was not sustained over the post-session period.
4. Delayed questionnaire outcomes showed selective baseline-to-final improvement, including higher physical quality of life, lower depressive symptom scores, and higher resilience, while sustained PANAS affect changes were not observed.
5. Exploratory analyses suggested a possible gradual increase in RMSSD during the forest therapy session, accompanied by lower heart rate and wearable stress score. However, physiological changes were not robustly associated with the magnitude of acute psychological improvement, and daytime wrist-based HRV findings should be interpreted cautiously.

Recommendations

1. Future forest therapy studies should include a randomized or matched control condition to separate intervention effects from time, expectation, and social participation.
2. Repeated forest therapy sessions should be tested to determine whether stronger or sustained nocturnal HRV and sleep effects emerge after a larger intervention dose.
3. Future studies should combine wearable monitoring with daily diaries on caffeine, alcohol, illness, medication, physical activity, and sleep timing.
4. Immediate-session HRV should be interpreted carefully and, where possible, supported by posture, movement, and breathing data or validated against ECG.
5. Questionnaire batteries should be kept focused to reduce participant burden and avoid excessive secondary outcomes.

VILNIAUS UNIVERSITETAS
GYVYBĖS MOKSLŲ CENTRAS

Laurynas Žemaitis
Magistro baigiamasis darbas

Miško terapijos sesijos ūminiai ir uždelsti psichofiziologiniai atsakai: HRV ir savęs vertinimo klausimynų tyrimas

SANTRAUKA

Miško terapija, arba shinrin-yoku, yra struktūruota lėto ir sąmoningo buvimo miške praktika, paremta įsitraukimu per pojūčius į natūralią aplinką. Mokslinėje literatūroje ji siejama su mažesniu psichologiniu stresu ir geresne savijauta, tačiau fiziologinių rodiklių, ypač širdies ritmo variabilumo (HRV), rezultatai išlieka nevienareikšmiai. Šiame magistro darbe buvo tiriamas ūminis ir uždelstas miško terapijos psichofiziologinis poveikis, derinant dėvimo įrenginio fiziologinius duomenis ir savęs vertinimo klausimynus.

Į pagrindines analizes įtraukti 25 suaugę dalyviai, dalyvavę vedamoje miško terapijos sesijoje Dvarčionių šaltinio miško teritorijoje Vilniuje. Fiziologiniai duomenys buvo renkami naudojant Garmin vívosmart 5 įrenginius ir eksportuojami per Fitrockr platformą. Pagrindinis naktinės HRV rodiklis buvo RMSSD, apskaičiuotas iš patvirtinto miego 5 minučių epochų. Savęs vertinimo rodikliai apėmė būsenos nerimą, teigiamą ir neigiamą afektą, gyvenimo kokybę, depresijos simptomus, psichologinį atsparumą ir Žmogaus sveikatos paso bendrą balą.

Po miško terapijos nustatytas aiškus ūminis psichologinis pagerėjimas: sumažėjo būsenos nerimas, padidėjo teigiamas afektas ir sumažėjo neigiamas afektas. Tačiau naktinis RMSSD ir naktinis širdies ritmas reikšmingai nekito nei ūminę naktį po sesijos, nei vėlesniu laikotarpiu. Uždelsti klausimynų rezultatai parodė fizinės gyvenimo kokybės, depresijos simptomų ir psichologinio atsparumo pagerėjimą, tačiau Žmogaus sveikatos paso bendras balas ir ilgalaikiai PANAS afekto rodikliai reikšmingai nepakito. Žvalgomoji fiziologinių pokyčių analizė sesijos metu parodė galimą RMSSD didėjimą kartu su širdies ritmo ir dėvimo įrenginio streso rodiklio mažėjimu, tačiau fiziologinių ir psichologinių pokyčių tarpusavio ryšys išliko neaiškus.

Apibendrinant, miško terapija šiame tyrime buvo susijusi su stipriu ūminiu psichologiniu poveikiu ir galimu momentiniu autonominės nervų sistemos atsipalaidavimo atsaku sesijos metu, tačiau uždelstų naktinio RMSSD pokyčių nenustatyta. Tyrimas rodo, kad savęs vertinimo klausimynų ir dėvimų įrenginių duomenų derinimas gali būti vertingas vertinant miško terapijos poveikį, tačiau kartu atskleidžia riešo PPG pagrindu apskaičiuotų HRV rodiklių interpretavimo ribotumus.

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Laurynas Žemaitis
Master's Thesis

Acute and Delayed Psychophysiological Responses to a Guided Forest Therapy Session: A Wearable HRV and Self-Report Study

ABSTRACT

Forest therapy, or shinrin-yoku, is a structured practice of slow and mindful presence in a forest environment through sensory engagement with nature. Previous research links it with lower psychological stress and improved well-being, but physiological findings, especially heart rate variability (HRV), remain inconsistent. This master's thesis investigated acute and delayed psychophysiological responses to a guided forest therapy session by combining wearable-derived physiological data with self-report questionnaires.

The main analyses included 25 adults who participated in a guided forest therapy session in the forest area near Dvarčionių šaltinis in Vilnius. Physiological data were collected using Garmin vívosmart 5 devices and exported through the Fitrockr platform. The primary nocturnal HRV outcome was RMSSD calculated from confirmed-sleep 5-minute epochs. Self-report outcomes included state anxiety, positive and negative affect, quality of life, depressive symptoms, resilience, and the Human Health Passport total score.

Forest therapy was associated with clear acute psychological improvement: state anxiety decreased, positive affect increased, and negative affect decreased immediately after the session. However, nocturnal RMSSD and nocturnal heart rate did not change significantly on the acute night after the session or during the later post-session period. Delayed questionnaire outcomes showed improvement in WHOQOL-BREF physical health, depressive symptoms, and resilience, while Human Health Passport total score and sustained PANAS affect did not change significantly. Exploratory analysis of physiological changes during the session suggested a possible increase in RMSSD together with reductions in heart rate and wearable stress score, but associations between physiological and psychological changes remained unclear.

Overall, forest therapy in this study was associated with a strong acute psychological response and a possible immediate autonomic relaxation response during the session, while delayed nocturnal RMSSD changes were not detected. The study suggests that combining self-report questionnaires with wearable monitoring can be valuable for evaluating forest therapy effects, but it also highlights the interpretive limitations of HRV parameters derived from wrist-based PPG.

Author’s personal contribution

I contributed to the development of the thesis idea, the practical organization of the forest therapy component, participant communication, coordination of device pickup and return logistics, and preparation of the study workflow together with the supervisor and project team. I participated in data organization, cleaning, analysis planning, result interpretation, and the preparation of the thesis text.

The wearable and questionnaire data were collected within the broader PsySoma-UA-LT project context under the supervision of Dr. Zoryna Boiarska and collaborating researchers. The forest therapy session was guided by Jurgita Šikšnienė. Statistical analyses and thesis tables were prepared from pseudonymized data. Final scientific interpretation, thesis writing, and responsibility for the submitted work remain my own.

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Appendices

Appendix A. Participant information, informed consent, and study instructions

A.1. Participant information sheet and informed consent

This appendix documents the participant information and consent materials used in the broader PsySoma-UA-LT project. The information sheet presented the study purpose, voluntary participation, right to withdraw, confidentiality, pseudonymization, aggregated reporting, minimal expected risk, and the non-diagnostic nature of the collected physiological and psychological information.

Project title. PsySoma-UA-LT: Integruotas psichosomatinės sveikatos vertinimo modelis visuomenės krizės sąlygomis.

Purpose of the document. To provide clear information about the scientific study so that participants could decide whether they wished to participate.

Study aim. To better understand associations between psychological well-being indicators and daily physiological data, and to support development of a psychosomatic health assessment model.

Participant rights. Participation was voluntary. Participants could refuse participation or withdraw later without giving a reason and without negative consequences.

Confidentiality. Collected data were handled confidentially and pseudonymized. Participant identity was not disclosed in research documents, publications, or analysis tables. Public results were reported only in aggregated form.

Risk and burden. The study was non-invasive. Questionnaire completion could evoke emotional self-reflection, but no medical or physical risk was expected.

Non-diagnostic use. Individual physiological or psychological data were not provided to participants because the study was not intended for diagnosis or individual health assessment.

Consent statement. The participant confirmed that they had received and read the study information, had the opportunity to ask questions, understood the right to withdraw, and voluntarily agreed to participate.

A.2. Participant instructions and forest therapy memo

The participant instruction memo described device use, synchronization, questionnaire completion, and additional instructions for forest therapy participants. Personal telephone numbers and direct survey links were omitted from the appendix to protect participant privacy and avoid publishing active study links.

Table A1. Summary of participant instructions

Instruction area	Instruction used in the study
Wearable monitoring	Participants were instructed to wear the Garmin vívosmart 5 device continuously until the end of the project, especially during night sleep.
Synchronization	Participants were instructed to synchronize the device with the Fitrockr Sync application every morning.
Questionnaires	Participants completed baseline long-form questionnaires and PANAS when receiving the device, acute questionnaires around the forest therapy session, and final questionnaires before device return.
Forest therapy site	Dvarčionių šaltinis, near Nemenčinės plentas, Vilnius; approximate meeting point coordinates 54.731678° N, 25.357919° E.
Session duration	Approximately 3 hours. Participants wore the Garmin vívosmart 5 device during the session.
Activities	Sensory forest therapy practice, reflection, and tea circle.
Practical preparation	Comfortable clothes and footwear, insect protection, water or tea, and a blanket or mat for sitting outdoors.

Direct personal contact details and survey links were omitted from this appendix.

Appendix B. Questionnaire scoring sources

This appendix summarizes the questionnaire materials used in the thesis and documents the scoring approach applied to each measure.

Table B1. Questionnaire outcomes used in the thesis

Measure	Construct	Main use in thesis	Score range / interpretation
STAI-S	State/reactive anxiety	Acute pre-post session analysis; also baseline-final delayed analysis	20-80; higher score = higher state anxiety
STAI-T	Trait anxiety	Baseline-final delayed analysis	20-80; higher score = higher trait anxiety
PANAS PA	Positive affect	Acute pre-post session analysis and baseline-final delayed analysis	10-50; higher score = stronger positive affect
PANAS NA	Negative affect	Acute pre-post session analysis and baseline-final delayed analysis	10-50; higher score = stronger negative affect
WHOQOL-BREF physical domain	Physical quality of life	Baseline-final delayed analysis	Transformed to 0-100; higher score = better physical quality of life
HHP total score	Broad health-functioning profile	Baseline-final delayed analysis	0-21 raw total score; higher score = more favourable health/functioning profile
Burns depression score	Depressive symptoms	Baseline-final delayed analysis	Higher score = more severe depressive symptoms
CD-RISC-10	Psychological resilience	Baseline-final delayed analysis	0-40; higher score = greater resilience

B.1. Positive and Negative Affect Schedule (PANAS)

PANAS was used as a self-report measure of positive and negative affect. The short 20-item version contains 10 positive affect descriptors and 10 negative affect descriptors. Participants rated each affective state on a 1-5 scale. In this study, PANAS was used for acute pre-post session assessment and for baseline-final delayed assessment.

Table B2. PANAS scale composition used for scoring

Scale	Items/descriptors included	Scoring
Positive affect	Susidomėjęs (-usi); Susijaudinęs (-usi); Stiprus (-i); Entuziastingas (-a); Didžiuojuosi savimi; Budrus (-i); Įkvėptas (-a); Ryžtingas (-a); Dėmesingas (-a); Aktyvus (-i)	Sum of 10 items; possible range 10-50.
Negative affect	Nusiminęs (-usi); Sutrikęs (-usi); Kaltas (-a); Išsigandęs (-usi); Piktas (-a); Dirglus (-i); Susigėdęs (-usi); Nervingas (-a); Neramus (-i); Baimingas (-a)	Sum of 10 items; possible range 10-50.

Note. The Lithuanian PANAS-X validation study supports Lithuanian positive and negative affect descriptors.

B.2. Spielberger State-Trait Anxiety Inventory (STAI)

State and trait anxiety were assessed using the Spielberger anxiety inventory source provided in Lithuanian. The questionnaire includes 40 items: 20 items for reactive/state anxiety and 20 items for trait/personal anxiety. The present thesis used STAI-S for acute pre-post session change and STAI-S/STAI-T for delayed baseline-final comparisons.

Table B3. STAI scoring rules used in the thesis

Subscale	Items	Scoring formula / interpretation
Reactive/state anxiety (RN / STAI-S)	Items 1-20	RN = Σ1 - Σ2 + 50. Σ1 includes items 3, 4, 6, 7, 9, 12, 13, 14, 17, 18; Σ2 includes items 1, 2, 5, 8, 10, 11, 15, 16, 19, 20.
Trait/personal anxiety (AN / STAI-T)	Items 21-40	AN = Σ1 - Σ2 + 35. Σ1 includes items 22, 23, 24, 25, 28, 29, 31, 32, 34, 35, 37, 38, 40; Σ2 includes items 21, 26, 27, 30, 33, 36, 39.
Interpretation	Both subscales	0-30 = low anxiety; 31-45 = moderate anxiety; >45 = high anxiety.

B.3. WHOQOL-BREF physical health domain

The WHOQOL-BREF physical health domain was used as the quality-of-life outcome in the delayed questionnaire analysis. The domain reflects subjective physical functioning, pain, dependence on medical treatment, energy, mobility, sleep, daily activity, and work capacity over the previous two weeks.

Table B4. WHOQOL-BREF physical health scoring used in the thesis

Component	Scoring rule
Physical health items	Q3, Q4, Q10, Q15, Q16, Q17, Q18.
Reverse-scored items	Q3 and Q4 are reverse-scored as 6 - Q3 and 6 - Q4.
Domain score formula	Physical health = 4 x [(6 - Q3) + (6 - Q4) + Q10 + Q15 + Q16 + Q17 + Q18] / 7.
0-100 transformation	Transformed score = (domain score - 4) x (100 / 16).
Interpretation	Higher transformed score indicates better physical quality of life.

B.4. Burns depression questionnaire

Depressive symptoms were analysed using the Burns depression questionnaire used in REDCap. The appendix records the interpretation ranges used for the total score. Because the thesis is not diagnostic, the score was interpreted only as a research indicator of depressive symptom burden.

Table B5. Burns depression score interpretation ranges

Total score	Interpretation
0-5	No depression
6-10	Within normal range, but unhappy
11-25	Mild depression
26-50	Moderate depression
51-75	Severe depression
76-100	Extreme depression

Note. Clinical interpretation in this thesis should remain cautious and non-diagnostic.

B.5. Connor-Davidson Resilience Scale, 10-item version (CD-RISC-10)

Psychological resilience was assessed using the 10-item Connor-Davidson Resilience Scale (CD-RISC-10). The CD-RISC-10 is a short self-report measure of perceived resilience and adaptation to stress. Participants rate each item on a 5-point scale from 0 to 4. The total score is calculated by summing all 10 item scores, giving a possible range from 0 to 40. Higher scores indicate greater psychological resilience.

The exact item text is not reproduced in this appendix because the CD-RISC is copyrighted and not in the public domain. The administered item wording was retained in the PsySoma-UA-LT project documentation. In this thesis, only the total CD-RISC-10 score was used for baseline-to-final delayed questionnaire analysis.

Table B6. CD-RISC-10 response scale

Response score	Meaning
0	Not true at all / visiškai netinka
1	Rarely true / retai tinka
2	Sometimes true / kartais tinka
3	Often true / dažnai tinka
4	True nearly all the time / beveik visada tinka

Appendix C. Human Health Passport questionnaire and scoring rules

The Human Health Passport (HHP) was used as a broad health-functioning profile. It includes 21 binary scored items covering physical, sensory, cognitive, social, mobility, balance, falls, and blood-pressure-related indicators. Each item is scored as 1 when the participant meets the predefined favourable criterion and 0 when the criterion is not met. In the thesis results, the raw HHP total score from 0 to 21 was used; higher values indicate a more favourable health-functioning profile.

Table C1. HHP item-level scoring rules

No.	HHP item	Scoring rule
1	Unintentional weight loss	1 = no unintentional weight loss; 0 = unintentional weight loss present.
2	Decrease in appetite	1 = no decrease in appetite; 0 = decreased appetite present.
3	Sequence task / missing numbers	1 = all predefined correct answers provided; 0 = at least one answer incorrect or incomplete.
4	Friendly communication circle	1 = five or more people; 0 = fewer than five people.
5	Daily walking distance	1 = favourable walking-distance criterion met; 0 = criterion not met.
6	Tinnitus	1 = no tinnitus; 0 = tinnitus present.
7	Hearing difficulties	1 = no hearing difficulties; 0 = hearing difficulties present.
8	Recall of three words	1 = all three words correctly recalled; 0 = fewer than three words recalled.
9	Face recognition at 6 metres	1 = recognizes faces well; 0 = difficulty recognizing faces.
10	Reading plain text without glasses	1 = can read plain text without glasses; 0 = cannot.
11	Distance vision without glasses	1 = sees well in the distance without glasses; 0 = does not.
12	Walking 500 metres without help or cane	1 = able; 0 = unable.
13	Climbing stairs to the first floor without help or cane	1 = able; 0 = unable.
14	Chair-rise test	1 = can sit down and stand up from a chair 5 times within 14 s without using hands; 0 = unable, uses hands/help, or exceeds time limit.
15	Balance test: left leg, eyes closed	1 = balance time meets the sex- and age-specific threshold; 0 = below threshold.
16	Lifting a 5 kg load	1 = able to lift 5 kg; 0 = unable.
17	Frequency of going outside	1 = favourable criterion met; 0 = criterion not met.
18	Restrictions in daily physical activity during the last 6 months	1 = no restrictions; 0 = restrictions present.
19	Falls during the last 6 months	1 = no falls; 0 = one or more falls.
20	Systolic blood pressure	1 = within age-specific normal range; 0 = outside range.
21	Diastolic blood pressure	1 = within age-specific normal range; 0 = outside range.

C.1. Selected calculated HHP item rules

Table C2. Detailed HHP thresholds for selected calculated items

Calculated item	Criterion for 1 point
Item 3: sequence task	All predefined correct answers must be provided. In the project scoring instruction, the example correct answers were 7, 2, 0, and 1.
Item 4: communication circle	Participant reports five or more people in their friendly communication circle.
Item 15: balance, sex code 2	≤39 years: ≥60 s; 40-49 years: ≥40 s; 50-59 years: ≥30 s; 60-69 years: ≥20 s; ≥70 years: ≥10 s.
Item 15: balance, sex code 1	≤39 years: ≥30 s; 40-49 years: ≥20 s; 50-59 years: ≥18 s; ≥60 years: ≥10 s.
Item 20: systolic BP	≤39 years: 115-125 mmHg; 40-59 years: 125-135 mmHg; ≥60 years: 115-125 mmHg.
Item 21: diastolic BP	≤39 years: 65-75 mmHg; ≥40 years: 75-85 mmHg.

Raw score used in thesis. The main delayed questionnaire results used the raw HHP total score with a possible range from 0 to 21.

Optional conversion. If needed for comparability, the score can be transformed as HHP converted score = HHP total score × 100 / 21. This conversion was documented in the project scoring instruction but was not used as the main thesis table value.

Appendix D. Wearable data preprocessing and analysis-sample rules

D.1. Main nocturnal HRV preprocessing

The primary physiological analysis used confirmed-sleep 5-minute RMSSD epochs from the detailed Fitrockr health-log data. Sleep windows were defined using device-confirmed sleep information. Within confirmed sleep windows, 5-minute epochs were extracted and cleaned before aggregation at participant-night level.

Table D1. Confirmed-sleep nocturnal HRV preprocessing rules

Processing step	Rule used
Data source	Detailed Fitrockr health-log export and device-confirmed sleep-window information.
Epoch duration	5-minute epochs.
Primary HRV metric	RMSSD in milliseconds.
Main analysis window	Confirmed sleep only.
Excluded epochs	Epochs overlapping with awake periods, non-wear, invalid values, zero wearing time, or clearly unusable records.
Night-level aggregation	Median RMSSD across valid 5-minute sleep epochs.
Baseline/pre-session value	Valid confirmed-sleep nights before the participant's forest therapy session.
Acute-night value	Night immediately after the forest therapy session.
Post-period value	Valid confirmed-sleep nights after the forest therapy session.
Secondary nocturnal outcomes	Nocturnal heart rate and sleep/window duration, using the same confirmed-sleep logic where possible.

D.2. Rationale for confirmed-sleep analysis

Confirmed sleep was selected for the main HRV analysis because it provides a more controlled physiological context than free-living daytime recordings. Daytime HRV may be influenced by movement, posture, conversation, food intake, phone use, stressors, and physical activity. Sleep does not eliminate all confounders because sleep stage and sensor quality remain relevant, but it reduces behavioural variability and therefore provides a more conservative HRV window for the main analysis.

The nightly median was selected because 5-minute wearable-derived HRV epochs can contain unstable or extreme values. The median is less sensitive to outliers than the mean and is therefore appropriate for summarising multiple sleep epochs in a small field-study sample.

D.3. Exploratory immediate-session physiology

The immediate-session analysis was exploratory and was designed to describe physiological dynamics during the guided forest therapy session. The analysis used 5-minute daytime epochs around the forest therapy session and normalized each participant's RMSSD values to their own 1-hour pre-session baseline.

Table D2. Immediate-session analysis phases

Phase	Definition / use
1 hour before session	Individual pre-session baseline used for normalization.
First hour	First hour of the forest therapy session.
Second hour	Second hour of the forest therapy session.
Final/closing segment	Final/closing part of the session, including closing/reflection/tea-circle context where applicable.
1 hour after session	Post-session window used to examine whether physiological change persisted after the guided session.
Whole session	Participant-level average across the whole session window.

Table D3. Session windows used for exploratory immediate-session HRV analysis

Session date	Exploratory session window
April 25, 2026	13:20-16:00
April 26, 2026	15:10-17:35

Exploratory status. Immediate-session physiology was treated as exploratory because daytime wrist PPG-derived HRV can be influenced by movement, posture, breathing, speech, sensor contact, and activity context.

Statistical unit. Formal comparisons were based on participant-level phase summaries, not on individual 5-minute epochs, to avoid pseudo-replication.

D.4. Missing data and analysis-sample rules

Because the thesis used a naturalistic field-study design, available data differed slightly across analyses. The main rule was paired complete-case analysis: participants were included in each comparison only when the required paired values were available for that outcome and time window. No imputation was applied.

Table D4. Analysis-specific inclusion and missing-data rules

Analysis set	Inclusion rule	N in thesis
Confirmed forest therapy participants	Participant attended a forest therapy session and was included in the tracking file as confirmed participant.	25
Acute psychological analysis	Valid pre-session and post-session questionnaire data for STAI-S/PANAS.	25
Confirmed-sleep RMSSD acute-night comparison	Valid pre-session confirmed-sleep value and valid acute-night confirmed-sleep value.	24
Confirmed-sleep RMSSD post-period comparison	Valid pre-session confirmed-sleep value and valid post-period confirmed-sleep value.	25
Immediate 5-minute physiology analysis	Participant had sufficient valid 5-minute data around the session window; post-session 1-hour phase had one fewer participant.	25; post-session 1 h phase n = 24
Delayed questionnaire outcomes	Valid baseline and final values for the specific questionnaire outcome.	18-22 depending on outcome

Interpretive consequence. Different sample sizes across tables reflect outcome-specific data availability rather than different conceptual study populations.

Reason for no imputation. Imputation was avoided because the sample was small, the study was exploratory, and missingness differed across wearable and questionnaire data sources.