2026 35th IEEE International Conference on
Robot and Human Interactive Communication (RO-MAN)
August 24-28, 2026. Kitakyushu, Japan

2026 IEEE 35th International Conference on Robot and Human Interactive Communication (RO-MAN) | 979-8-3195-1055-6/26/$31.00 ©2026 IEEE | DOI: 10.1109/RO-MAN72286.2026.11714763

Forest Walking with a Robot Companion: Understanding the Effects of Engagement and Authority

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***Abstract*— Nature-based activities like walking in forests with companions are known to support psychological well-being and strengthen human–nature connectedness. As robots increasingly enter outdoor contexts, it remains unclear whether robot companionship also has a similar effect. This study examined how robot authority (leader vs. follower) and engagement (active vs. passive) influence human–nature connectedness during forest walks. 38 participants walked in the forest with a mobile robot, whose nature connectedness, mindfulness, and social cognition were measured afterwards. Results show that neither robot authority nor engagement significantly affected any dimensions of nature connectedness, nor were they mediated through social-cognition or mindfulness. In contrast, awareness of bodily sensations during walking emerged as a robust predictor of nature connectedness. These findings highlight the primacy of embodied experience over robot-mediated social cues in nature and suggest that outdoor companion robots may be more effective when designed to support bodily awareness rather than social cognition or authority.**

I. INTRODUCTION

Humans are inherently connected to nature, shaped by and dependent on it for survival and well-being [1]. Nature, in general, refers to the natural world beyond built environments, including outdoor settings like forests, vegetation, and non-human living systems [2]. The biophilia hypothesis [3] denotes an innate human tendency to seek connections with nature and other living systems, a predisposition shaped through evolutionary dependence on natural environments [4]. However, contemporary perspectives in HCI and design, more specifically posthumanist and more-than-human approaches, conceptualize nature not as a passive backdrop or resource for human experience, but as a dynamic assemblage of interconnected human and non-human actors, including animals, plants, technologies, and ecological processes [5], [6]. These perspectives emphasize that humans are entangled within broader multispecies ecologies, where agency and meaning emerge through ongoing interactions rather than being exclusively human-centered [7]. Accordingly, in this work, we adopt a view of nature that encompasses these relational dimensions, recognizing forests not only as environments inhabited by humans but as complex socio-ecological systems.

Among everyday forms of nature engagement, walking is a particularly accessible activity, while walking in the forest has been shown to yield restorative and affective benefits, especially when shared with a companion [8]. While the word companion may traditionally refer to other human beings or animals, companionship in the near future, and even in the present, can also come from non-living agents, such as robots. Recent advances in mobile companion robots have opened new possibilities for diverse human-robot walking scenarios [9]. These robots, capable of moving alongside people and interacting with them in real time, might introduce novel dynamics to the human–nature relationship through companionship [10], [11]. This connection is further supported by the biophilic principle [12] whereby many robotic designs take inspiration from nature, especially how they move, perceive, and behave, blurring the boundary between humans, robots, and nature.

Companion robots in outdoor contexts have been explored, as jogging companions [13] as well as outdoor walking companions [10], which indicates that they have the potential to shape human experiences outdoors, but have not been widely expanded upon. Given the encouraging initial findings, it is timely to examine how companion robots influence walking in nature, which might provide new insights into both human–robot interaction (HRI) and our evolving relationship with nature. Theoretically, a companion robot's level of engagement with its environment and its authoritative role in an interaction might significantly influence the user's interaction experience [11]. Building on these insights, this study empirically attempts to answer the question: *How do a companion robot's varying levels of engagement and authority influence humans' nature connectedness?* Through empirical testing in a forest setting, this study offers empirical guidance for the design of outdoor human-robot interactions.

II. BACKGROUND AND HYPOTHESES

A useful parallel of companion robots can be drawn from human–animal relationships, particularly companion animals such as dogs, which are well documented as catalysts for outdoor activity and social interaction [14], [15], [16]. Dogs not only accompany humans on walks; they actively shape the experience through their behaviors, attentional shifts, and responsiveness [17], [18]. Prior research suggests that robots may evoke comparable forms of companionship [19], [20], [21], positioning them as potential mediators of nature experiences, elevating mindfulness, while encouraging awareness of sensory cues [22], [23]. Within HRI, similar mechanisms have been observed, since robot behaviors such as initiative-taking [24], contingent responsiveness [25], and

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adaptation to human cues [26] influence engagement, trust, and attentional allocation [27], [28]. In forest settings, an actively engaging robot that initiates behaviors and highlights environmental elements may shape nature experiences by orienting attention toward the present sensory environment while simultaneously activating social cognition through perceived intentionality and shared focus, leading to the following hypothesis:

H1: An actively engaging robot will facilitate higher nature connectedness compared to a passive robot.

H1a: An actively engaging robot will provide higher perceived social cognition compared to a passive robot.

H1b: An actively engaging robot will facilitate higher mindfulness compared to a passive robot.

Beyond engagement, the robot's role within the interaction may further shape the experience. A robot that assumes a leader role, guiding the route, setting the pace, or directing attention, may impose additional structure on the walk, potentially increasing focus. Such structuring may deepen immersion, particularly by reducing cognitive load associated with navigation and decision-making. Accordingly, we hypothesize:

H2: A leader robot will facilitate higher nature connectedness compared to a follower robot.

H2a: A leader robot will facilitate higher mindfulness compared to a follower robot.

III. THE EMPIRICAL STUDY

This section provides a detailed overview of the study, including the participants, procedure, data collection, and analysis.

A. Participants

A total of 40 participants took part in the study, but 38 of them completed it. Call for participants was distributed online through the university's intranet, social media, and research group website, while flyers were distributed on the university campuses. The participant sample (N=38) consisted of 21 women, 15 men, one non-binary participant, and one undisclosed response. Ages ranged from 18 to above 40, with three participants aged 18–20, 14 aged 21–25, nine aged 26–30, eight aged 31–40, and four above 40. Most participants reported frequent forest engagement, with 25 visiting forests one to two times per week, 10 visiting three to four times per week, and three visiting five times or more. None of the participants reported having any kind of mobility impairment. The study used the Spot robot from Boston Dynamics [29], a mobile robot deployed as a companion capable of autonomous navigation in outdoor environments.

B. Study Design and Procedure

We employed a mixed factorial experimental design to examine how two behavioral dimensions of a robot companion: authority and engagement, shape participants' experiences during forest walks. Robot authority (leader vs. follower) was manipulated between participants, while robot engagement (active vs. passive) was manipulated within participants. This design allowed us to examine how different authority roles influence interaction dynamics while also enabling participants to directly compare different engagement behaviors across two walking experiences.

Participants were randomly assigned to one of two authority conditions. In the leader condition, the robot assumed a guiding role during the walk. It initiated movement, determined the walking pace, and guided the route through the forest. Participants were instructed to follow the robot as it navigated the path. In the follower condition, the robot adopted a responsive role in which it adapted to the participant's movements and followed them from behind. Participants walked freely along the same route while the robot adjusted its trajectory and speed to remain behind or near the participant. Within each authority condition, participants completed two separate walking sessions corresponding to the engagement manipulation: an active condition and a passive condition. The order of engagement conditions was counterbalanced across participants to mitigate potential order effects. Each walk followed the same predefined forest route to ensure comparability across conditions.

Engagement conditions differed in how the robot interacted with the surrounding environment. In the passive condition, the robot moved continuously along the route without initiating additional interactions or environmental references. In the active condition, the robot exhibited initiative-taking behaviors by pausing at six predefined locations along the route. Each stop corresponded to a distinct forest element (e.g., a tree formation, rock structure, or other notable environmental feature). At these locations, the robot temporarily halted before continuing along the path, thereby signaling potential points of shared attention during the walk. The walking route was designed to ensure a consistent forest experience. As shown in Fig. 1, the walk began and ended at the same location, forming a semi-loop through the six stopping points. Walking direction, turns, and detours were indicated by yellow markers placed along the path, which participants followed throughout the walk.

The implementation of authority behaviors differed across conditions. In the leader condition, the robot's navigation was implemented using a Wizard-of-Oz approach operated by the first author, who remotely controlled the robot to ensure reliable navigation along the predefined route while maintaining consistent pacing and stopping behaviors. In the follower condition, the robot used a detect-and-follow program to track and follow the participant's movement along the route, using fiducial markers attached to a waist-mounted wearable.

To ensure experimental consistency, all robot movements and behavioral sequences were predetermined. The robot executed an identical set of scripted movements and stopping behaviors across all sessions. No adaptive behaviors or learning-based frameworks were implemented on the robot. Additionally, the robot was not pre-calibrated to the specific forest environment beyond the scripted behavior plan. This approach ensured that observed differences across conditions resulted from the experimental manipulations rather than

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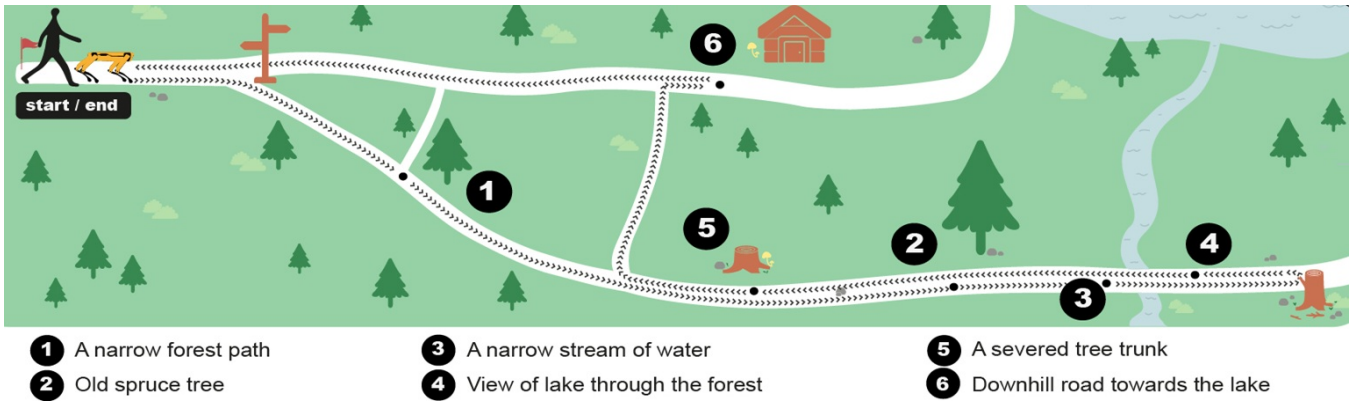


Fig. 1. Walking Route including stopping points.



Fig. 2. Different walking and interaction conditions: from the left, a) robot as follower, b) robot as leader, c) active robot in follower condition, and d) active robot in leader condition.

adaptive variations in robot behavior. Fig. 2 illustrates the different interaction modes used in the study, including examples of the leader, follower, and active engagement behaviors.

C. Procedure

Upon arrival, participants were briefed on the study and provided informed consent. All participants wore a custom waist-mounted wearable with fiducial markers to enable robot following in follower conditions; the wearable was used across all conditions to ensure consistency. Participants were introduced to the robot companion and informed whether it would lead or follow during the walk. They received route and safety instructions and were informed that they would complete two walking sessions, with the condition details and order undisclosed. Each walking session lasted approximately 8–15 minutes, depending on several factors, such as experiment condition, walking pace, road conditions, weather conditions, and unplanned interruptions. After each walk, participants completed questionnaires, reporting on their nature connectedness, perceived mindfulness, and social cognition with the robot. Each participant was compensated with a gift valued at up to 7 euros.

D. Measurements and Questionnaires

Participants' connection to nature was assessed using the ABC connectedness to nature scale [30], which served as the primary outcome measure. This validated scale enables the measurement of the affective, behavioral, and cognitive dimensions of nature connectedness. We additionally measured participants' state mindfulness and social cognition with the robot. State mindfulness was measured using the State Mindfulness Scale (SMS) [31], which measures the mindfulness of both mind and body. Social cognition with the robot was measured using the Perceived Social Intelligence scale [32]. All measurements used a 5-point Likert scale.

E. Reliability and Validity

The quantitative data were analyzed using structural equation modeling (SEM) [33]. SEM was chosen because the study hypothesized a structured network of relationships between experimentally manipulated variables (robot engagement and authority), mediating experiential constructs (mindfulness, social cognition, social intelligence, and trust), and the primary outcomes (nature connectedness and HR companionship). SEM enables simultaneous estimation of direct and indirect effects while accounting for measurement error, making it particularly suitable for testing mediation models involving multiple latent constructs. The structural model

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TABLE I

CONSTRUCT RELIABILITY AND CONVERGENT VALIDITY

Construct	Cronbach's α	Composite Reliability (ρ_c)	AVE
Nature Connectedness – Affective	0.769	0.844	0.526
Nature Connectedness – Behavioral	0.647	0.785	0.556
Nature Connectedness – Cognitive	0.797	0.854	0.546
Perceived Social Intelligence	0.904	0.918	0.509
State Mindfulness of Body	0.771	0.846	0.527
State Mindfulness of Mind	0.844	0.881	0.515

TABLE II

DISCRIMINANT VALIDITY (HTMT)

	Authority	Engagement	NC-A	NC-B	NC-C	PSI	SMS-B	SMS-M
Authority								
Engagement								
NC – Affective	0.170	0.068						
NC – Behavioral	0.075	0.094	0.789					
NC – Cognitive	0.060	0.085	0.830	0.943				
Perceived Social Intelligence	0.230	0.138	0.246	0.241	0.228			
State Mindfulness – Body	0.245	0.164	0.478	0.552	0.589	0.521		
State Mindfulness – Mind	0.095	0.057	0.459	0.382	0.411	0.318	0.758	

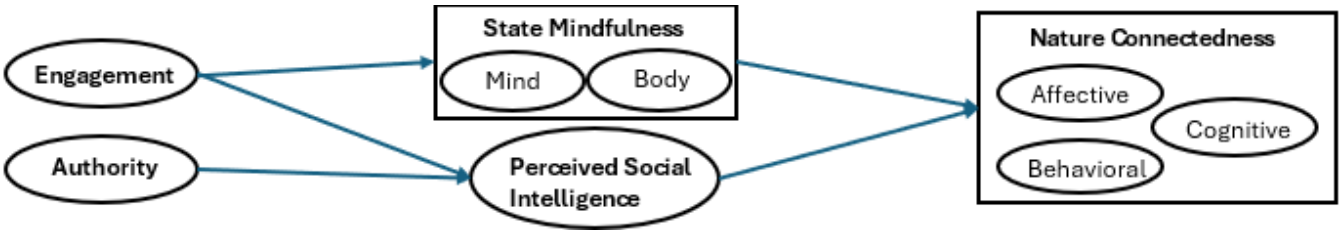


Fig. 3. Structural Model.

for analysis is shown in Fig. 3. Measurement reliability and validity were assessed following established PLS-SEM guidelines [33], [34]. Internal consistency was supported by Cronbach's alpha and composite reliability (ρ_c), with all constructs exceeding the 0.70 threshold except Nature Connectedness–Behavioral (α = 0.647), which was considered acceptable given the exploratory design and limited item count [35]. As reported in Table 2, convergent validity was confirmed, as all AVE values exceeded 0.50. Discriminant validity was assessed using Heterotrait-Monotrait ratio of correlations (HTMT), as reported in Table 3; most values were below 0.85, with one marginal exceedance between the behavioral and cognitive nature connectedness dimensions (HTMT = 0.943), which can be attributed to closely related subdimensions of the scale.

F. RESULTS

We first examined the total effects of robot engagement (active vs. passive) on nature connectedness. Total effects from the structural model are reported in Table 3. Robot engagement did not significantly predict behavioral (β = 0.10, 95% CI [-0.16, 0.34]), cognitive (β = 0.12, 95% CI [-0.16, 0.37]), or affective (β = 0.04, 95% CI [-0.25, 0.28]) dimensions of nature connectedness, as all confidence intervals included zero. Thus, H1 was not supported. With respect to the proposed mechanisms, robot engagement did not significantly influence perceived social intelligence (β = 0.28, 95% CI [-0.32, 0.72]), state mindfulness of the body (β = 0.26, 95% CI [-0.21, 0.69]), or state mindfulness of the mind (β = 0.07, 95% CI [-0.41, 0.52]). These results suggest that increasing the robot's level of engagement did not systematically alter participants' cognitive, affective, or attentional states. Accordingly, H1a and H1b were not supported.

We next tested the total effects of robot authority (leader vs. follower) on nature connectedness. Robot authority did not exhibit significant total effects on behavioral (β = 0.04, 95% CI [-0.10, 0.33]), cognitive (β = 0.02, 95% CI [-0.09, 0.24]), or affective (β = 0.13, 95% CI [-0.07, 0.37]) nature connectedness. Effect directions were again inconsistent and relatively small, providing no evidence for a meaningful influence of authority role. Therefore, H2 was not supported. Robot authority also did not significantly predict perceived social intelligence (β = -0.53, 95% CI [-0.92, 0.32]), indicating that adopting a leader role did not reliably enhance perceived social-cognitive of the robot. The negative coefficient, although non-significant, suggests that a leader role may even reduce perceived social intelligence, but this pattern should be interpreted cautiously due to the wide confidence interval. Furthermore, authority did not show any indirect effect through attentional or mindfulness-related mechanisms. Consequently, H2a was not supported.

Specific indirect effects from the mediation analysis have been reported in Table 4. Across all tested mediation paths,

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TABLE III

TOTAL EFFECTS FROM THE STRUCTURAL MODEL. NC = NATURE CONNECTEDNESS; PSI = PERCEIVED SOCIAL INTELLIGENCE; SMB = STATE MINDFULNESS OF BODY; SMM = STATE MINDFULNESS OF MIND.

Path	β	p	95% CI
Authority → $NC_{Behavioral}$	0.041	.689	[-0.102, 0.326]
Authority → $NC_{Cognitive}$	0.018	.824	[-0.091, 0.237]
Authority → $NC_{Affective}$	0.126	.275	[-0.069, 0.371]
Authority → PSI	-0.525	.067	[-0.922, 0.324]
Engagement → $NC_{Behavioral}$	0.097	.449	[-0.161, 0.338]
Engagement → $NC_{Cognitive}$	0.116	.387	[-0.156, 0.371]
Engagement → $NC_{Affective}$	0.043	.751	[-0.247, 0.283]
Engagement → PSI	0.277	.294	[-0.324, 0.717]
Engagement → SMB	0.264	.254	[-0.211, 0.691]
Engagement → SMM	0.065	.785	[-0.409, 0.517]
PSI → $NC_{Behavioral}$	-0.078	.652	[-0.436, 0.233]
PSI → $NC_{Cognitive}$	-0.034	.807	[-0.306, 0.222]
PSI → $NC_{Affective}$	-0.240	.158	[-0.539, 0.117]
SMB → $NC_{Behavioral}$	0.428	.008	[0.087, 0.719]
SMB → $NC_{Cognitive}$	0.454	.006	[0.114, 0.761]
SMB → $NC_{Affective}$	0.358	.040	[0.027, 0.717]
SMM → $NC_{Behavioral}$	0.090	.509	[-0.297, 0.302]
SMM → $NC_{Cognitive}$	0.087	.587	[-0.240, 0.389]
SMM → $NC_{Affective}$	0.223	.099	[-0.095, 0.456]

TABLE IV

SPECIFIC INDIRECT EFFECTS FROM MEDIATION ANALYSIS. NC = NATURE CONNECTEDNESS; PSI = PERCEIVED SOCIAL INTELLIGENCE; SMB = STATE MINDFULNESS OF BODY; SMM = STATE MINDFULNESS OF MIND.

Indirect Path	β	p	95% CI
Engagement → SMM → $NC_{Affective}$	0.015	.828	[-0.096, 0.193]
Authority → PSI → $NC_{Affective}$	0.126	.275	[-0.069, 0.371]
Engagement → SMB → $NC_{Affective}$	0.095	.350	[-0.044, 0.396]
Engagement → SMM → $NC_{Behavioral}$	0.006	.893	[-0.060, 0.135]
Authority → PSI → $NC_{Behavioral}$	0.041	.689	[-0.102, 0.326]
Engagement → PSI → $NC_{Affective}$	-0.067	.441	[-0.306, 0.050]
Engagement → SMB → $NC_{Behavioral}$	0.113	.288	[-0.057, 0.379]
Engagement → SMM → $NC_{Cognitive}$	0.006	.905	[-0.060, 0.156]
Authority → PSI → $NC_{Cognitive}$	0.018	.824	[-0.091, 0.237]
Engagement → PSI → $NC_{Behavioral}$	-0.022	.754	[-0.248, 0.059]
Engagement → SMB → $NC_{Cognitive}$	0.120	.302	[-0.064, 0.409]
Engagement → PSI → $NC_{Cognitive}$	-0.009	.862	[-0.171, 0.065]

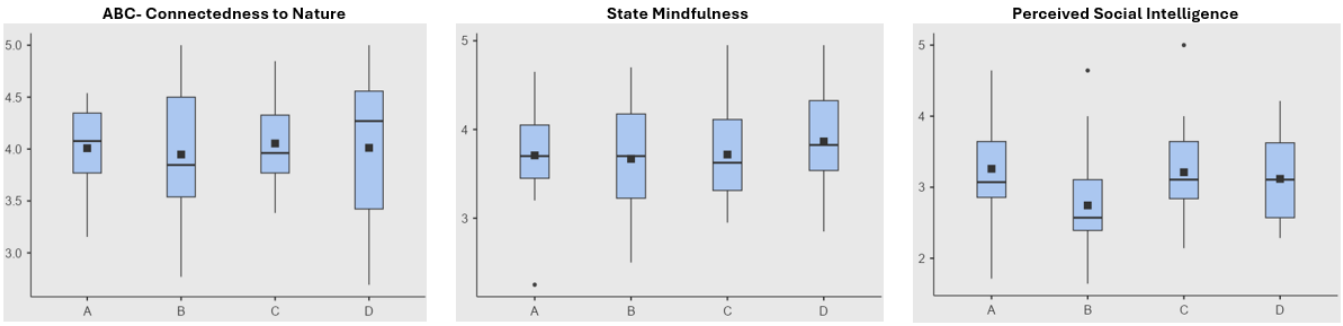


Fig. 4. Box plots showing the distribution of outcome variables across four experimental conditions (A = Passive Follower, B = Passive Leader, C = Active Follower, and D = Active Leader).

confidence intervals consistently included zero, indicating that none of the hypothesized indirect mechanisms were statistically supported. In contrast to the robot-related variables, state mindfulness of the body showed strong and consistent total effects on all dimensions of nature connectedness. Higher bodily mindfulness was associated with increased behavioral (β = 0.43, 95% CI [0.09, 0.72]), cognitive (β = 0.45, 95% CI [0.11, 0.76]), and affective (β = 0.36, 95% CI [0.03, 0.72]) nature connectedness. State mindfulness of the mind did not significantly predict behavioral or cognitive nature connectedness, and its association with affective connectedness did not reach statistical significance (β = 0.22, 95% CI [-0.10, 0.46]). Perceived social intelligence of the robot also did not significantly predict any dimension of nature connectedness. Overall, the model suggests that internal experiential factors (i.e., bodily mindfulness) are more

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strongly related to nature connectedness than the manipulated robot characteristics.

Descriptive statistics in Figure 4 show that differences between conditions were modest across outcomes. For Nature Connectedness, the Active Leader condition (D) showed the highest central tendency. State Mindfulness was also highest in D, with relatively similar levels across the remaining conditions. For Perceived Social Intelligence, Active Follower (C) and Active Leader (D) showed higher values than both passive conditions, with Passive Leader (B) consistently lowest. Overall, active engagement conditions, particularly when combined with a leader role, tended to show higher descriptive levels across outcomes, though variability was substantial across participants.

IV. DISCUSSION

A. Implications and Contributions

1) Limits of Robot Sociality in More-than-Human Nature Contexts: A central contribution of this work lies in demonstrating the limits of social and authoritative robot cues in shaping nature connectedness. While prior HRI research has shown that robot engagement and authority can influence trust, compliance, and social perception in task-oriented or social contexts [28], [25], our findings suggest that such cues may be comparatively ineffective in forest-based experiences. Nature, as a richly stimulating and meaning-laden environment, may already command users' attention and affective engagement, leaving limited room for robot-mediated social dynamics to meaningfully alter the experience. In such settings, the environment itself, its sensory richness, novelty, and affective resonance may overshadow attempts by robots to guide, persuade, or socially influence participants. This implies that the mechanisms by which robots shape user experience indoors or in controlled scenarios do not necessarily transfer to sensory-dense outdoor contexts. From a more-than-human perspective, this can be understood as a redistribution of agency, where forests, vegetation, sounds, and other non-human elements actively participate in shaping the experience. Rather than interacting within a human–robot dyad, participants are embedded in a multispecies environment in which the robot is only one of many actors and may not hold a privileged position in directing attention or meaning-making.

2) Embodied Experiences Over Mediation: In natural environments, technological mediation may be secondary, or even peripheral, to the embodied human–environment relationship, particularly when the activity already affords reflection, immersion, and sensory engagement. This interpretation is strengthened by the strong and consistent effects of state mindfulness of the body across all dimensions of nature connectedness. The robustness of this pathway aligns with embodied cognition [36] perspectives, which emphasize that perception, meaning, and experience emerge from bodily engagement with the world. It also fits within environmental psychology theories [37], which highlight the role of affective, multisensory, and reflective processes in shaping individuals' relationships with nature. Together, these perspectives suggest that robots designed to support nature experiences may be more effective when they encourage grounded bodily presence rather than relying on traditional social cues such as expressivity, engagement, or authority. Walking in a forest involves continuous interaction with terrain, plants, sounds, and atmospheric conditions, suggesting that experience emerges relationally rather than being guided by one single agent such as a robot.

3) Re-framing the Role of the Robot: Although the study did not confirm the hypothesized effects of robot engagement and authority, the findings provide important empirical boundary conditions for the influence of social robots in outdoor contexts. This helps refine expectations about where robot sociality matters and where it may not. While social cues can meaningfully shape user behaviors and judgments in structured, indoor, or socially framed interactions [38], [39], their influence appears less pronounced in environments that are already intrinsically engaging and attention-capturing. This does not diminish the role of robots in outdoor or wellbeing-oriented settings, but rather redirects design priorities toward modalities that are compatible with the experiential qualities of nature. Rather than leading or influencing users through authority or engagement cues, robots may instead act as facilitators that attune users to non-human elements, for example, by subtly directing attention to environmental features, rhythms, or interactions occurring within the landscape.

4) Grounding the Human–Robot–Nature Relationship: By systematically testing and reporting the (in)effectiveness of robot authority and engagement in a natural setting, this work contributes to a more nuanced understanding of human–robot–nature interaction. Null or weak effects are often underreported in HRI, yet they play a crucial role in preventing overgeneralization from laboratory findings and in shaping realistic design expectations for field-based interventions. The present results, therefore, represent a constructive adjustment to assumptions about robot persuasiveness, revealing that social cues alone may not be sufficient to shape complex, introspective, or environmentally situated outcomes such as nature connectedness. This contributes both methodologically and conceptually by highlighting the importance of natural outdoor context when evaluating robot influence and by pointing toward embodied, experiential, and sensory-oriented design strategies for future systems. Importantly, these findings also call for a broader ecological framing of outdoor HRI, where it is understood as part of a larger network of relationships involving landscapes, non-human organisms, and environmental processes. Such a framing aligns with emerging work in more-than-human HCI, which emphasizes the need to consider how technologies participate in and reshape multispecies relations [5], [6], [40] rather than focusing solely on human-centered outcomes.

B. Limitations and Future Directions

This study has several limitations that should be considered when interpreting the findings. First, the walking

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scenario and robot behaviors were deliberately constrained to maintain experimental control, which may have limited the expressive, adaptive, or context-aware capacities through which a robot could more strongly influence embodied or environmental engagement. Second, the relatively short duration of each walking session (8–15 minutes) may have been insufficient, meaning longer or repeated exposures might yield different results. Third, the sample size and composition limit generalizability, and individual differences such as prior affinity with nature and familiarity with robots were not modeled and may have moderated observed effects. Fourth, the analysis did not consider the participants' prior experience of walking in the same path, which might have an effect on how they approach the walk. Finally, the novelty of encountering a robot in a forest may have drawn participants' attention toward the robot itself, potentially competing with both the natural environment and the intended mediating mechanisms.

V. CONCLUSION

This study examined whether robot engagement and authority roles influence human–nature connectedness during forest-based walking experiences. The results indicate that robot-mediated social cues did not significantly shape nature connectedness, whereas embodied experiential states—particularly mindfulness of the body—emerged as the primary pathway through which participants connected with the natural environment. These findings highlight clear boundary conditions for the role of social robots in nature-based contexts and suggest that, in immersive outdoor settings, the environment itself remains the dominant actor shaping experience. Rather than acting as social leaders or mediators, outdoor companion robots may be more effective when designed as subtle facilitators that support bodily awareness and sensory attunement, complementing rather than competing with the human–nature relationship.

ACKNOWLEDGMENT

This work was supported by the *Research Council of Finland's Flagship Programme UNITE* (decision 359173).

We are grateful to *NEXUS - Research Infrastructure for Interaction Between Humans, Technology, and Society*, for providing infrastructure support.

Generative AI Tool (ChatGPT 5) has been used for polishing and copy-editing, following the methods outlined in [41]. The final content is thoroughly checked, and authors assume the full responsibility of the core ideas, concepts, and articulations in the manuscript.

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