scientific reports

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The linguistic feedback of tourism robots significantly influences visitors' ecotourism behaviors

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With the extensive application of artificial intelligence technology in the tourism industry, robot-assisted tourism has become a vital strategy for enhancing tourist experiences and promoting sustainable tourism practices. This study aims to explore the impact of language feedback from tourism robots on tourists' ecotourism behavior and analyze potential mediating and moderating mechanisms. Through three experimental studies, we found that robot guides with language feedback capabilities significantly improve tourists' ecotourism behavior. Specifically, environmental responsibility acts as a moderator between the robot's language feedback and tourists' ecotourism behavior, indicating that the robot's language feedback is more effective when tourists have a higher sense of environmental responsibility. Furthermore, the robot's language feedback enhances tourists' environmental awareness and responsibility by increasing cognitive trust and feedback propensity. The findings have practical implications for tourism destinations and operators in designing and implementing intelligent tourism services to promote tourists' ecological engagement.

Keywords Tourism robots, Linguistic feedback, Ecotourism behaviors, Cognitive trust, Feedback tendency, Environmental responsibility

Robot-assisted tourism has emerged as a significant strategy for destinations aiming to enhance visitor experiences, streamline operations, and promote sustainable tourism practices[1] However, there is a growing debate regarding the actual impact of robotic interactions on tourists' ecological behaviors[2]. To elucidate this issue, researchers have embarked on investigating how robotic communication (e.g., linguistic cues, interaction patterns), technological characteristics (e.g., AI capabilities, customization), and other robot attributes (e.g., appearance, reliability) influence tourists' ecological engagement[3]. While initial findings have provided valuable insights into the potential of robot-assisted tourism, further inquiries are necessary to identify additional factors that can amplify the ecological impact of tourism initiatives[4].

Within the tourism sector, an intriguing trend has emerged where robots are increasingly being employed as tour guides. These robotic tour guides are progressively being integrated into various tourist destinations and gaining popularity among tech-savvy travelers[5]. The ascendancy of robotic tour guides signifies the deepening integration of artificial intelligence within the tourism industry, offering potential economic benefits such as reduced labor costs and heightened operational efficiency[6]. Despite their growing prevalence, limited research has examined the impact of robotic tour guides on tourists' ecotourism behaviors, particularly with respect to the quality of visitor experiences and long-term ecological sustainability[7].

Our objective is to bridge this knowledge gap by assessing the differential impacts of robotic tour guides with and without linguistic feedback on tourists' ecotourism behaviors and unraveling the underlying mechanisms that may explain these differences[8]. Through a series of three experimental studies, we observed that robots equipped with linguistic feedback exhibited greater efficacy in guiding tourists towards ecotourism activities, evoking environmental awareness, and fostering sustainable tourism behaviors[9]. This advantage is primarily attributed to the enhanced affinity and interactivity conferred by linguistic feedback, which fosters trust and favorability among tourists[10]. Specifically, the robots' linguistic feedback, a positive interactive experience, triggers tourists' environmental responsibility[11], subsequently reinforcing their trust in the robots and identification with ecotourism activities. Furthermore, we discovered that in specific ecotourism settings (e.g., nature reserves, eco-farms), robots with linguistic feedback can capitalize on their strengths even more. In these contexts, the robots' linguistic feedback effectively conveys ecotourism behavior information that favors tourists' cognitive trust and feedback tendency, encouraging more environmentally friendly and sustainable tourism practices[12]. Lastly,

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we propose a definitive manipulation method for robotic linguistic feedback (i.e., with vs. without linguistic feedback), thereby providing empirical support for exploring the causal relationships between factors such as environmental responsibility, cognitive trust, feedback tendency, and tourists' ecotourism behaviors in the context of robotic tour guide feedback (linguistic vs. non-linguistic)[8].

This study makes significant contributions to the field of sustainable tourism, primarily manifested in three aspects. Firstly, it broadens the discourse on ecotourism by contrasting the impact of robotic tour guides with and without linguistic feedback on tourists' ecotourism behaviors[13]. While existing research has explored the role of technology in tourism and the application of AI in enhancing tourist experiences, studies examining the influence of robotic tour guides' linguistic feedback on tourists' ecotourism behaviors remain scarce[14]. Secondly, by establishing a link between linguistic feedback and the perceived reliability of robotic tour guides, this study expands the understanding of the determinants of robotic tour guide effectiveness[15]. Prior research has considered factors such as technological interactivity, user interface design, and content personalization, yet the unique role of linguistic feedback has often been overlooked, lacking empirical evidence to validate its effectiveness in promoting tourists' ecotourism behaviors[7]. Lastly, this study contributes to the tourism technology domain by exploring novel applications of robotic interactions[2]. By integrating linguistic feedback and its implications for tourism, the study reveals the influential role of interactivity in enhancing robotic tour guides' capacity to facilitate sustainable tourism practices. For tourism destinations and operators, this study holds practical implications, indicating that robotic tour guides with linguistic feedback can significantly enhance tourists' engagement and the likelihood of environmentally responsible behaviors, even among those who may not be inherently interested in technology[16]. Consequently, tourism managers should consider incorporating linguistically capable robotic tour guides into their operational strategies to promote tourists' ecological engagement.

Theoretical background and research hypotheses

Stimulus-response theory

The stimulus-response theory, a central concept in behavioral psychology, posits that human behavior is elicited by specific responses to external stimuli[17]. This theory maintains that all behaviors of organisms are formed through the connection established between stimuli and responses[18]. The Stimulus-Response Theory presents a framework for analyzing how the linguistic feedback of tourism robots influences tourists' ecotourism behaviors, enabling the prediction and guidance of tourists' actions through external stimuli, such as the robots' verbal cues[19].

Tourists engage in the identification and processing of linguistic stimuli provided by tourist robots[20]. These robots offer information, suggestions, or warnings through verbal feedback, which serve as external stimuli received by the visitors. The senses of the tourists capture these stimuli, which are then processed through the nervous system. During this process, the cognitive evaluations and emotional responses of the tourists are activated; they interpret the language of the robot and form an understanding of the current situation[21]. For instance, the robot may alert visitors to the fragility of a specific ecosystem and suggest adopting particular environmental behaviors. This recognition and processing of stimuli constitute the first stage of behavior occurrence, laying the foundation for subsequent behavioral responses.

Following the reception of the stimuli, tourists undergo a series of psychological activities, such as emotional reactions, cognitive assessments, and attitude formation[22]. For example, tourists may feel a sense of pride due to the positive feedback from the robot, thereby enhancing their willingness to engage in eco-friendly behaviors. Subsequently, tourists exhibit corresponding behavioral responses[23]. These may include approach behaviors, such as participating in environmental activities, or avoidance behaviors, such as refraining from damaging the environment[24]. The linguistic feedback from the tourist robot can serve as a positive reinforcement, encouraging visitors to adopt eco-friendly actions. The emergence of such responses is a direct result of the stimulus-response chain, reflecting the visitors' immediate reaction to the stimuli[25].

Therefore, the Stimulus-Response Theory provides a useful framework for understanding how the linguistic feedback from tourist robots can influence the ecotourism behavior of visitors[26]. By designing appropriate verbal feedback, tourist robots can effectively guide and shape the behavior of tourists, promoting environmentally friendly and sustainable tourism practices.

Research on tourism robots

Tourism robots, as the product of the deep integration of artificial intelligence and the tourism industry, are gradually emerging as a novel force in the modern tourism service sector[27]. Tourism robots represent intelligent service devices specifically designed for tourism scenarios[28]. They not only integrate advanced technologies such as natural language processing and machine learning, but also undergo optimization tailored to the unique needs of the tourism industry, aiming to provide a more personalized, efficient, and convenient service experience[29].

In practical applications within the tourism industry, the role of tourism robots is increasingly prominent. Within scenic areas, they function as intelligent tour guides, providing visitors with detailed introductions to attractions and route planning, thereby facilitating a deeper understanding and experience of the culture, history, and local customs of the tourism destination[30]. Furthermore, through interactions with visitors, tourism robots gather and analyze visitor preferences and feedback, offering valuable reference information for scenic area managers and contributing to the continuous improvement and optimization of scenic area services.

Moreover, in the realm of tourism accommodation, tourism robots have demonstrated immense potential[31]. They can assist hotels in tasks such as check-in procedures, room service, and luggage handling, alleviating the workload of staff and enhancing service efficiency[32]. Additionally, leveraging intelligent speech recognition and interaction technologies, tourism robots offer visitors a more convenient and personalized service experience, such as providing weather forecasts, travel recommendations, dining suggestions, and more[33].

As technology continues to advance and application scenarios expand, the development prospects for tourism robots will become even broader. They will continually integrate new technologies and concepts, enhancing service quality and user experience, thereby becoming a vital component of smart tourism[34]. Simultaneously, tourism robots will deeply integrate with other aspects of the tourism industry, driving its digital transformation and intelligent upgrading, ultimately delivering more convenient, efficient, and enjoyable travel experiences for tourists[35].

Linguistic feedback and individual behavior

Linguistic feedback[36], as a mode of communication, refers to the direct or indirect responses received by the communicator during the exchange process regarding the effectiveness of their verbal expressions. This feedback can be verbal, written, or conveyed through nonverbal means such as body language and facial expressions (gestures and facial cues)[37]. The impact of linguistic feedback on individual behavior is multifaceted, as it enhances the precision and efficacy of information transmission while also influencing individuals' emotions, attitudes, and behavioral intentions[38].

Linguistic feedback is intricately linked to various psychological and social dynamics. Positive linguistic feedback, such as praise and affirmation, can bolster individuals' self-confidence and motivation, encouraging them to continue or repeat specific behaviors[39]. For instance, research has revealed that positive linguistic feedback can effectively stimulate consumer purchasing behavior[40]. Conversely, negative linguistic feedback, including criticism and disapproval, may lead to behavioral changes among consumers, resulting in the reduction or cessation of certain actions[41]. In tourism settings, tourists' positive evaluations and feedback towards tour guides can significantly boost the guides' professional pride. Consequently, the timing and manner of linguistic feedback also impact individual behavior. Immediate feedback is often more effective than delayed feedback as it allows individuals to immediately recognize the consequences of their actions[42]. Furthermore, constructive feedback[43], even if potentially negative, can aid individuals in understanding how to improve their behavior when provided appropriately, thereby fostering personal growth.

With the advancement of technology, the application of intelligent robots within scenic areas has become increasingly prevalent, and the influence of their linguistic feedback mechanisms on individual tourist behavior has become increasingly prominent[44]. Equipped with natural language processing technology, robots can mimic human communication styles, providing personalized services and guidance to tourists[45]. This linguistic feedback not only enhances tourists' touring efficiency and satisfaction but also profoundly impacts their ecotourism behaviors. Specifically, robots can reinforce tourists' environmental awareness through positive linguistic feedback[46], such as praising eco-friendly behaviors or offering suggestions for ecological protection, thereby encouraging them to adopt more environmentally conscious travel practices, such as reducing waste generation and protecting wildlife and flora. Additionally, robots can promptly correct and guide tourists' inappropriate behaviors through linguistic feedback, mitigating the potential damage to the scenic area's environment[47]. Consequently, robotic linguistic feedback plays a pivotal role in promoting ecologically and ethically responsible individual tourist behaviors. Based on the above analysis, this study proposes the following research hypothesis:

H1: The linguistic feedback provided by tourism robots (versus no linguistic feedback) promotes tourists' ecotourism behaviors.

Moderating effect of environmental responsibility

Environmental responsibility refers to the duties and obligations undertaken by individuals or organizations to maintain ecological balance, reduce pollution, and protect natural resources when utilizing their resources, engaging in economic activities, or enjoying the natural environment[48]. In the tourism sector, environmental responsibility manifests as tourists' proactive adoption of environmental protection measures during their travels, aiming to minimize negative impacts on the environment and promote the sustainable development of ecotourism[49]. This sense of responsibility profoundly influences tourists' ecological behaviors, urging them to make more prudent choices in tourism activities and engage more actively in ecological conservation, thereby enabling the sustainable utilization of tourism resources[50].

On the one hand, robots deployed in scenic areas can enhance tourists' ecotourism behaviors by emphasizing their environmental responsibility[51]. When equipped with linguistic feedback capabilities and capable of communicating based on principles of environmental responsibility, these robots can effectively reinforce tourists' environmental stewardship[52]. For instance, by narrating environmental conservation stories, sharing eco-friendly knowledge, or pointing out the impact of inappropriate behaviors on the environment, robots can stimulate tourists' awareness and contemplation regarding environmental protection[53], thereby motivating them to participate more conscientiously in ecotourism. In contrast, robots lacking linguistic feedback are unable to provide such in-depth environmental education through vocal communication, potentially hindering the effective reinforcement of tourists' environmental awareness[9].

On the other hand, environmental responsibility also manifests in guiding tourists' eco-friendly behaviors. Robots with linguistic feedback capabilities can provide timely and personalized feedback and guidance tailored to specific tourist behaviors[54]. For instance, when a tourist is about to litter, the robot can promptly remind them and suggest proper disposal methods; whereas, if the tourist engages in environmentally conscious actions[55], the robot can offer affirmation and praise. This instant feedback mechanism aids tourists in continuously adjusting their behaviors during their travels, gradually fostering good eco-friendly habits[56]. Conversely, robots without linguistic feedback are unable to offer such immediate guidance and support, potentially leaving tourists lacking sufficient motivation and direction in their eco-friendly endeavors.

Furthermore, environmental responsibility encompasses the dissemination and promotion of eco-friendly culture. Robots with linguistic feedback capabilities serve not only as messengers of information but also as ambassadors of environmental conservation culture[57]. They can showcase the significance and urgency of

environmental protection to tourists through vivid language, engaging stories, or interactive formats, thereby igniting tourists' enthusiasm and participation in environmental protection efforts[58]. This cultural transmission fosters eco-conscious values and beliefs within tourists, motivating them to become advocates and practitioners of eco-friendly actions[59]. In contrast, robots lacking linguistic feedback struggle to shoulder the weighty responsibility of cultural dissemination in this regard. It can be inferred that the linguistic feedback provided by tourism robots to tourists' behaviors effectively bolsters their capacity to execute ecotourism behaviors[7]. Based on the above analysis, this study proposes the following research hypothesis:

H2: Tourists' environmental responsibility moderates the relationship between linguistic feedback provided by tourism robots (versus no linguistic feedback) and tourists' ecotourism behaviors.

Chain mediation effect of feedback tendency and cognitive trust

Feedback tendency refers to an individual's receptivity and responsiveness to feedback, encompassing how they receive, process, and respond to external and internal feedback, reflecting cognitive differences in feedback processing[60]. Cognitive Trust denotes the rational evaluation of the reliability[61], honesty, competence, and accountability of others (or systems), forming a critical component of trust. In the context of robotic feedback, tourists'Feedback tendency directly influences their Cognitive Trust in robotic feedback[62]. Tourists with high Feedback tendency tend to actively seek and respond to external feedback, thereby more readily establishing trust in robotic feedback. This trust enhances their understanding of the robot's capabilities, features, and dependability, ultimately driving pro-environmental tourism behaviors[63]. Conversely, tourists with low Feedback tendency may exhibit skepticism toward robotic feedback, reducing their reliance on the robot's suggestions or information[64].

Feedback tendency plays a pivotal role in the relationship between robot language feedback (vs. non-language feedback) and tourists'pro-environmental behaviors. As a personality trait, Feedback tendency determines how tourists receive, process, and respond to information from external sources, particularly intelligent systems such as robots[65]. When robots provide language-based feedback on eco-tourism, tourists with high Feedback tendency typically comprehend and apply this information more swiftly, demonstrating heightened interest and enthusiasm, which translates into more environmentally sustainable actions[66]. In contrast, tourists with low Feedback tendency may display indifference or doubt toward robotic language feedback, struggling to convert such feedback into tangible pro-environmental behaviors[67]. Thus, Feedback tendency not only acts as a mediating variable but also amplifies the positive impact of robot language feedback on tourists' pro-environmental behaviors. Based on the above analysis, this study proposes the following research hypotheses:

H3: robot language feedback (vs. non-language feedback) positively impacts tourists' feedback tendency.

H4: Tourists' feedback tendency positively impacts their cognitive trust.

H5: Tourists' cognitive trust positively impacts their pro-environmental behaviors.

H6: Robot language feedback (vs. non-language feedback) positively impacts tourists' cognitive trust.

H7: Tourists' feedback tendency positively impacts their pro-environmental behaviors.

H8: Feedback tendency and cognitive trust sequentially mediate the relationship between robot language feedback (vs. non-language feedback) and tourists' pro-environmental behaviors.

The conceptual model is presented in (Fig. 1).

Overview of the study

To verify the 8 hypotheses, 8 scenario - based experiments were carried out. In experiment 1a, the effect of robot language feedback (vs. no feedback) on tourists' ecotourism behavior was assessed to test H1. A longitudinal experiment 1b replicated 1a to enhance result accuracy. Experiment 2a examined the moderating role of

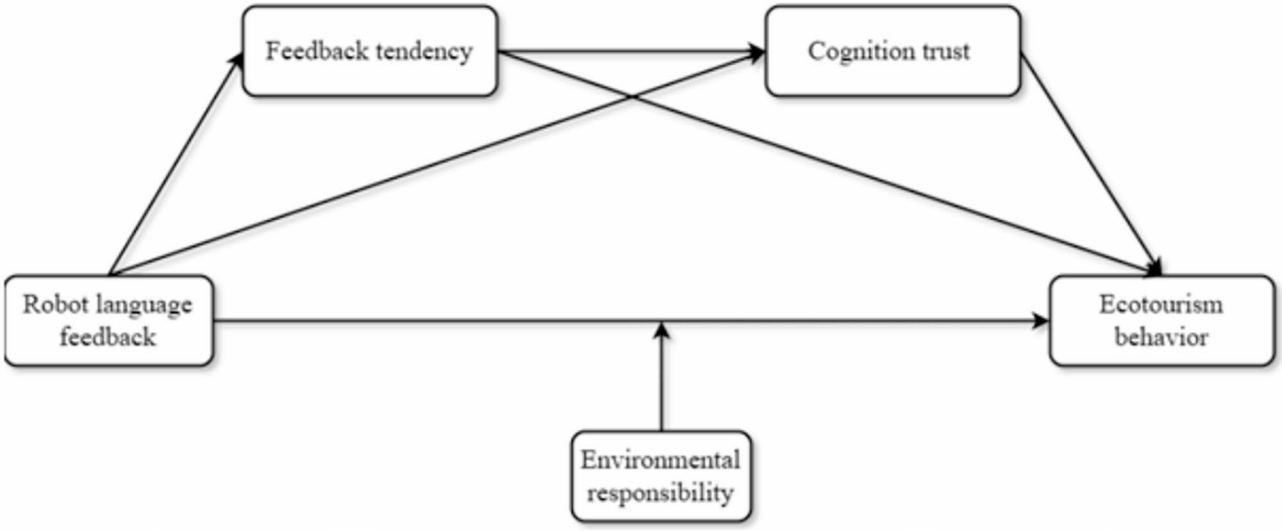

Fig. 1. Theoretical model framework.

environmental responsibility (high vs. low) in the relationship between robot language feedback (vs. no feedback) and tourists' ecotourism behavior, testing H2. Subsequently, longitudinal experiment 2b was conducted to re - validate H2. Experiment 3a explored the chain - mediating effect of feedback tendency and cognitive trust between robot language feedback (vs. non - linguistic feedback) and tourists' pro - environmental behaviors. Then, longitudinal experiment 3b was done to confirm H3 - H8. Considering platform - and online - vs. - offline experiment - related external validity, offline longitudinal experiments 4a and 4b were conducted to re - validate the chain - mediating effect (testing H3-H8), using different feedback materials in each experiment. Demographic details for the 4 experiments are in (Table 1).The frameworks associated with these four experiments are shown in (Table 2).

I confirm that all methods were performed in accordance with the relevant guidelines. All procedures were performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. I confirm that after we ask participants if they want to participate in the study, participants need to sign informed consent. All participants provided written Informed Consent for the study. This study was reviewed and approved by the Ethics Committee of Huainan Normal University.

Experiment 1a: the main effect of robotic linguistic feedback on tourists' ecotourism behaviors

Research design

Experiment 1a aimed to investigate the impact of robotic linguistic feedback (present vs. absent) on tourists' ecotourism behaviors. We employed a between-subjects design with a single factor (robotic linguistic feedback: present vs. absent) and recruited 309 participants through a professional survey platform, Credamo (https://www.credamo.com/). Subsequently, all participants were randomly assigned to two groups: the linguistic feedback group ($n = 153$) and the non-language feedback group ($n = 156$).

The experimental procedure was as follows. Initially, all participants were asked to imagine themselves visiting an ecological farm tourism destination where they casually discarded trash, which was observed by a robot on the premises. In the linguistic feedback group, the robot would verbally remind them: "This scenic area is my home; please keep the ground litter-free and cherish my environment." Conversely, in the non-language feedback group, the same message was displayed on the robot's screen: "This scenic area is my home; please keep the ground litter-free and cherish my environment." Subsequently, all participants were asked to complete a questionnaire measuring their ecotourism behaviors, including questions such as: "After receiving feedback from the robot, do you feel responsible for protecting the environment?" (1 = Strongly Disagree, 7 = Strongly Agree)[68]. Finally, demographic information related to the participants was collected.

Research result

Main effect test

We conducted a one-way ANOVA with robotic linguistic feedback (present vs. absent) as the independent variable and tourists' ecotourism behaviors as the dependent variable. The results revealed that tourists in the robotic linguistic feedback group exhibited significantly higher ecotourism behaviors ($M = 6.069$, $SD = 0.971$) compared to those in the non-language feedback group ($M = 5.786$, $SD = 1.342$), $F(1, 307) = 4.502$, $p = 0.035$. This finding indicates that under the influence of robotic linguistic feedback, tourists are more inclined to engage in ecotourism behaviors, thus validating Hypothesis H1.

Control variable analysis

Given previous research by Turner[69], which found that gender is a significant factor influencing tourists' ecotourism behaviors, we included gender as an independent variable in a one-way ANOVA. The results indicated that gender had no significant impact on tourists' ecotourism behaviors ($F(1, 307) = 0.209$, $p = 0.648$). By excluding gender as a control variable, we re-validated Hypothesis H1, confirming that the effect of robotic linguistic feedback on tourists' ecotourism behaviors holds true regardless of gender.

Discussion

In Experiment 1a, we validated the impact of robotic linguistic feedback on tourists' ecotourism behaviors. Upon receiving environmental education and conservation messages from robots, tourists were more inclined to adopt responsible tourism behaviors. Thus, robotic linguistic feedback, as an emerging mode of communication, effectively conveys ecological awareness and knowledge. Concurrently, we excluded the influence of gender on the experimental results, enhancing their accuracy. However, Experiment 1a only employed a cross-sectional study, which is incapable of establishing the temporal sequence between variables. To address the limitations of the aforementioned study, we conducted Experiment 1b, utilizing longitudinal data to explore the impact of language feedback on ecotourism behaviors.

Experiment 1b: longitudinal test of main effects

Experimental design

Experiment 1b aims to investigate the impact of robot language feedback on ecotourism behavior. We designed a single-factor between-subjects design (Robot Language Feedback: Yes vs. No). Referring to the longitudinal experimental design method by Huang, et al.[70], we randomly recruited 476 participants during the T1 period (March 7, 2025) and the T2 period (March 15, 2025). All participants were randomly assigned to two groups: the language feedback group (238 participants) and the non-language feedback group (238 participants). The experimental stimuli and measurement items used in Experiment 1b were consistent with those in Experiment 1a. Specific demographic information is presented in (Table 1).

Characteristics of subjects		Experiment 1a	Percentage (%)	Experiment 1b	Percentage (%)	Experiment 2a	Percentage (%)	Experiment 2b	Percentage (%)	Experiment 3a	Percentage (%)	Experiment 3b	Percentage (%)	Experiment 4a	Percentage (%)	Experiment 4b	Percentage (%)
Gender	Male	151	48.9	232	48.70	149	50	126	47.30	123	52.3	268	49.4	92	50.8	188	49.6
	Female	158	51.1	244	51.30	149	50	127	52.70	112	47.7	274	50.60	89	49.20	191	50.4
	18–25 years old	157	50.8	132	27.70	157	52.7	82	32.40	131	55.7	412	76.0	47	26.0	130	34.3
	26–40 years old	85	27.5	168	35.30	79	26.5	82	32.40	68	28.9	78	14.40	66	36.50	126	33.2
	41–60 years old	35	11.3	76	16.00	31	10.4	48	19.00	17	7.2	27	5.00	34	18.8	74	19.5
	Over 60years old	32	10.4	100	21.00	31	10.4	41	16.20	19	8.1	25	4.60	34	18.8	49	13
Education background	Primary school	13	4.2	28	5.90	9	3	15	5.90	7	3	9	1.70	13	7.20	20	5.3
	Middle school	12	3.9	26	5.50	10	3.4	13	5.10	7	3	8	1.50	8	4.40	46	12.1
	High school and technical secondary school	24	7.8	28	5.90	20	6.7	16	6.30	12	5.1	8	1.50	10	5.50	23	6
	Junior college	21	6.8	32	6.70	0	0	17	6.70	0	0	6	1.10	8	4.40	50	13.2
	Undergraduate college	109	35.3	280	58.80	98	32.9	140	55.30	87	37	488	90.00	111	61.30	130	34.3
	Master degree candidate	89	28.8	52	10.90	98	32.9	32	12.60	80	34	13	2.40	16	8.80	84	22.2
	Doctor-postgraduate	41	13.3	30	6.30	42	14.1	20	7.90	30	12.8	10	1.80	15	8.30	26	6.9

Table 1. Demographic information related to the three experiments.

Experiment	Experiment1a and 1b	Experiment 2a and 2b	Experiment 3a and 3b	Experiment 4a and 4b
Purpose	To test for main effects (H 1)	To test the moderating role of environmental liability(H2)	To test the Chain mediation of feedback tendency and cognition trust (H3-H8)	To test the Chain mediation of feedback tendency and cognition trust (H3-H8)
Data collection	Online	Online	Online	Field
Independent variable	Robot language feedback	Robot language feedback	Robot language feedback	Robot language feedback
Dependent variable	Ecotourism behavior	Ecotourism behavior	Ecotourism behavior	Ecotourism behavior
Mediators	–	–	Feedback tendency and cognition trust	Feedback tendency and cognition trust
Moderator	–	Environmental responsibility	–	–
Methods	ANOVA	ANOVA	ANOVA	ANOVA
		PROCESS 1	PROCESS 6	PROCESS 6
Results	Supported H1	Supported H2	Supported H3-H8	Supported H3-H8

Table 2. Research framework related to the three experiments.

Experimental results

Main effect test

Consistent with the results of Experiment 1a, tourists in the robot language feedback group exhibited significantly higher ecotourism behaviors (M = 5.434, SD = 1.147) than those in the non-language feedback group (M = 4.319, SD = 0.798), $F(1, 474) = 151.243$, $p < 0.001$. Therefore, under the influence of robot language feedback, tourists are more willing to engage in ecotourism behaviors, thus verifying Hypothesis H1.

Control variable analysis

We conducted an analysis of covariance (ANCOVA) with gender as a covariate. The results showed that gender had no significant impact on ecotourism behaviors between the two robot language feedback groups ($F(1, 474) = 64.362$, $p < 0.001$). Thus, gender did not significantly affect the experimental results.

Discussion

Experiment 1b reaffirmed Hypothesis H1 through a longitudinal experiment and enhanced the robustness of Experiment 1a. In Experiment 1b, it was once again demonstrated that tourists' inclination towards ecotourism behaviors is stronger under the influence of robot language feedback. However, despite the repeated validation of the relationship between robot language feedback and ecotourism behavior in Experiments 1a and 1b, the internal mechanisms and boundary conditions between the two were not discussed. Therefore, in Experiment 2, we introduced environmental responsibility as a moderator to examine its moderating effect on the relationship between robot language feedback and ecotourism behavior.

Experiment 2a: the moderating effect of environmental responsibility

Experimental design

In Experiment 2a, we designed a 2 (Robotic Linguistic Feedback: present vs. absent) x 2 (Environmental Responsibility: High vs. Low) factorial ANOVA experiment to explore the moderating effect of environmental responsibility on the impact of robotic linguistic feedback on tourists' ecotourism behavior. We recruited 298 participants on the professional survey platform Credamo (https://www.credamo.com/). Subsequently, all participants were randomly assigned to two groups: the linguistic feedback group (149 people) and the non-language feedback group (149 people).

The experimental procedure was as follows. All participants were instructed to imagine themselves touring a scenic lake area with a well-preserved ecological environment. At this moment, they were watching the fish swimming in the lake but had not noticed that a piece of paper litter had fallen from their hands. Immediately, in the verbal feedback group, a robot verbally approached them with a reminder: "The scenic area's environment depends on everyone. Please do not let litter scatter everywhere. Let's cherish our home." In contrast, in the non-verbal feedback group, the robot displayed the message on its screen: "The scenic area's environment depends on everyone. Please do not let litter scatter everywhere. Let's cherish our home." Subsequently, we administered questions to measure participants' perceptions of environmental responsibility, such as, "I believe that protecting the environment of ecotourism destinations is worthwhile" (1 = Strongly Disagree, 7 = Strongly Agree)[71]. Participants were also asked to respond to questions assessing their ecotourism behaviors, for example, "After the robot's feedback, I feel obligated to support initiatives that commit to environmentally friendly transportation planning" (1 = Strongly Disagree, 7 = Strongly Agree)[68].

The experimental procedure is as follows. First, we asked all participants to imagine they were touring a lake scenic area with a good ecological environment. At the moment, they were watching the fish swimming in the lake without noticing the paper litter that had fallen from their hands. Second, in the linguistic feedback group, the robot would approach with a verbal reminder: "The scenic area's environment depends on everyone, do not let the paper litter scatter everywhere, please take care of our home." In contrast, in the non-language feedback group, the robot's display screen showed the message: "The scenic area's environment depends on everyone, do not let the paper litter scatter everywhere, please take care of our home." Third, we inquired about the participants' attitudes towards environmental responsibility with questions such as: "To what extent do you agree that protecting the environment of ecotourism destinations is worthwhile?" (1 = strongly disagree, 7 = strongly agree)[71]. Participants were required to respond to questions measuring tourist ecotourism behavior,

such as: "After the robot's feedback, I feel obliged to support initiatives that commit to eco-friendly transportation planning" (1 = strongly disagree, 7 = strongly agree)[68]. Fourth, we controlled for the variable of tourist emotions and invited participants to answer relevant questions. Finally, we collected demographic information related to the participants.

Experimental results

Main effect testing was conducted. We treated robotic linguistic feedback (linguistic feedback present vs. linguistic feedback absent) as the independent variable and tourists' ecotourism behavior as the dependent variable, performing a one-way ANOVA. The results indicated that tourists' ecotourism behavior (M linguistic feedback group = 5.961, SD linguistic feedback group = 1.09; M non-language feedback group = 4.675, SD non-language feedback group = 0.869), $F(1,296) = 126.653$, $P < 0.001$. This suggests that, compared to the non-language feedback group, the robotic linguistic feedback group more effectively promotes tourists' engagement in ecotourism behavior, thus confirming hypothesis H1.

Moderating effect testing was conducted. We utilized environmental responsibility as the moderating variable, robotic linguistic feedback as the independent variable, and tourists' ecotourism behavior as the dependent variable. We employed Process Model 1 to assess the moderating effect of environmental responsibility. The experimental results indicated that the interaction between environmental responsibility and robotic linguistic feedback significantly influenced tourists' ecotourism behavior ($\beta = 0.6774$, $P < 0.001$); environmental responsibility significantly affected tourists' ecotourism behavior ($\beta = 0.5086$, $P < 0.001$); and robotic linguistic feedback significantly impacted tourists' ecotourism behavior ($\beta = 1.2078$, $P < 0.001$). Consequently, environmental responsibility has a significant moderating effect on the relationship between robotic linguistic feedback and tourists' ecotourism behavior, as illustrated in (Fig. 2), thereby confirming Hypothesis H2.

We controlled for tourists' emotions by including them as covariates in the analysis[72].The analysis of covariance results indicated that there was no significant impact of tourists' emotions on ecotourism behavior between the two groups with robotic linguistic feedback ($F(1,296) = 62.932$, $P < 0.001$). Therefore, tourists' emotions did not significantly influence the experimental outcomes.

Discussion

In Experiment 2a, we demonstrated that environmental responsibility has a significant moderating effect on the relationship between robotic linguistic feedback and tourists' ecotourism behavior. When tourists perceive a higher level of environmental responsibility, the linguistic feedback provided by robots is more effective in promoting their eco-friendly behaviors. Environmental responsibility, as a factor influencing perceived behavior, enhances the stimulating effect of robotic feedback, increasing tourists' identification with the robotic linguistic feedback and eliciting deeper intrinsic motivation. Furthermore, we ruled out the influence of tourists' emotions on the experimental outcomes. However, Experiment 2a used cross - sectional data for mediation analysis. The sample was selected at a specific time point, which may not represent the entire population's characteristics, potentially causing research bias. To enhance the accuracy of the research results, we conducted Experiment 2b, using longitudinal data to demonstrate the moderating effect of environmental responsibility.

Experiment 2b: longitudinal test of the moderating role of environmental responsibility

Experimental design

Experiment 2b employed a 2 (robot language feedback: yes vs. no) × 2 (environmental responsibility: high vs. low) between - subjects longitudinal experimental design to assess the moderating role of environmental responsibility. Referring to Huang, et al.[70] longitudinal experimental design, we recruited 253 participants at T1 (March 7, 2025) and T2 (March 15, 2025). All participants were randomly assigned to either the language feedback group (136 individuals) or the non - language feedback group (117 individuals). The experimental stimuli and measurement items used in Experiment 2b were consistent with those in Experiment 2a. Specific demographic information is presented in (Table 1).

Experimental results

Consistent with the main effect test in Experiment 2a, the results indicated a significant effect of robot language feedback on tourists' ecotourism behavior (M language feedback group = 5.365, SD language feedback group = 1.217; M non - language feedback group = 4.313, SD non - language feedback group = 0.745), $F(1, 251) = 66.032$, $P < 0.001$. This suggests that robot language feedback is more effective than non - language feedback in promoting ecotourism behavior, thereby validating H1.

For the moderation test, we examined the moderating effect of environmental responsibility using Process Model 1. The results revealed a significant interaction effect between environmental responsibility and robot language feedback on tourists' ecotourism behavior ($\beta = 0.675$, $P < 0.001$). Additionally, environmental responsibility ($\beta = 0.4213$, $P < 0.001$) and robot language feedback ($\beta = 1.1014$, $P < 0.001$) each had significant effects on tourists' ecotourism behavior. Thus, environmental responsibility significantly moderates the relationship between robot language feedback and tourists' ecotourism behavior, confirming H2, as illustrated in (Fig. 3).

Discussion

Experiment 2b reaffirmed H2 through a longitudinal study and tested the main effect from Experiment 1. In Experiment 2, participants in the language feedback group with high environmental responsibility exhibited higher ecotourism behavior than those with low environmental responsibility. In contrast, no significant difference was found between the high and low environmental responsibility groups in the non - language

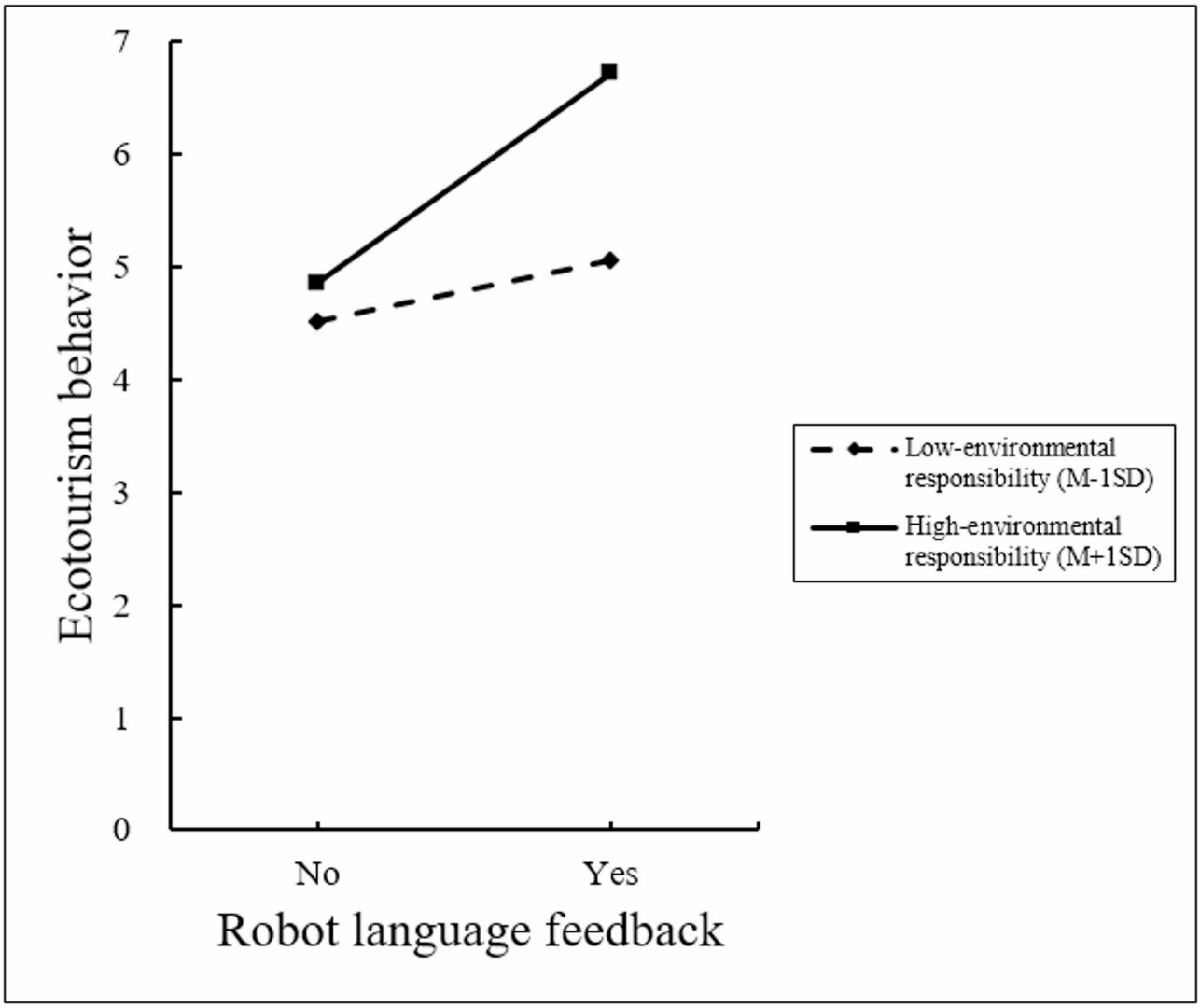

Fig. 2. Interaction effect result graph.

feedback group. Despite these findings, Experiment 2b did not further examine whether there is a mediating mechanism between robot language feedback and ecological behavior. Therefore, in Experiment 3, we introduced cognitive trust and feedback tendency as mediators to verify the chain - mediating effect of robot language feedback on tourists' ecotourism behavior.

Experiment 3a: the serial mediating role of cognitive trust and feedback inclination

Experimental design

Experiment 3a aims to explore the serial mediating role of cognitive trust and feedback inclination between robotic linguistic feedback and tourists' ecotourism behavior. We designed a one-factor between-subjects experiment (robotic linguistic feedback: present vs. absent) and recruited 250 participants on the professional survey platform Jian Shu (https://www.credamo.com/), from which 15 participants were excluded due to consistent questionaire filling and failure to pass the attention check. Subsequently, all participants were randomly assigned to two groups: the linguistic feedback group (117 people) and the non-language feedback group (118 people).

Experimental procedure

We asked all participants to imagine that they were touring a mountainous scenic area with a forest coverage rate of 80%. At that moment, they were enjoying the natural beauty on the mountainside when a strong wind blew a plastic bottle from their hands to a nearby trash bin. Subsequently, in the linguistic feedback group, the robot approached and verbally reminded them: "Protecting the environment is everyone's responsibility; please do not litter." In contrast, in the non-language feedback group, the robot's display screen showed the message: "Protecting the environment is everyone's responsibility; please do not litter." Next, participants were required to answer questions measuring cognitive trust[73], such as: "Regarding the robot's feedback, I believe my privacy

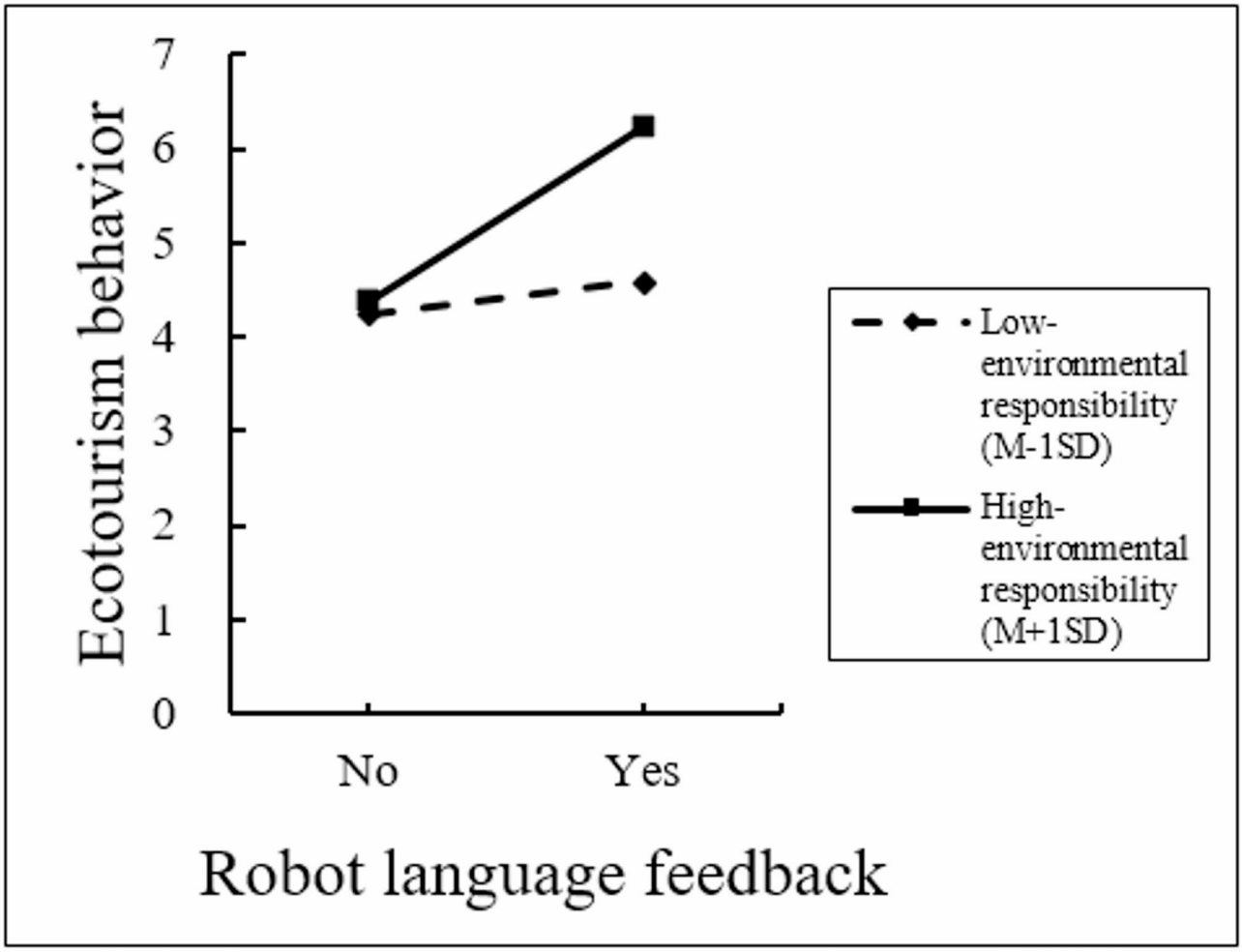

Fig. 3. Interaction effect result graph in experiment 2b.

will be protected." Following that, we inquired about feedback inclination with questions like[74]: "The robot's feedback makes me appreciate detailed, critical evaluations, even if it may cause harm." Meanwhile, participants also needed to respond to questions measuring tourists' ecotourism behavior. Consistent with Experiment 2, we controlled for tourists' emotions and used the same questions for measurement. Finally, we collected demographic information related to the participants.

Experimental results

Main effect testing was conducted. We used robotic linguistic feedback (present vs. absent) as the independent variable and tourists' ecotourism behavior as the dependent variable, performing a one-way ANOVA. The experimental results indicated that the tourists' ecotourism behavior in the linguistic feedback group ($M = 6.005$, $SD = 0.959$) was significantly higher than that in the non-language feedback group ($M = 4.55$, $SD = 0.756$), $F(1, 233) = 166.647$, $P < 0.001$. This suggests that under the influence of robotic linguistic feedback, tourists are more willing to engage in ecotourism behavior, thus confirming hypothesis H1.

Serial mediation test

We employed cognitive trust and feedback inclination as mediating variables, robotic linguistic feedback as the independent variable, and tourists' ecotourism behavior as the dependent variable. We utilized Process Model 6 to validate the serial mediating roles of cognitive trust and feedback inclination (Bootstrap sample: 5000;[75]. The experimental results indicated that the mediating effect of robotic linguistic feedback—cognitive trust—tourists' ecotourism behavior was significant ($\beta = 0.083$, $SE = 0.041$; 95% CI [0.01 ~ 0.1718]); the mediating effect of robotic linguistic feedback—feedback inclination—tourists' ecotourism behavior was significant ($\beta = 0.06$, $SE = 0.032$; 95% CI [0.0016 ~ 0.1294]); and the serial mediating effect of robotic linguistic feedback—feedback inclination—cognitive trust—tourists' ecotourism behavior was significant ($\beta = 0.0365$, $SE = 0.023$; 95% CI [0.0006 ~ 0.0906]). Specifically, robot language feedback has a significant positive impact on feedback inclination ($\beta = 0.4625$, $p < 0.01$), verifying Hypothesis H3. Robot language feedback also has a significant positive impact on tourists' cognitive trust ($\beta = 0.4486$, $p < 0.001$), verifying Hypothesis H6. Additionally, robot language feedback has a significant positive impact on tourists' ecotourism behaviors ($\beta = 1.2751$, $p < 0.001$), verifying Hypothesis

H1. Tourists' feedback inclination has a significant positive impact on ecotourism behaviors (β = 0.1795, $p < 0.01$), verifying Hypothesis H7, and tourists' cognitive trust has a significant positive impact on ecotourism behaviors (β = 0.1344, $p < 0.05$), verifying Hypothesis H5. Tourists' feedback tendency positively influences their cognitive trust (β = 0.5874, $P < 0.001$), verifying Hypothesis H4. This suggests that cognitive trust and feedback inclination fully mediate the relationship between robotic linguistic feedback and tourists' ecotourism behavior, see (Fig. 4), thus confirming hypothesis H8.

Control variable analysis

Consistent with Experiment 2, we included tourists' emotions as a covariate and performed a covariance analysis. The results indicated that tourists' emotions had no significant effect on tourists' ecotourism behavior ($F(1, 233) = 30.687$, $P < 0.001$). Therefore, tourists' emotions did not significantly influence the experimental outcomes.

Discussion

In Experiment 3a, we validated the serial mediating roles of cognitive trust and feedback inclination between robotic linguistic feedback and tourists' ecotourism behavior. Robotic linguistic feedback enhances tourists' cognitive trust, which effectively increases their willingness to accept information and take action, translating into a higher feedback inclination, ultimately leading to a greater tendency for tourists to engage in eco-friendly tourism behaviors.

Experiment 3b: longitudinal chain—mediating effect of cognitive trust and feedback tendency

Experimental design

Experiment 3b aimed to explore the longitudinal chain - mediating effect of cognitive trust and feedback tendency. Referring to Huang, et al.[70] longitudinal experimental design, we recruited 542 participants at T1 (March 7, 2025) and T2 (March 15, 2025). All participants were randomly assigned to either the language feedback group (279 individuals) or the non - language feedback group (263 individuals). The experimental stimuli and measurement items used in Experiment 3b were consistent with those in Experiment 3a. Specific demographic information is presented in (Table 1).

Experimental results

Consistent with the main effect test in Experiment 3a, results showed that tourists in the robot language feedback group had significantly higher ecotourism behavior (M = 6.03, SD = 0.953) than those in the non - language feedback group (M = 4.46, SD = 0.798), $F(1, 540) = 430.611$, $p < 0.001$. This indicates that robot language feedback effectively promotes tourists' ecotourism behavior, thereby validating H1.

Serial mediation test

We performed a chain mediation analysis, treating cognitive trust and feedback tendency as mediators, robot language feedback as the independent variable, and tourists' ecotourism behavior as the dependent variable. Using Process Model 6 (Bootstrap sample: 5000;[75], the results showed that the indirect effect of robot language feedback on tourists' ecotourism behavior through cognitive trust was significant (β = 0.0543, SE = 0.0213, 95% CI [0.0143, 0.098]). The indirect effect through feedback tendency was also significant (β = 0.053, SE = 0.0184, 95% CI [0.0168, 0.0887]). Furthermore, the chain mediation effect of robot language feedback on tourists' ecotourism behavior through both feedback tendency and cognitive trust was significant (β = 0.0501, SE = 0.0204, 95% CI [0.0164, 0.0969]). Specifically, robot language feedback has a significant positive impact on feedback tendency (β = 0.3001, $p < 0.01$), verifying Hypothesis H3. Robot language feedback also has a significant positive impact on tourists' cognitive trust (β = 0.1969, $p < 0.01$), verifying Hypothesis H6. Additionally, robot language feedback has a significant positive impact on tourists' ecotourism behaviors (β = 1.4156, $p < 0.001$), verifying Hypothesis H1. Tourists' feedback tendency has a significant positive impact on ecotourism behaviors (β = 0.1811, $p < 0.001$), verifying Hypothesis H7, and tourists' cognitive trust has a significant positive impact on ecotourism behaviors (β = 0.2692, $p < 0.05$), verifying Hypothesis H5. Tourists' feedback tendency positively influences their cognitive trust (β = 0.6203, $P < 0.001$), verifying Hypothesis H4. Thus, cognitive trust and feedback tendency

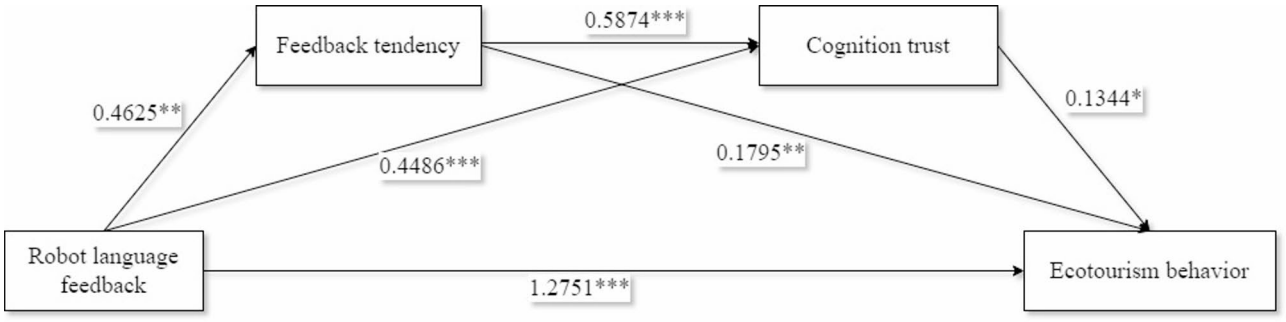

Fig. 4. Chain mediated path coefficient diagram.

were confirmed to be full chain mediators between robot language feedback and tourists' ecotourism behavior, supporting H8, see (Fig. 5).

Discussion

The consistent findings of Experiments 3a and 3b confirm that cognitive trust and feedback tendency fully mediate the relationship between robot language feedback and tourists' ecotourism behavior, thus supporting H6. Optimizing robot language feedback can enhance tourists' cognitive trust and positive feedback tendency, offering a better, more personalized ecotourism experience. This meets tourists' expectations, encourages sustainable ecotourism practices, and boosts their awareness and involvement in ecotourism, ultimately driving its sustainable development.

Experiment 4a: field experiment on cognitive trust and feedback tendency

Experimental design

We conducted a field experiment to explore the chain - mediating effect of cognitive trust and feedback tendency. We recruited 200 participants from a university in Anhui (Five participants withdrew during the experiment, and four failed to complete the post - experiment questionnaire). They were randomly divided into two groups: the language feedback group (85 participants) and the non - language feedback group (96 participants).

Procedure

We took the two groups of participants into separate experimental tourism environments and gave them the same instructions. Then, we guided the two groups into different experimental settings successively. In the non - language feedback group, the robot screen displayed "Everyone has a duty to protect the environment. Please do not litter." In the language feedback group, the robot verbally reminded participants, "Everyone has a duty to protect the environment. Please do not litter." Next, participants responded to cognitive trust items[73], such as "I believe my privacy will be protected regarding robot feedback". Then, we asked them about feedback tendency items[74], like "Robot feedback makes me prefer detailed and critical evaluations, despite possible negative impacts". Meanwhile, participants answered questions on ecotourism behavior and demographic information. Finally, participants who completed the experiment received 10 yuan as a reward.

Experimental results

The main effect test revealed that tourists in the robot language feedback group exhibited significantly higher ecotourism behavior ($M = 5.08$, $SD = 1.25$) compared to those in the non - language feedback group ($M = 4.517$, $SD = 0.916$), $F(1, 179) = 12.179$, $p < 0.001$. This indicates that robot language feedback effectively promotes tourists' ecotourism behavior, thereby validating H1.

Serial mediation test

We performed a chain mediation analysis with cognitive trust and feedback tendency as mediators, robot language feedback as the independent variable, and tourists' ecotourism behavior as the dependent variable. Using Process Model 6 (Bootstrap sample: 5000;[75], the results showed that the indirect effect of robot language feedback on tourists' ecotourism behavior through cognitive trust was significant ($\beta = -0.1318$, $SE = 0.0682$, 95% CI [−0.2832, −0.0119]). The indirect effect through feedback tendency was also significant ($\beta = -0.1315$, $SE = 0.0677$, 95% CI [−0.2802, −0.0234]). Furthermore, the chain mediation effect of robot language feedback on tourists' ecotourism behavior through both feedback tendency and cognitive trust was significant ($\beta = -0.0511$, $SE = 0.0214$, 95% CI [−0.097, −0.0128]). Specifically, robot language feedback has a significant impact on feedback tendency ($\beta = -0.6782$, $p < 0.001$), verifying Hypothesis H3. Robot language feedback also has a significant impact on tourists' cognitive trust ($\beta = -0.5991$, $p < 0.001$), verifying Hypothesis H6. Additionally, robot language feedback has a significant impact on tourists' ecotourism behaviors ($\beta = 0.8794$, $p < 0.001$), verifying Hypothesis H1. Tourists' feedback tendency has a significant impact on ecotourism behaviors ($\beta = 0.1943$, $p < 0.001$), verifying Hypothesis H7, and tourists' cognitive trust has a significant impact on ecotourism behaviors ($\beta = 0.2195$,

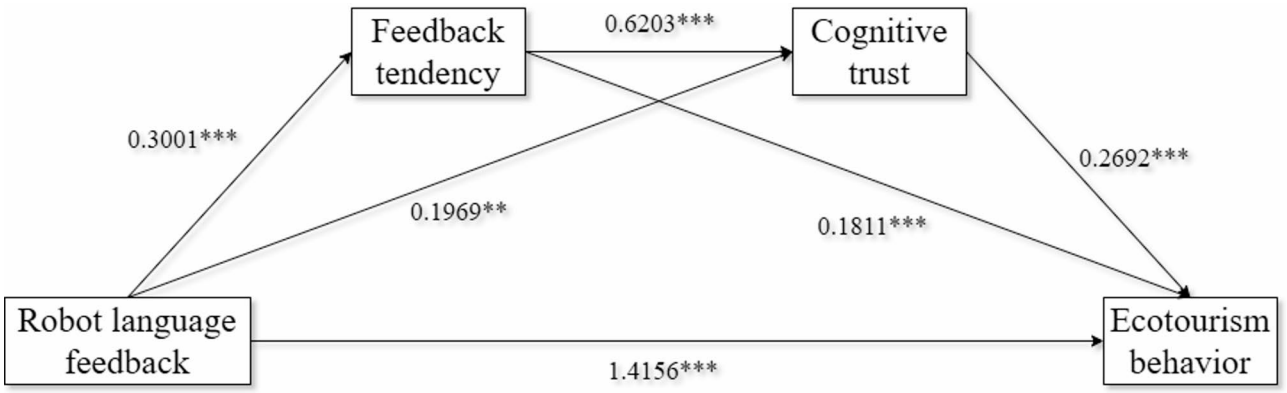

Fig. 5. Chain mediated path coefficient diagram in experiment 3b.

$p < 0.01$), verifying Hypothesis H5. Tourists' feedback tendency influences their cognitive trust (β = 0.3431, $P < 0.001$), verifying Hypothesis H4. Thus, cognitive trust and feedback tendency were confirmed to be full chain mediators between robot language feedback and tourists' ecotourism behavior, supporting H8, see (Fig. 6).

Discussion

In experiment 4a, we conducted a real - field experiment to re - validate H3 - H8. This experiment confirmed that cognitive trust and feedback tendency fully mediate the relationship between robot language feedback and tourists' ecotourism behavior. This further enhances the accuracy of our study and broadens its external validity.

Experiment 4b: field longitudinal experiment on cognitive trust and feedback tendency

Experimental design

In Experiment 4b, a longitudinal field experiment was conducted to explore the longitudinal chain mediating effect of cognitive trust and feedback disposition. Following the longitudinal experimental design of Huang, et al.[70], we recruited 379 participants at T1 (March 8, 2025) and T2 (March 15, 2025). All participants were randomly assigned to either the verbal feedback group (194 participants) or the non-verbal feedback group (185 participants). The experimental stimuli and measurement items used in Experiment 4b were consistent with those used in Experiment 4a. See Table 1 for specific demographic information.

Experimental results

The main effect test showed that the ecotourism behavior of tourists in the verbal feedback group (M = 6.269, SD = 0.744) was significantly higher than that in the non-verbal feedback group (M = 4.621, SD = 0.526), $F(1,377) = 613.095$, $p < 0.001$. This indicates that the robot language feedback effectively promotes the ecotourism behavior of tourists, thus validating H1.

Serial mediation test

We performed a chain mediation analysis with cognitive trust and feedback tendency as mediators, robot language feedback as the independent variable, and tourists' ecotourism behavior as the dependent variable. Using Process Model 6 (Bootstrap sample: 5000;[75], the results showed that the indirect effect of robot language feedback on tourists' ecotourism behavior through cognitive trust was significant (β = 0.1085, SE = 0.0361, 95% CI [0.0318, 0.1758]). The indirect effect through feedback tendency was also significant (β = −0.0426, SE = 0.0258, 95% CI [−0.102, −0.0028]). Furthermore, the chain mediation effect of robot language feedback on tourists' ecotourism behavior through both feedback tendency and cognitive trust was significant (β = −0.0227, SE = 0.0146, 95% CI [−0.0568, −0.0008]). Specifically, robot language feedback has a significant impact on feedback tendency (β=−0.1847, $p < 0.05$), verifying Hypothesis H3. Robot language feedback also has a significant impact on tourists' cognitive trust (β = 0.5198, $p < 0.001$), verifying Hypothesis H6. Additionally, robot language feedback has a significant impact on tourists' ecotourism behaviors (β = 1.6049, $p < 0.001$), verifying Hypothesis H1. Tourists' feedback tendency has a significant impact on ecotourism behaviors (β = 0.2304, $p < 0.001$), verifying Hypothesis H7, and tourists' cognitive trust has a significant impact on ecotourism behaviors (β = 0.2087, $p < 0.001$), verifying Hypothesis H5. Tourists' feedback tendency influences their cognitive trust (β = 0.5894, $P < 0.001$), verifying Hypothesis H4. Thus, cognitive trust and feedback tendency were confirmed to be full chain mediators between robot language feedback and tourists' ecotourism behavior, supporting H8, see (Fig. 7).

Discussion

We conducted a field longitudinal experiment in Experiment 4b to again verify the chain mediating role of feedback tendency and cognitive trust in robot verbal feedback and tourist ecotourism behavior, and again verify hypotheses H3 to H8.

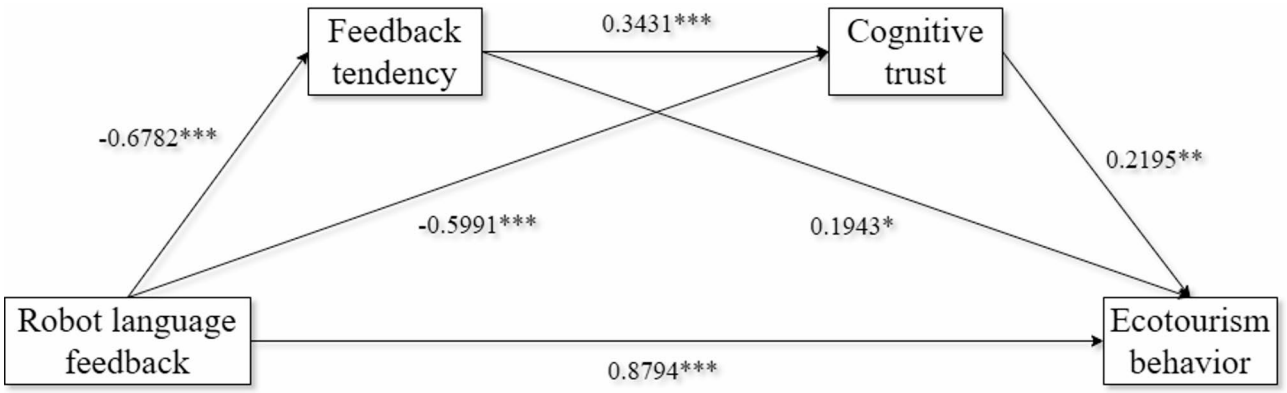

Fig. 6. Chain mediated path coefficient diagram in experiment 4a.

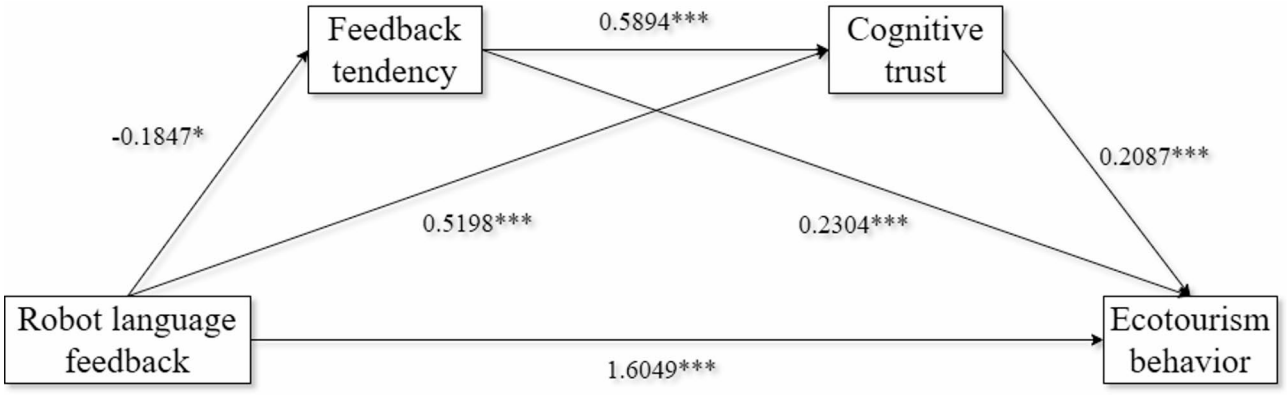

Fig. 7. Chain mediated path coefficient diagram in experiment 4b.

General discussion

Summary

This study validated eight hypotheses through eight scenario - based experiments, focusing on the impact of robot language feedback on tourists' ecotourism behavior and its mechanisms. Experiment 1a compared the ecotourism behavior of tourists receiving robot language feedback with those who did not, finding that robot language feedback significantly enhanced such behavior, thus validating H1. This experiment laid the groundwork for subsequent research, highlighting the potential of robot language feedback in influencing tourist behavior. Experiment 1b longitudinally replicated Experiment 1a, further confirming the positive impact of robot language feedback on tourists' ecotourism behavior and enhancing the reliability of the results. Experiment 2a introduced environmental responsibility as a moderator, revealing its significant regulatory role in the relationship between robot language feedback and tourists' ecotourism behavior, thereby validating H2. This indicates that tourists' sense of environmental responsibility can strengthen the effect of language feedback. Experiment 2b longitudinally replicated Experiment 2a, reaffirming the moderating role of environmental responsibility and further confirming the stability of H2. Experiment 3a explored the chain - mediating effect of feedback tendency and cognitive trust between robot language feedback and tourists' pro - environmental behaviors, preliminarily validating H3 - H8. The results showed that feedback tendency and cognitive trust sequentially mediated this relationship. Experiment 3b, a longitudinal experiment, further confirmed the results of Experiment 3a, validating the chain - mediating effect of feedback tendency and cognitive trust and reinforcing the reliability of H3 - H8. Experiments 4a and 4b were offline longitudinal experiments that again validated the chain - mediating effect of feedback tendency and cognitive trust. By using different feedback materials, these experiments enhanced the external validity of the results and further confirmed H3 - H8.

Theoretical contributions

This study makes several crucial theoretical contributions. Firstly, it significantly contributes to the understanding of the impact of robotic language feedback on tourists' ecotourism behaviors, particularly elucidating how the availability of language feedback from robots profoundly influences tourists' decision-making and behaviors during their travels[76]. With the ubiquitous adoption of intelligent technologies in tourism, scenic robots have emerged as pivotal tools for enhancing tourist experiences and guiding ecotourism practices[77]. Nonetheless, despite the advancing maturity of robotic technologies, scholarly investigations into the specific ways in which their language feedback influences tourist behaviors remain relatively scarce[78]. Prior research has delved into the effects of robotic interactions on tourist experiences[79], yet few have delved deeply into the direct role of the specific factor of robotic language feedback on tourists' ecotourism behaviors[80]. This study aims to bridge this research gap by designing experiments to contrast the different impacts of robots with and without language feedback on tourists' ecotourism behaviors, utilizing a rigorous experimental design to validate our hypotheses. The experimental results indicate that when scenic robots provide language feedback, tourists' ecotourism behaviors are significantly strengthened, with a heightened propensity to adopt environmentally friendly and sustainable tourism practices[81]. This finding not only elucidates the specific mechanism underlying the influence of robotic language feedback on tourist behaviors but also provides empirical evidence for how the tourism industry can more effectively harness intelligent technologies to promote ecotourism[82]. Consequently, this study opens new avenues for comprehending the application effects of robotic language feedback within the tourism sector.

Secondly, this study delves into the moderating role of environmental responsibility in the impact of robotic language feedback on tourists' ecotourism behaviors, offering a more comprehensive perspective on understanding tourist behaviors[83]. Our research recognizes that tourists' environmental responsibility, as an internal psychological state, can influence how they receive and respond to external information such as robotic language feedback[84]. Specifically, tourists with a stronger sense of environmental responsibility are more likely to actively attend to and respond to the language feedback about ecotourism provided by robots. This feedback not only reinforces their environmental awareness but also motivates them to take concrete actions to protect the natural environment[85]. Conversely, for tourists with weaker environmental responsibility,

the influence of robotic language feedback may be relatively limited. Importantly, this study builds upon the research of[86]by further demonstrating that factors influencing tourists' environmental behaviors encompass not only internal factors but also external stimuli, particularly linguistic stimuli. In summary, by revealing the moderating effect of environmental responsibility in the relationship between robotic language feedback and tourists' ecotourism behaviors, this study enriches the theoretical framework of factors influencing ecotourism behaviors. It underscores that in promoting ecotourism, attention should be paid not only to the application of technological means but also to the guidance and cultivation of tourists' internal psychological states (e.g., via robotic language feedback)[87]. This not only facilitates increased tourist participation in ecotourism but also promotes the sustainable development of the tourism industry.

Thirdly, in examining the impact of scenic robot language feedback on tourists' ecotourism behaviors, this study integrates theories of feedback processing and trust establishment from psychology to reveal how robotic language feedback shapes tourists' ecotourism behaviors by influencing their feedback tendency and cognitive trust[7]. Our findings indicate that the availability of language feedback from robots is directly correlated with tourists' feedback tendency—that is, their willingness to listen to and accept the robots' suggestions. More crucially, when robots provide feedback verbally, tourists' cognitive trust increases significantly, making them more inclined to believe in the robots' guidance and consider it a reliable reference for their ecotourism behaviors[88]. Specifically, our experiments reveal that when scenic robots offer language feedback, tourists' feedback tendency strengthens notably, causing them not only to pay closer attention to the robots' advice but also to proactively adjust their tourism behaviors to align with ecotourism standards[89]. Additionally, this verbal feedback effectively establishes tourists' cognitive trust in the robots by showcasing their professionalism and caring demeanor, and this sense of trust serves as a significant impetus for tourists to engage in eco-friendly behaviors[90]. Thus, this study not only uncovers the pivotal role of robotic language feedback in guiding ecotourism behaviors but also delves into the specific pathways of feedback tendency and cognitive trust as mediating mechanisms[91]. This discovery not only enriches the theoretical framework of robotic interaction design but also provides practical guidance for the tourism industry on how to effectively apply intelligent technologies to promote sustainable development.

Lastly, in investigating the impact of scenic robots on tourists' ecotourism behaviors, our research specifically focused on how the language feedback provided by robots (vs. non-language feedback) emerges as a crucial factor influencing tourist behaviors[92]. Through controlled experiments, we examined how robots equipped with language feedback functionality and those without such feedback interacted with tourists in an ecotourism context and observed how these interactions shaped tourists' feedback tendency and cognitive trust. Our findings indicate that when scenic robots offer language feedback, tourists' willingness to participate in ecotourism activities is significantly higher than when no language feedback is provided[93]. This suggests that language feedback, as a fundamental component of human-robot interaction, can notably enhance tourists' ecotourism experiences and foster their awareness and trust in environmentally responsible behaviors. Prior research has predominantly centered on advancements in robotic technology and its applications in tourism, with less emphasis on the specific modes of interaction between robots and tourists and their impacts[94]. Our study fills this gap, particularly by contrasting the presence and absence of language feedback to elucidate its unique role in ecotourism behaviors. Additionally, our research demonstrates that scenic robots' language feedback not only directly elevates tourists' ecotourism experiences but also potentially indirectly promotes their acceptance and adoption of ecotourism principles by strengthening their cognitive trust[95]. This discovery offers novel insights into the design and application of scenic robots, emphasizing the importance of emotional communication and information transmission in human-robot interactions to better serve the sustainable development goals of ecotourism.

Practical implications

Our research underscores the crucial role of scenic robots' language feedback (present and absent) in tourists' ecotourism behaviors, particularly with respect to shaping their feedback tendency and cognitive trust[96]. These findings offer a series of managerial implications for the design and management of tourist robots as well as ecotourism behaviors. Firstly, it is emphasized that robotic language feedback is not advocated as the sole determinant of tourists' ecotourism behaviors; although our analysis reveals its significant influence, this effect likely intertwines with various other factors. Nevertheless, robotic language feedback, as a straightforward and easily implementable mode of interaction, has the potential to notably enhance tourists' engagement and satisfaction during ecotourism experiences, thereby contributing to the sustainable development of ecotourism. Consequently, our study advises that scenic areas should prioritize and optimize their robots' language feedback capabilities[97]. By fostering friendly and personalized linguistic exchanges, these robots can enrich tourists' ecotourism experiences, fostering a positive shift in their feedback tendency and cognitive trust. This approach not only elevates tourists' overall satisfaction but also fosters a favorable reputation and repeat visitation for scenic areas.

Furthermore, when exploring the practical significance and relevance of scenic robots' language feedback on tourists' ecotourism behaviors, it is essential to refer to the norms observed in related fields regarding the magnitude of effects using similar research designs and variables. Specifically, in the context of ecotourism, routine observational studies focusing on tourists' feedback tendency and cognitive trust often reveal relatively small yet practically significant differences[98], which are attributable to the presence or absence of robotic language feedback. In particular, compared to scenarios without language feedback, the presence of language feedback from scenic robots exerts a comparable magnitude of influence on tourists' feedback tendency and cognitive trust in ecotourism behaviors, mirroring the effects of certain known factors that notably shape tourist behaviors[19]. Given that we have not identified a plausible explanation suggesting that the presence or absence of robotic language feedback operates entirely independently from other factors influencing tourists during

ecotourism experiences, this underscores the potential pivotal role of robotic language feedback in ecotourism behaviors[12]. Considering that scenic area managers are continually striving to enhance tourists' ecotourism experiences to foster sustainable tourism development, optimizing the language feedback capabilities of scenic robots may emerge as a viable strategy to more proactively shape tourists' feedback tendency and cognitive trust, thereby promoting positive ecotourism behaviors[99].

Lastly, our research also sheds light on the potential disparities in environmental responsibility[100] among tourists' ecotourism behaviors influenced by scenic robots' language feedback (vs. non-language feedback). Specifically, robots devoid of language feedback may inadvertently lead tourists to overlook the protection and respect for ecological environments in the absence of clear guidance, thereby diminishing opportunities for them to assume environmental responsibilities. Given the current trend of tourists seeking personalized travel experiences, we argue that scenic areas can balance tourists' individual needs with environmental protection responsibilities[101] by designing smarter and more instructive language feedback content. For instance, scenic areas can optimize their robots' language feedback systems to provide timely information and advice on environmental protection during ecotourism activities. In this manner, robots can raise tourists' awareness of the impact of their actions on ecological environments and encourage more responsible behaviors[102]. As tourists often find themselves in a relaxed and enjoyable state during travel, they may not actively attend to environmental protection issues. Consequently, the explicit and engaging language feedback from scenic robots emerges as a crucial factor in enhancing tourists' environmental responsibility consciousness. By consistently emphasizing the importance of environmental protection, robots can help tourists subconsciously develop respect and affection for ecological environments[103]. To further promote tourists' environmentally responsible behaviors[104], scenic areas can harness the language feedback capabilities of robots to foster a positive atmosphere. For example, robots can promptly acknowledge and praise tourists who engage in environmentally friendly behaviors, while gently yet firmly reminding those who exhibit inappropriate behaviors. In this way, scenic areas can encourage tourists to learn from and emulate each other's good environmental practices, collectively contributing to the sustainable development of ecotourism.

Limitations and future research

The present study acknowledges certain limitations. Firstly, it primarily focuses on the binary scenario of robots with and without language feedback, neglecting the potential exploration of more diversified types of language feedback, such as positive encouragement, objective description, or humorous styles, which could offer insights into the specific impacts of these varying feedback types on tourists' environmentally responsible behaviors[105]. Secondly, the study's sample may have been predominantly concentrated on tourist groups within the Chinese cultural context, overlooking the pivotal role of cultural differences in shaping tourists' perceptions and behaviors towards environmental responsibilities in ecotourism[106]. Hence, future research should incorporate more diversified cultural samples to comprehensively analyze the applicability and effectiveness of robotic language feedback across different cultural backgrounds.

Data availability

The data cannot be made publicly available upon publication because no suitable repository exists for hosting data in this field of study. The data that support the findings of this study are available upon reasonable request from the corresponding authors.

Received: 20 December 2024; Accepted: 2 May 2025
Published online: 08 May 2025

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Acknowledgements
The authors have confirmed that any identifiable participants in this study have given their consent for publication.

Author contributions
R.C.: Data analysis and writing of the first draft of the paper D.Y.: Data analysis and research questionnaire design D.L.: Data analysis J.C.: Assist in data analysis Y.W.: Assist in data analysis D.X. : Provide research funding support.

Declarations

Competing interests
The authors declare no competing interests.

Ethical statement
I confirm that all methods were performed in accordance with the relevant guidelines. All procedures were performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. I confirm that after we ask participants if they want to participate in the study, participants need to sign informed consent. All participants provided written Informed Consent for the study. This study was reviewed and approved by the Ethics Committee of Huainan Normal University.

Additional information
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