
RESEARCH ARTICLE

Effects of Repeated Exposure and Nature Type in Immersive Virtual Reality on Pro-Environmental Behavioral Intention

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ABSTRACT

The current study aims to examine the effects of immersive VR exposure type (single vs. repeated) and nature type presented (intact vs. destroyed) on nature relatedness and pro-environmental behavioral intention, while also taking into account the sense of environmental indebtedness as a moderating factor. A laboratory experiment (N= 207) was conducted using a 2 (exposure type to immersive 360° video: single vs. repeated) × 2 (Nature type: intact vs. destroyed) between-subjects design. The results showed that repeated exposure to immersive VR videos depicting destroyed natural environments led to the highest scores of nature relatedness. Moderated mediation analyses revealed that nature relatedness fully mediate the relationship between VR exposure characteristics (repetition and content type) and pro-environmental behavioral intention, and that sense of environmental indebtedness positively moderates the effect of nature relatedness on pro-environmental behavioral intention. This study stands out for its novel combination of two dimensions rarely explored together in immersive VR: the number of exposures (single vs. repeated) and the type of environmental content (intact vs. destroyed). It highlights not only the direct effect of these characteristics on nature relatedness, but also the full mediating role of this variable in the formation of pro-environmental intentions. The introduction of the sense of environmental indebtedness as a moderating factor constitutes an original contribution, as this concept is still rarely used in the literature.

KEYWORDS

Repeated exposure to immersive VR; nature type; nature relatedness; pro-environmental behavioral intention; sense of environmental indebtedness.

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1. Introduction

Ecological deterioration and environmental pollution constitute substantial worldwide concerns (Zhang et al., 2024). Environmental issues are generally driven by human lifestyle choices and actions, which lead to overexploitation of natural resources and serious disruptions in ecological systems (Morganti et al., 2017). Addressing these pressing ecological challenges needs profound changes in human behavior, with a focus on stimulating pro-environmental decision-making characterized by increased awareness of environmental concerns and the subsequent transition to sustainable practices (Yu et al., 2024). In recent years, environmental communication has emerged as a prominent area of interest for immersive VR, particularly through 360° videos experienced by HMD (Nouri et al., 2025). Therefore, immersive VR is becoming increasingly recognized as a powerful tool and persuasive medium for spotlighting the damaging effects of environmental concerns (Van Horen et al., 2024).

Numerous studies have highlighted the effectiveness and the persuasive power of immersive 360° videos in reinforcing pro-environmental attitudes and behaviors (Plechata et al., 2022). Nevertheless, a thorough examination of literature review revealed

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that, in contrast to other contexts, research on persuasive environmental communication in immersive media remains insufficient (Breves, 2023). Moreover, previous research has mostly investigated how immersive VR differs from non-immersive VR in terms of its effect on behavioral change (Thoma et al., 2023; Nouri et al., 2025). However, the majority of these studies have overlooked the potential benefits of repeated exposure in alleviating the adverse side effects of immersive VR such as cybersickness, and have predominantly relied on single session exposure, which may in fact induce such symptoms (Kourtesis et al., 2024; Nouri et al., 2025). Thus, a growing evidence demonstrates that the occurrence and severity of cybersickness steadily diminish with repeated exposure to HMD-based VR (Risi and Palmisano, 2019). Nonetheless, to the best of our knowledge, these studies have focused mainly on reducing cybersickness, without examining the potential effects of repeated exposure on nature relatedness and pro-environmental behavioral intentions. Furthermore, it has been widely demonstrated that exposure to nature is associated with various psychological and social benefits (Bratman et al., 2019). These benefits can promote a more positive perception of nature and, as a result, strengthen individuals' motivation to make an effort toward maintaining and preserving the intactness of the natural environment (Lange and Truysens, 2022). Although many studies have examined the impact of nature exposure on pro-environmental behaviors, the results remain mixed (Yu et al., 2024). Some research shows that viewing intact natural landscapes can increase environmental engagement (Zelenski et al., 2015; Ibanez and Roussel, 2022), while others report no significant effect (Klein and Hilbig, 2018; Lange and Truysens, 2022). These divergences suggest that simply contemplating intact landscapes is not always enough to inspire a desire to act and may even create the impression that no action is necessary (Klein and Hilbig, 2018). Conversely, exposure to degraded natural environment could increase the sense of urgency and encourage more responsible behavior (Klein and Hilbig, 2018; Yu et al., 2024). Even though, most of this research is based on single and/or traditional exposures, and, to our knowledge, no study has explored the effects of repeated exposures. Given these limitations, it is necessary to examine whether repeated immersive VR experiences, combined with variations in the type of nature (intact vs. destroyed), can strengthen nature relatedness.

Besides, while earlier research has supported the positive effect of nature relatedness (Liu et al., 2019; Van Horen et al., 2024) on pro-environmental behaviors, the underlying psychological mechanisms that shape the process of how affective reactions manifest in concrete eco-friendly practices, in the context of repeated immersive VR experiences combined with variations in nature type (intact vs. destroyed), have, to our knowledge, not yet been studied. Specifically, the moderating role of the sense of environmental indebtedness- considered as a feeling of obligation to protect the environment, grounded in moral values and principles (Xiong et al., 2018)- remains understudied. It is therefore essential to determine whether this feeling influences the effect of nature relatedness on pro-environmental behavioral intention. It is plausible that individuals with a strong sense of environmental indebtedness react differently than those with a weak sense.

Drawing upon the Stimulus-Organism-Response (SOR) model, the current research investigates how different stimuli (exposure type to immersive VR and nature type) affect individuals' affective (nature relatedness) states, which in turn shape their behavioral responses (pro-environmental behavior intention). Furthermore, it examines the moderating role of the sense of environmental indebtedness within the domain of interactions with the natural environment.

The structure of this paper is as follows: the first section presents theoretical foundations of immersive VR along with hypothetical relationships. The second section outlines the methodological protocol, detailing data collection through an experimental investigation and the subsequent analysis procedures. The following sections discuss the results, contributions, limitations, and future research directions.

2. Theoretical background and research hypotheses

2.1 Stimulus-Organism-Response theory

The SOR model was initially developed by Mehrabian and Russell (1974), suggesting that environmental stimuli trigger approach or avoidance behavior through an individual's internal state. The stimulus is the external environment that stimulates and affects an individual's internal state (Peng and Kim, 2014). Organism is considered as a mediating link between stimulus and response (Fu et al., 2021). Organism is an individual's internal state reflected in both cognitive and affective reactions (Zheng et al., 2019). The cognitive state represents a process of managing the situation during training (Fang, 2014). While affective state refers to emotional reactions of an individual, response refers to behavioral reactions to the stimulus (Mehrabian and Russell, 1974; Zhang et al., 2022). The SOR model has been widely used in order to explain consumer's behaviors or preferences, particularly by investigating the effect of external environmental factors on consumer's internal psychological state and eventual behavioral responses (Zhang et al., 2022). The SOR framework serves as a foundational model in consumer behavior research, offering valuable insights into the cognitive and emotional mechanisms through which individuals perceive and evaluate VR stimuli, and the subsequent behaviors these experiences provoke (Erensoy et al., 2024). This theory proves particularly effective in immersive VR settings, where rich sensory input plays a crucial role in eliciting targeted psychological responses (Jin et al., 2021). Empirical studies have supported the effectiveness of the SOR approach in illustrating the complex interplay between VR stimuli and consumer behavior, underscoring its applicability within the domain of emerging retail technologies (Jin et al., 2021).

Furthermore, emotional internal states have been widely emphasized in the SOR paradigm as the main organisms influencing behavioral responses to external stimuli (Mehrabian and Russell, 1974; Nagano et al., 2023; Bouallegue et al., 2025). In this approach, affective states are often prioritized as the primary organisms rather than cognitive states because they capture the experiential and emotional mechanisms underpinning consumer behavior. Unlike the existing literature of the SOR model, to our knowledge, the current research is the pioneer to adopt this theory regarding the repeated exposure to immersive VR in the context of natural environmental and to explain the relationships among stimuli (immersive VR video), organisms (nature relatedness), response (pro-environmental behavior), by highlighting nature relatedness as a deep affective bond and connection with the natural environment, the study underscores its stronger and pivotal role in shaping eco-friendly behavioral patterns compared to cognitive appraisals alone.

2.2 The effect of exposure type to immersive VR video on nature relatedness

Nature relatedness or nature connectedness refers to an individual's emotional connection with the natural environment (Zelenski and Nisbet, 2014). Previous studies have shown the effectiveness of immersive VR in cultivating and enhancing individuals' connectedness and relatedness to the nature environment. For example, Thoma et al. (2023) indicated that immersive VR video enhances individuals' sense of relatedness to nature more effectively than non-immersive VR. Likewise, Spangenberg et al. (2022) found that immersive VR simulations that place individuals in the perspective of being within a tree enhance their sense of connectedness to the natural environment. According to Biedermann et al. (2024), repeated exposure to immersive VR has been shown to effectively elicit emotional states. From this perspective, it can be argued that repeated exposure to immersive VR video can enhance individuals' sense of relatedness to the natural environment compared to single exposure to immersive VR. Consequently, we propose the following hypothesis:

H1: Repeated exposure to immersive VR video (vs. single exposure) positively influences nature relatedness

2.3 The effect of nature type on nature relatedness

Empirical evidence indicates that exposure to natural content provides various psychological and social advantages (Bratman et al., 2019), which can cultivate a deeper appreciation for nature, and in turn, increase individuals' commitment to conserving natural environments (Lange and Truysens, 2022). Previous experimental studies have investigated the effects of viewing natural versus urban environments in video format, demonstrating that nature-based content can encourage sustainable decision-making in social dilemmas (Zelenski, et al., 2015) and promote environmentally responsible behaviors, including charitable contributions and recycling (Ibanez and Roussel, 2022). The study of Klein and Hilbig (2018) identified a notable impact of exposing individuals to destroyed nature scenes, suggesting that media portraying ecological degradation is more effective in promoting pro-environmental behavior by highlighting the urgency of environmental protection. Recently, Yu et al. (2024) suggest that participants' efforts to protect the environment are higher when they are exposed to destroyed nature than when they are exposed to intact nature. Furthermore, previous research has underscored the beneficial physiological and emotional responses elicited by immersive exposure to natural environments through VR. According to Anderson et al. (2017), exposure to immersive virtual nature has also been found to decrease physiological arousal and alleviate negative emotional states. Additionally, research conducted by Wang et al. (2019) revealed that viewing 360° videos depicting various forest settings enhances mood and reduces stress levels. Exposure to virtual videos depicting natural environment elicited considerably higher levels of positive affect among participants than exposure videos of built environment (Newman et al., 2022). According to Van Horen et al. (2024), immersive VR video featuring space and earth natural environment increases individuals' sense of relatedness to nature. From this point of view, we expect that immersive VR video depicting destroyed nature can increase individuals' sense of relatedness to nature compared to intact nature. Thus, we propose the following hypothesis:

H2: Immersive VR video of destroyed nature (vs. intact nature) positively influences nature relatedness

2.4 The role of nature relatedness

Existing literature indicates that a connection with nature is associated to the intention to engage in more sustainable behaviors (Zelenski et al., 2015). For example, studies have demonstrated that individuals who feel deeply connected and related to nature are more likely to opt for vegan and vegetarian foods (Krizanova et al., 2021) and exhibit a greater willingness to contribute in environmental causes (Li et al., 2023). Prior research claimed a strong association between individuals' relatedness to nature and their engagement in pro-environmental behavior (Liu et al., 2019; Van Horen et al., 2024). Furthermore, Levstek et al. (2024) revealed that the relationship between media type (AR vs. video) and sustainability beliefs is mediated by emotional connectedness with nature in the field of immersive storytelling. Van Horen et al. (2024) found that nature relatedness totally mediates the link between technological immersiveness of VR and pro-environmental behaviors. Building on the SOR framework, individuals' internal states are recognized as a mediating process that connects external stimuli and conative responses. Grounded in the aforementioned studies, the following hypotheses are formulated:

H3a: Repeated exposure to immersive VR video (vs. single exposure) has a positive effect on pro-environmental behavioral intention, *indirectly* through nature relatedness

H3b: Immersive VR video of destroyed nature (vs. intact nature) has a positive effect on pro- environmental behavioral intention, *indirectly* through nature relatedness

2.5 The moderating effect of the sense of environmental indebtedness

A sense of environmental indebtedness refers to a voluntary consumer reaction to balancing emotional engagement with the natural environment, shaped by moral values and norms (Xiong et al., 2018). Consumers who are exposed to environmental pollution experience anxiety and humiliation (Kollmuss and Agyeman, 2002). While these feelings of guilt and indebtedness as negative emotions, they have an advantageous function in encouraging people to act in a way that conforms with moral principles and social standards (Pham, 2007). Research indicates that environmental guilt among Chinese consumers can activate a heightened sense of moral responsibility, which motivates them to engage in eco-friendly consumption as a compensatory response to environmental degradation (Qiu et al., 2020). The strength of the environmental guilt felt by consumers as a personally emotional response is influenced by differences in personal consumer traits (Park et al., 2015). Therefore, individuals who feel guilty about the environment are more likely to develop a stronger sense of moral obligation as their guilt grows, making them more willing to act in an environmentally friendly manner to alleviate their bad feelings (Sun and Xing, 2023). These authors examined that the sense of environmental indebtedness positively and significantly moderates the relationship between continued use of gamification and green consumption behavior. In light of these works, it is therefore plausible to suggest that the effect of nature relatedness on pro-environmental behavioral intention is amplified when individuals feel a strong sense of environmental indebtedness. Given the above considerations, we posit the following hypothesis:

H4: The sense of environmental indebtedness moderates the relationship between nature relatedness and pro-environmental behavioral intention

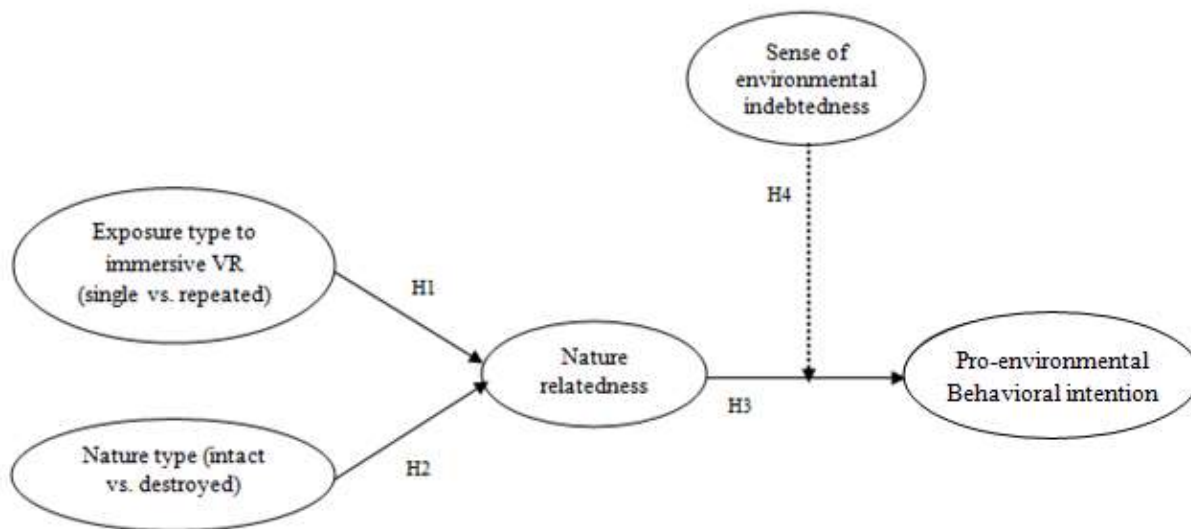


Figure 1: Conceptual model

3. Methodology

3.1 Design and procedure

This study aims to examine the impact of repeated exposure to immersive VR on consumer responses to a video depicting a destroyed or intact natural environment. Two 360° videos have been specially designed for this study. The first depicts a natural environment that has been severely degraded by human activity: a damaged landscape, felled trees, rubbish on the ground, a sky covered in pollution, accompanied by unpleasant sounds such as the roar of chainsaws. This video seeks to provoke a feeling of unease, loss or indignation. In contrast, the second video presents exactly the same environment, but in an intact, preserved and harmonious state: lush vegetation, pure air, soothing natural sounds (birdsong, rustling leaves, murmuring water), creating a serene and inspiring atmosphere. This version aims to evoke positive emotions such as serenity and admiration.

To achieve the objectives of this study, a laboratory experiment was conducted, using a between-subjects factorial design of 2 (exposure type to 360° immersive video: single vs. repeated) × 2 (state of environment: intact vs. destroyed). Participants were

university students recruited on a voluntary basis via the university's internal communication channels (mailing lists, etc.). They were given the opportunity to select their participation slot in order to maximize flexibility, reduce logistical constraints and limit waiting times. Three research assistants ensured the implementation of the protocol and the individual reception of participants.

Upon arrival, participants were informed of the voluntary nature of their participation, the confidentiality and anonymity of data gathering, and their right to withdraw at any time without consequence. After signing the informed consent form, participants were assigned to one of the four experimental conditions by random draw, using opaque face-down cards labeled: "*single exposure - intact nature*"; "*repeated exposure - intact nature*"; "*single exposure - destroyed nature*"; and "*repeated exposure - destroyed nature*". The draw was made directly by the participant, which ensured randomness of assignment while reducing potential experimental bias. This method also increased transparency and the participant's feeling of control over their participation in the study, thus contributing to respect for ethical principles and voluntary adherence to the experimental procedure. Participants in the single condition took part in a single laboratory session, while those in the repeated condition took part in four consecutive sessions spaced 24 hours apart, in accordance with the methodological recommendations of Doty et al. (2024). This organization aimed to guarantee scientific rigor of the study, ensure comparability with previous work and facilitate the reproducibility of results. Each session lasted between 25 and 30 minutes and was conducted using a VR headset (HMD), ensuring complete immersion in the assigned environment. After exposure, participants completed a questionnaire assessing their feeling of nature relatedness, their pro-environmental behavioral intention and their sense of environmental indebtedness. In the single condition, the questionnaire was administered immediately after the session; in the repeated condition, it was completed at the end of the fourth session.

3.2 Measures

The measurement scales employed in the experimental study draw on existing research to measure nature relatedness, pro-environmental behavioral intention and sense of environmental indebtedness and have been scrupulously adjusted to the present research context. *Nature relatedness* was assessed using six items sourced from the scale of Nisbet et al. (2009) reflecting the participants' level of connection and relationship with the nature. *Pro-environmental behavioral intention* was evaluated using four items derived from the study of Yu et al. (2024), indicating participants' intention to behave in an environmentally friendly way such as reducing ecological footprints, waste management and abstaining from plastic while shopping. The *sense of environmental indebtedness* was estimated using three items adapted from the scale of Qiu et al. (2020), capturing individuals' feelings of guilt and indebtedness while experiencing damage and harm to the natural environment. All items were scaled using a seven-point Likert scale type ranging from 1= strongly disagree to 7= strongly agree. Moreover, demographic information about *gender*, *age* and *educational level* was also collected.

4. Results

4.1 Demographic profile

The initial sample consisted of 210 students. Three participants assigned to the repeated exposure condition were excluded because they did not complete the required four sessions. The final sample retained for analyses therefore consisted of 207 individuals. The gender distribution indicates a female predominance (53.1% women versus 46.9% men). The average age of participants was 25.96 years (range: 18–38 years). Regarding educational level, 46.8% of respondents were enrolled in a license's degree, 30% in a master's degree, and 23.2% in a doctoral degree. Detailed demographic characteristics of participants are presented in Table 1.

Table 1: Respondents' profile

		Frequency	Percentage
Gender	Woman	110	53.1
	Men	97	46.9
Education level	Licence's degree	97	46.8
	Master's degree	62	30
	Doctoral degree	48	23.2
Age	Mean	25.96	Range
			18-38 years

4.2 Randomization Check

To ensure that the differences observed between the four experimental groups were indeed attributable to the manipulation of exposure type to immersive video (single vs. repeated) and nature type (intact vs. destroyed), randomization control analyses were conducted. The objective was to verify the initial equivalence of the groups on a set of demographic variables likely to

affect the results. The comparisons revealed no statistically significant differences between the experimental conditions in terms of age ($F = .920$; $p = .339$), gender ($X^2_{\text{Exposure type}} = 2.608$, $p = .106$; $X^2_{\text{Nature type}} = .233$; $p = .629$), or educational level ($F = .310$; $p = .578$). These results indicate that the randomization procedure resulted in comparable groups, thereby strengthening the internal validity of the study. Hence, none of these variables were integrated as covariates in the hypothesis testing.

4.3 Reliability and validity analyses

A preliminary test for common method bias (CMB) was conducted prior to the validity and reliability analyses to ensure methodological rigor of the study. CMB poses a serious threat to the survey reliability and validity (Podsakoff et al., 2003). In view of this, Harman's single factor test was conducted and the results show that the single factor explained 39% of the total variance, which was below than the 50% threshold, thus the CMB is not an issue for this study. Following the constructs' reliabilities, Cronbach Alpha and composite reliability (CR) were calculated. As depicted in Table 2, Cronbach alpha and CR values exceeded the recommended criterion of 0.7, suggesting that the items were internally consistent (Nunnally and Bernstein, 1994). Furthermore, the AVE values are greater than the benchmark of 0.5, ranging from 0.727 to 0.785, thus demonstrating convergent validity (Fornell and Larcker, 1981).

Table 2: Measures

Items	Cronbach's alpha	Composite reliability	AVE
Nature relatedness	.923	.941	.727
NR1			
NR2			
NR3			
NR4			
NR5			
NR6			
Pro-environmental behavioral intention	.922	.934	.779
BI1			
BI2			
BI3			
BI4			
The sense of environmental indebtedness	.915	.916	.785
SEI1			
SEI2			
SEI3			

4.4 Hypotheses testing

In order to test the research hypotheses, a two-way ANOVA analysis and two moderate mediation analyses using macro PROCESS, model 14, with 5000 *bootstraps* (Hayes, 2018) were performed. The use of two-way ANOVA analysis makes it possible to simultaneously assess the influence of exposure type (single vs. repeated) and nature type (intact vs. destroyed) on nature relatedness. It is used not only to measure the main effect of each factor taken in isolation, but also to examine their interaction. Thus, this method offers a comparison of the means between the different groups defined by the combination of the two factors. In these analyses, exposure type (single vs. repeated) was coded 0 and 1, respectively, and nature type (intact vs. destroyed), also coded 0 and 1, respectively.

The results of two-way ANOVA analysis (see Table 3) show a significant effect of exposure type (single vs. repeated) on nature relatedness ($F = 52.585$, $p < .001$, $\eta^2 = .206$). Specifically, participants repeatedly exposed to immersive 360° video reported significantly higher levels of nature relatedness than those exposed only once ($M_{\text{Repeated exposure}} = 4.24$ vs. $M_{\text{Single exposure}} = 3.08$). Thus, repetition of immersive VR experience appears to increase nature relatedness. The results also show a significant effect of nature type (intact vs. destroyed) on nature relatedness ($F = 79.548$, $p < .001$, $\eta^2 = .282$). Specifically, participants exposed to immersive 360° video of destroyed nature reported significantly higher levels of nature relatedness than those exposed to immersive 360° video of intact nature ($M_{\text{Destroyed nature}} = 4.37$ vs. $M_{\text{Intact nature}} = 2.94$). Thus, immersive 360° video of destroyed nature appears to increase nature relatedness. The results also indicate a significant interaction effect between exposure type and nature type on nature relatedness ($F = 5.076$, $p < .05$, $\eta^2 = .024$). Analysis of the means shows that repeated exposure to immersive video of destroyed nature is associated with the highest nature relatedness scores ($M_{\text{Repeated exposure to destroyed nature}} = 5.13$), followed by single exposure to immersive video of destroyed nature ($M_{\text{Single exposure to destroyed nature}} = 3.61$), then repeated exposure to immersive video of intact nature

($M_{\text{Repeated exposure to intact nature}} = 3.34$), and finally single exposure to immersive video of intact nature ($M_{\text{Single exposure to intact nature}} = 2.54$). These results suggest that the effect of exposure type on nature relatedness depends on the type of nature presented. In particular, videos of destroyed nature, when repeated, seem to strengthen nature relatedness more than other combinations of exposure and nature types. This indicates that the interaction between exposure type and nature type plays a key role in increasing nature relatedness.

Table 3: Results of two-way ANOVA analysis

Independent variables			Dependent variable			
			Nature relatedness			
			Mean	F	p	Eta ²
Exposure type	Single		3.08	52.585	.000	.206
	Repeated		4.24			
Nature type	Intact		2.94	79.548	.000	.282
	Destroyed		4.37			
Exposure type * Nature type	Single exposure	Intact	2.54	5.076	.025	.024
		Destroyed	3.61			
	Repeated exposure	Intact	3.34			
		Destroyed	5.13			

The first moderated mediation analysis (Figure 2) shows that repeated exposure to immersive 360° video (vs. single exposure) significantly and positively influences nature relatedness ($\beta = 0.58$; $p < 0.001$), thus supporting hypothesis *H1*. These results suggest that repeated exposure to immersive VR strengthens nature relatedness more than single exposure. Downstream, nature relatedness ($\beta = 0.27$; $p < 0.001$) has a significant and positive effect on pro-environmental behavioral intention. Furthermore, the indirect effect of repeated exposure to immersive 360° video (vs. single exposure) on pro-environmental behavioral intention was significant ($\beta = 0.18$; $p < 0.001$), while the direct effect was not ($\beta = 0.08$; $p > 0.05$). These results highlight a full mediation of nature relatedness in the relationship between exposure type and pro-environmental behavioral intention. In other words, repeated exposure to immersive VR (vs. single exposure) does not directly influence pro-environmental behavioral intention, but has an indirect positive effect through nature relatedness, supporting hypothesis *H3a*. The results also revealed a significant and positive interaction between nature relatedness and sense of environmental indebtedness ($M^*W = 0.11$; $p < 0.05$), on pro-environmental behavioral intention (*H4v*). These results suggest that the effect of nature relatedness on pro-environmental behavioral intention is reinforced when individuals feel a strong sense of environmental indebtedness.

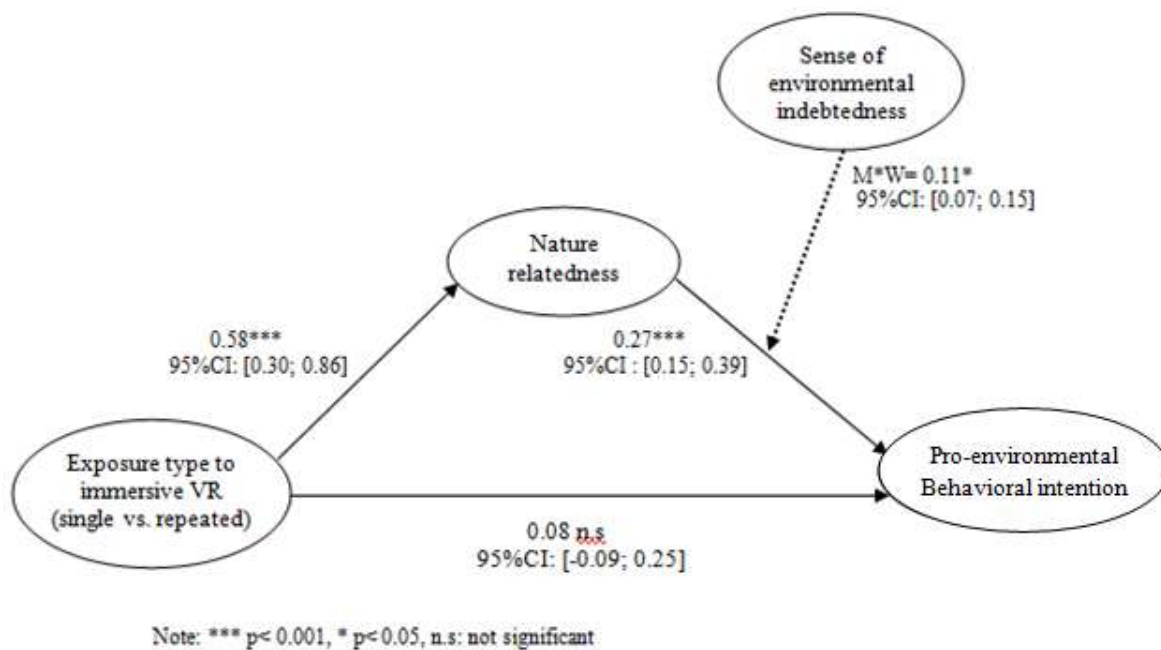


Figure 2: First moderated mediation analysis

The second moderated mediation analysis (Figure 3) shows that immersive VR video of destroyed nature (vs. intact nature) significantly and positively influences nature relatedness ($\beta = 0.69$; $p < 0.001$), thus supporting hypothesis H2. These results suggest that exposure to immersive VR video of destroyed nature strengthens nature relatedness more than exposure to intact nature. Downstream, nature relatedness ($\beta = 0.34$; $p < 0.001$) has a significant and positive effect on pro-environmental behavioral intention. Furthermore, the indirect effect of nature type (Intact vs. destroyed) on pro-environmental behavioral intention was significant ($\beta = 0.23$; $p < 0.001$), while the direct effect was not ($\beta = 0.09$; $p > 0.05$). These results highlight a full mediation of nature relatedness in the relationship between nature type (intact vs. destroyed) and pro-environmental behavioral intention. In other words, exposure of immersive VR video of destroyed nature (vs. intact nature) does not directly influence pro-environmental behavioral intention, but has an indirect positive effect through nature relatedness, supporting hypothesis H3b. The results also revealed, similarly to the result of the first moderate mediation analysis, a significant and positive interaction between nature relatedness and sense of environmental indebtedness ($M*W = 0.13$; $p < 0.05$), on pro-environmental behavioral intention (H4√).

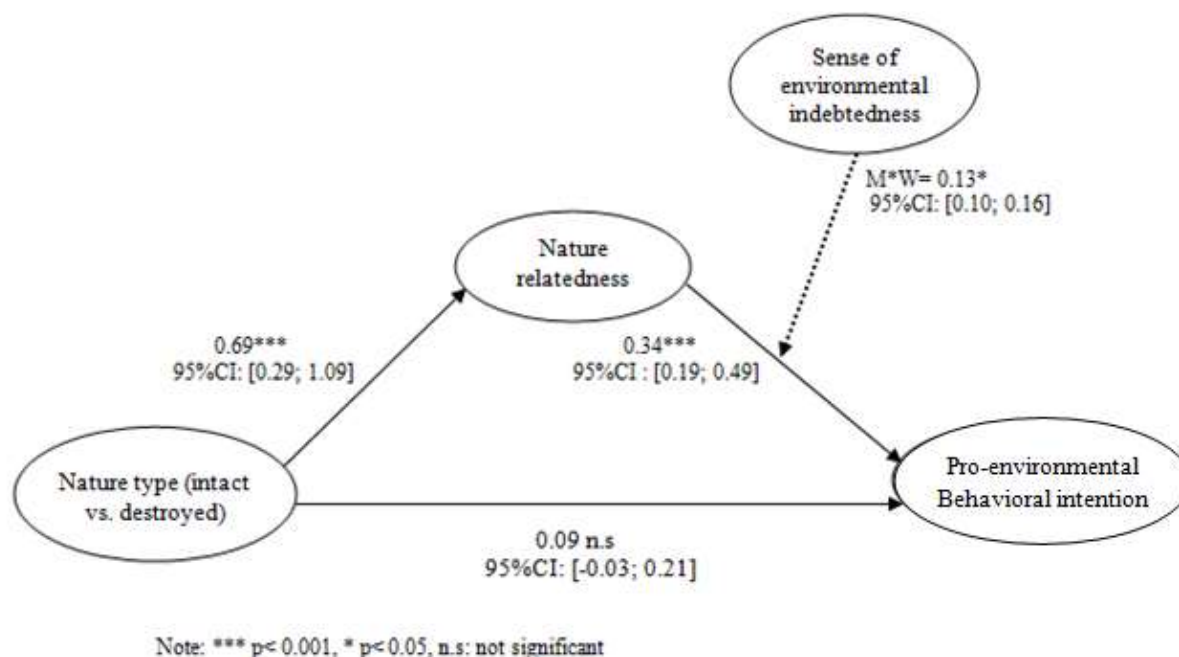


Figure 3: Second moderated mediation analysis

5. Discussion

The results of this study show that repeated exposure to immersive 360° video significantly and positively influences nature relatedness. This finding extends previous studies (Spangenberg et al., 2022; Thoma et al., 2023), which demonstrated the effectiveness of immersive VR in increasing individuals' connectedness and relatedness to the nature environment. Moreover, by emphasizing the importance of repetition, the significant effect observed on nature relatedness is consistent with the research of Biedermann et al. (2024), who showed that repeated exposure to immersive VR intensifies emotional responses. This emotional reinforcement could explain why multiple exposures to immersive video lead to a stronger sense of nature relatedness, compared to a single exposure. Repeated exposure is therefore not limited to reproducing the same content: it consolidates the emotional impact and amplifies the connection with the natural environment.

The results also show that exposure to immersive video depicting destroyed nature (vs. intact nature) has a significant and positive influence on nature relatedness. This result may seem counterintuitive, as one might expect that intact nature would elicit more connection. However, it is consistent with the work of Newman et al. (2022), who showed that exposure to virtual natural environments, compared to built environments, generates more positive affects and strengthens the relationship with nature. Furthermore, Van Horen et al. (2024) showed that immersive VR environments promote a sense of relatedness to nature. In our case, the representation of destroyed natural environment seems to activate a particular emotional mechanism: confrontation with loss or threat raises awareness of the value of nature and, paradoxically, strengthens the sense of connection and responsibility toward it.

Moreover, the study's findings demonstrate that repeated exposure (vs. single exposure) to immersive VR videos, as well as exposure to videos depicting destroyed nature (vs. intact nature), both have a positive effect on pro-environmental behavioral

intention, indirectly via nature relatedness. These results reinforce the idea that internal psychological mechanisms play a decisive role in the transition from immersive experience to pro-environmental action. The indirect effect via nature relatedness confirms the importance of affective dimension in eco-friendly patterns. Thus, Levstek et al. (2024) showed that emotional connection with nature plays a mediating role between media type and sustainability beliefs. Similarly, Van Horen et al. (2024) observed that nature relatedness fully mediates the link between VR immersion and pro-environmental behavior. In line with this, our results highlight that immersive VR, by strengthening feelings of belonging and closeness to nature — particularly through repeated exposure and depictions of destroyed nature — indirectly promotes pro-environmental behavioral intentions. This finding is consistent with the SOR (Stimulus-Organism-Response) model proposed by Mehrabian and Russell (1974), according to which internal states (in this case, nature relatedness) constitute a mediating mechanism linking external stimuli (nature type and exposure type to immersive VR) to behavioral responses (pro-environmental intention).

Finally, the results of this research show that the sense of environmental indebtedness moderates the relationship between nature relatedness and pro-environmental behavioral intention. In other words, when individuals feel a strong sense of indebtedness to the environment, the effect of their sense of nature relatedness on their behavioral intentions is amplified. These results are consistent with research highlighting the role of negative moral emotions—such as guilt—in motivating pro-environmental behavior. Qiu et al. (2020) showed that environmental guilt can strengthen feelings of moral responsibility, prompting individuals to compensate for ecological degradation through more environmentally friendly consumption choices. In the same vein, Sun and Xing (2023) observed that individuals who feel increased guilt toward the environment develop a stronger sense of moral obligation, which increases their willingness to adopt pro-environmental behaviors in order to alleviate these unpleasant emotions.

6. Conclusion

6.1 Theoretical contributions

This research makes several contributions to the literature on environmental psychology and the use of immersive technologies. First, it fills an important gap by examining the combined effects of exposure type to immersive VR (single vs. repeated) and nature type (intact vs. destroyed), an aspect that, to the best of our knowledge, has not yet been studied in existing research. While prior studies have primarily investigated exposure to a single session (Thoma et al., 2023; Nouri et al., 2025). The results show that repeated exposure to immersive VR, particularly to content depicting destroyed nature, intensifies nature-relatedness, highlighting the fundamental role of emotional processes in the formation of pro-environmental behavioral intentions. Second, this research clarifies the underlying mechanisms linking VR exposure characteristics (repetition and content type) to pro-environmental behavioral intentions. It identifies nature-relatedness as central psychological mechanisms that motivate these intentions. By showing that the effect of VR exposure characteristics (repetition and content type) operates indirectly through nature relatedness, this study emphasizes the decisive role of internal processes rather than the simple attributes of immersive experience. Furthermore, it underscores the importance of environmental indebtedness as a moderating variable, which amplifies the relationship between psychological mechanisms (O) and behavioral response (R). By simultaneously integrating mediation and moderation effects into a S–O–R perspective, this research offers a more nuanced explanatory framework for the psychological processes through which immersive technologies influence the transition from immersive experience (S) to pro-environmental action (R). It thus enriches the literature in environmental psychology and immersive communication by specifying not only whether but also under what conditions immersive experiences can promote the adoption of pro-environmental behaviors.

6.2 Managerial contributions

The results of this study offer several concrete insights for managers and decision-makers involved in environmental communication and the promotion of pro-environmental behaviors. Firstly, the study shows that repeated exposure to immersive VR videos generates higher nature relatedness than single exposure. For managers, this suggests that awareness campaigns should focus not only on high-quality immersive experiences, but also on repeating them over time in order to strengthen individuals' psychological engagement and maximize the impact on pro-environmental behaviors. Secondly, immersive content type appears to be a key strategic lever. The results indicate that immersive videos depicting destroyed nature generate stronger connection to nature than videos depicting intact nature. Therefore, organizations can tailor their VR content to the goals of their campaigns. For instance, employing degraded natural environment in immersive VR to generate support and promote sustainable behavior. This involves designing immersive content that provokes a strong emotional response, capable of mobilizing nature relatedness as lever to guide the behavior of target audiences. Thirdly, the moderating role of environmental indebtedness provides useful and promising insights for policymakers and campaigns in favor of sustainability. Findings demonstrate that when individuals feel a strong sense of indebtedness toward the environment, the positive impact of nature relatedness on pro-environmental behavior is accentuated. This implies that awareness-raising campaigns will have a more powerful impact if individuals evoke a feeling of responsibility and obligation toward the natural environment. In practical terms, companies can incorporate messages that underline humanity's debt to the environment. For

example, by portraying sustainability as a form of “giving back” to nature or restoring balance (Sun and Xing, 2023), ultimately heightening the effectiveness of actions and efforts to promote sustainable behavior. Moreover, environmental indebtedness can be considered as a psychographic segmentation criterion that can assist in personalizing strategies for various audiences. For businesses, policymakers and organizations promoting sustainability, this means that communication strategies should incorporate elements that remind people of their individual and collective responsibility toward the environment. For example, for individuals with a strong sense of environmental indebtedness, campaigns should highlight their contribution in environmental protection and show how their actions make a real difference. On the other hand, for individuals with a low sense of environmental indebtedness, it is preferable to create clear and informative messages of health benefits, emphasizing the concrete consequences of inaction and showing that others are already adopting responsible behaviors. Finally, the study provides a practical framework for incorporating both repeated exposure and immersive content typology, and taking into account psychological mechanisms and sense of environmental indebtedness, marketers have a more strategic approach to maximizing the impact of their initiatives. This approach not only makes it possible to measure the effectiveness of immersive experiences, but also to identify the conditions under which they most effectively lead to pro-environmental patterns.

6.3 Limitations and future avenues of research

This study has several limitations that open up avenues for future research. Firstly, the sample consisted solely of Tunisian university students, which limits the generalization of results to other age groups, cultural contexts or socio-economic backgrounds. Future research could include more diverse populations in order to test the robustness of the observed effects and examine cultural variations in response to immersive VR. Moreover, it is wise that future research could compare the efficacy of immersive VR in fostering pro-environmental behaviors across different countries and diverse populations through a cross-cultural study. Secondly, experimental study was conducted in a laboratory setting. Future research could implement immersive interventions in the field to strengthen the external validity of the study and favor the generalization of results. Thirdly, the variables were assessed through self-reporting, which may introduce biases related to social desirability or the expectancy effect (Beattie and Sale, 2011; Thoma *et al.*, 2023). Participants may present themselves as more respectful of the environment than they actually are, or tailor their responses to perceived expectations (Nouri *et al.*, 2025). To reduce these biases, future studies could combine questionnaires with objective behavioral or physiological measures. For example, it would be possible to track participants' actual pro-environmental behaviors after immersive exposure (waste sorting, reducing plastic use, participating in ecological actions) or use physiological and neurological indicators (heart rate, skin conductance, brain imaging) to assess emotional responses related to nature relatedness. Moreover, one of the main limitations of this research lies in the absence of a significant direct effect of immersive VR exposure characteristics (repetition frequency and content type) on pro-environmental behavioral intention, although these exert a positive influence on nature relatedness. This result thus highlights the conceptual limitations of the model used and suggests that other variables could play a more determining role in the formation of pro-environmental behavioral intention. To fill this gap, future research could include cognitive organism states, such as environmental awareness to better grasp the cognitive mechanisms that shape pro-environmental behaviors. Finally, qualitative approaches could enrich our understanding of psychological mechanisms at work. Semi-structured interviews or focus groups could explore in depth how participants perceive nature represented in VR, what emotions or reflections it elicits, and how these experiences influence their actual intentions or behaviors. These methods would complement quantitative measures and shed light on internal processes, motivations and barriers not captured by self-reports.

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