Natural Symbiosis Practitioners: Psychological and Neural Mechanisms of How Natural Sounds and Environmentalism Facilitate Pro-Environmental Purchase Decisions [open review]

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Abstract

Nudging pro-environmental purchase decisions is an important strategy for achieving sustainable development. This study investigated the effects of natural sounds and environmentalism on pro-environmental purchase decisions and the underlying physiological mechanisms through the SHOP task. The results showed that under the influence of natural sounds, the pro-environmental product purchase rate of individuals with high environmentalism significantly increased. During the phase of viewing pro-environmental product information, natural sounds effectively reduced the heart rate of high-environmentalism individuals and enhanced the power of beta waves in their right prefrontal cortex. During the price information phase, high-environmentalism individuals showed no significant differences in heart rate and beta wave power between pro-environmental and non-pro-environmental products. Further analysis revealed that heart rate during the product information phase significantly predicted changes in brain beta wave power during the subsequent price information phase. These results suggest that natural sounds enhanced attention to pro-environmental products among high-environmentalism individuals during the product information phase, while high-environmentalism individuals were not sensitive to additional price information. More importantly, changes in heart rate may serve as physiological feedback, modulating the brain's response patterns to information. In conclusion, this study, based on nudge theory, revealed the role of natural sounds and environmentalism in promoting pro-environmental purchase decisions and their cardiac and neural mechanisms, providing insights for nudging pro-environmental decisions.

Full Text

Preamble

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Research Highlights:
(1) Building upon previous research on the influence of natural sounds on pro-environmental purchase decisions, this study incorporates environmental movement activism to further understand the boundary conditions under which nudge theory exerts positive effects on pro-environmental purchase decisions.
(2) This study explores the physiological mechanisms through which natural sounds and environmentalism influence pro-environmental purchase decisions using cardiac and neural attention metrics, providing novel cardiac and neural attention indicators for the physiological mechanisms underlying nudge theory.

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Natural Symbiosis Practitioners: The Cardiac and Neural Mechanisms by Which Natural Sounds and Environmentalism Nudge Pro-Environmental Purchase Decisions

Abstract

Nudging pro-environmental purchase decisions represents an important strategy for achieving sustainable development. This study investigated the influence of natural sounds and environmental movement activism on pro-environmental purchase decisions and their underlying physiological mechanisms through a SHOP task. The results revealed that natural sounds significantly increased the purchase rate of pro-environmental products among individuals with high environmental movement activism. During the product information viewing phase, natural sounds effectively reduced heart rate and enhanced right prefrontal beta wave power among high environmentalism individuals. During the price information phase, no significant differences in heart rate or beta wave power were observed between pro-environmental and non-environmental products for high environmentalism individuals. Further analyses indicated that heart rate during the product information phase significantly predicted subsequent changes in brain beta wave power during the price information phase. These findings suggest that natural sounds enhance attention to pro-environmental products among high environmentalism individuals during the product information stage, while these individuals remain relatively insensitive to additional price information. Importantly, changes in heart rate may serve as physiological feedback that modulates the brain's response patterns to information. In summary, this study reveals the effects of natural sounds and environmentalism on pro-environmental purchase decisions and their cardiac-neural mechanisms based on nudge theory, providing insights for nudging pro-environmental decisions.

Keywords: pro-environmental purchase decisions; natural sounds; environmental movement activism; heart rate; β wave

Pro-environmental purchase decision refers to the process in which individuals seek to balance their personal needs with environmental protection during pro-environmental consumption (Steg & Vlek, 2009). Nudge theory posits that activating salient incentives can influence individuals' motivation and decision-making, thereby promoting voluntary compliance behaviors (Thaler & Sunstein, 2009). For example, compared with coercive interventions such as directly advertising pro-environmental products, having individuals watch videos of environmental pollution as a salient incentive more effectively promotes their preference for pro-environmental products (Lee et al., 2020). Reviewing previous research, natural sounds as a salient incentive may nudge individuals with high environmentalism toward pro-environmental product choices. Natural sounds refer to sounds originating from nature, such as bird songs (Ratcliffe et al., 2013), waterfall sounds (Koivisto et al., 2022), and raindrop sounds (Lin et al., 2022). Environmental movement activism refers to individuals' active support for or participation in organized environmental actions, and their demonstrated interest, support, and engagement in these activities (Milfont & Duckitt, 2010). Environmentalism emphasizes the "behavioral" component among cognitive, affective, and behavioral components—that is, the likelihood that people will take actual actions to protect the environment (Milfont & Duckitt, 2010). Research indicates that the effects of natural sounds are more pronounced among individuals with stronger connections to the natural environment, who show greater brainwave activity when exposed to natural sound signals (Koivisto et al., 2022).

Therefore, we reviewed the application of neuroscience techniques in nudging pro-environmental purchase decisions (see Appendix 1). We found that: (1) Previous studies have primarily focused on the impact of salient incentives on pro-environmental purchase decisions (Casado-Aranda et al., 2018; Jin et al., 2018; Jing et al., 2022; Li et al., 2023; Linder et al., 2010; Mehlhose & Risius, 2021; Wei et al., 2023; Yin et al., 2022; Yin & Lee, 2023; Zhang et al., 2023; Zhang et al., 2022; Zubair, Iqbal, et al., 2020; 王财玉 et al., 2018). Only two studies examined both salient incentives and specific populations, investigating how different advertising descriptions affect pro-environmental purchase decisions among individuals with varying environmental concerns (Gómez-Carmona et al., 2022) and how social observation contexts influence pro-environmental purchase decisions among individuals of different socioeconomic statuses (Zhong et al., 2024). Furthermore, at the theoretical level, researchers have identified an "intention–behavior gap" in pro-environmental purchase decisions (Carrington et al., 2014). This phenomenon may stem from differential responses to salient incentives across populations: environmentally concerned individuals tend to place greater emphasis on the relationship between products and the natural environment (Gómez-Carmona et al., 2022), making natural sounds as a salient incentive effective for them; whereas individuals less concerned with the environment may focus more on product quality or price (Medina et al., 2020), rendering the incentive effect of natural sounds insignificant. (2) Regarding physiological indicators of nudging pro-environmental purchase decisions, existing research has primarily concentrated on the effects of salient incentives on specific brain regions and time-domain EEG responses. Although studies have revealed the impact of salient incentives through specific brain regions (e.g., reward-related areas, Linder et al., 2010) and rapid post-stimulus brain responses (e.g., brainwaves at 100ms post-stimulus, Zubair, Wang, et al., 2020), there remains a shortage of research on heart rate and time-frequency EEG indicators. This limitation constrains a comprehensive understanding of the physiological mechanisms underlying nudge theory in pro-environmental purchase decisions. Therefore, this study, while examining the influence of natural sounds on pro-environmental purchase decisions, incorporates the factor of environmental movement activism to further reveal the boundary conditions for the positive effects of nudge theory in pro-environmental purchase decisions. Additionally, through exploration of cardiac and neural physiological indicators, this study aims to elucidate the physiological mechanisms by which natural sounds and environmentalism influence pro-environmental purchase decisions, thereby providing new perspectives on the physiological mechanisms underlying nudge theory.

1.1 The Influence of Natural Sounds and Environmentalism on Pro-Environmental Purchase Decisions

First, the influence of natural sounds and environmentalism on pro-environmental purchase decisions can be manifested through incentive-based purchase decisions. Previous research has primarily used attitudinal indicators to evaluate the effectiveness of nudging pro-environmental purchase decisions, such as willingness to pay (Linder et al., 2010), preference (Lee et al., 2020), and purchase intention (Li et al., 2023), as detailed in Appendix 1. However, as researchers have delved deeper into the "intention-behavior gap" phenomenon in pro-environmental purchase decisions, an increasing number of studies have shifted toward using incentive-based purchase decisions as the measurement criterion. This approach requires individuals to use initial funds to purchase products in a specific task, with their decisions being cashed out according to rules upon task completion (Liang et al., 2024; Sawe et al., 2022). Liang et al. (2024) used incentive-based purchase decisions to measure the nudging effect of natural sounds on pro-environmental products and found that natural sounds indeed have a nudging effect.

Natural sounds can effectively nudge pro-environmental purchase decisions, but this nudging effect is population-specific. A field experiment found that natural sounds only promoted pro-environmental products among male customers who initially had relatively low purchase intentions for such products (Spendrup et al., 2016). This experiment further demonstrated that male customers who self-reported stronger connections to the natural environment showed significantly higher purchase intentions for pro-environmental products (Spendrup et al., 2016). This result suggests that the influence of natural sounds on pro-environmental incentive purchase decisions may be more pronounced among high environmentalism individuals who value the environment.

Therefore, the first hypothesis of this study is that natural sounds, compared to non-natural sounds, significantly promote pro-environmental purchase decisions among high environmentalism individuals rather than low environmentalism individuals.

1.2 Cardiac and Neural Attention Mechanisms Through Which Natural Sounds and Environmentalism Promote Pro-Environmental Purchase Decisions

Based on nudge theory, Luo et al. developed a cognitive framework encompassing attention, perception, memory, effort, intrinsic motivation, and extrinsic motivation. Natural sounds as a salient incentive may influence pro-environmental decision-making among high environmentalism individuals through mechanisms closely related to attention. Attention restoration theory posits that natural environments facilitate the restoration of individuals' attentional resources (Kaplan, 1995). Additionally, Lee et al. (2014), based on goal-matching processes, noted that the interaction between individuals' retrieval of long-term memory regarding environmental viewpoints and information input pathways (i.e., the process of understanding and encoding pro-environmental product information) leads to enhanced internalized attention.

Physiological responses of attention mechanisms can be explored from both cardiac and cerebral perspectives. First, heart rate (HR) refers to the number of heartbeats per minute, typically estimated by counting R-wave peaks in an electrocardiogram per minute, measured in beats per minute (BPM). Heart rate is widely used as an indicator of attention. Specifically, decreased heart rate typically indicates enhanced attention (Corcoran et al., 2021; Lansink & Richards, 1997). Research shows that sounds significantly affect heart rate (Mehta et al., 2012). Particularly when exposed to natural sounds, individuals' heart rates tend to decrease (Michels & Hamers, 2023). Furthermore, studies have indicated that interactive virtual reality experiences attract individuals' attention more effectively than sightseeing virtual reality experiences and can reduce heart rate (Huang et al., 2024). Overweight and obese individuals exhibit more significant heart rate deceleration when viewing images of delicious food, indicating heightened sensitivity to food cues (Soussignan et al., 2019). Based on the above research, this study proposes the second hypothesis: natural sounds, compared to non-natural sounds, significantly reduce heart rate when high environmentalism individuals (rather than low environmentalism individuals) process pro-environmental product information.

Second, regarding EEG frequency spectra, low-frequency brainwaves (δ and waves, 1-7 Hz) primarily reflect attentional capture elicited by feature changes, whereas higher-frequency oscillation power in α (8-12 Hz) and β (13-30 Hz) bands reflects attentional control over temporal maintenance (Tavano & Poeppel, 2019). Among these, β waves are associated with active attentional control (Prinsloo et al., 2013). Research shows that β wave amplitude is significantly higher in natural environments (e.g., marine environments) than in non-natural environments (e.g., urban roads) (Li et al., 2021). Additionally, β waves increase significantly when individuals focus on products (Wang et al., 2016). During hotel selection, β waves show significant differences between viewing information with and without smiley emoticons (Hsu & Chen, 2020). Moreover, changes in β waves during movie trailer viewing can significantly predict individuals' subjective preferences (Boksem & Smidts, 2015). Based on the above research, this study proposes the third hypothesis: natural sounds, compared to non-natural sounds, significantly enhance β wave activity when high environmentalism individuals (rather than low environmentalism individuals) process pro-environmental product information.

Although high environmentalism individuals show enhanced attention when processing pro-environmental product information, this attentional enhancement may not be present during price information processing. According to microeconomic theory, purchasing behavior is driven by both individual preferences and price (Knutson et al., 2007). Therefore, existing research typically divides purchase process information processing into product information and price information stages (Lee et al., 2014; Medina et al., 2020; Knutson et al., 2007). Natural sounds can promote connections between individuals and nature (Ray et al., 2021); thus, they may primarily affect high environmentalism individuals during the product information stage that highlights pro-environmental features, while having relatively less influence during the price information stage. Furthermore, research shows that prosocial individuals exhibit lower activation in attention-related anterior cingulate cortex when processing product price information (Medina et al., 2020). Based on these observations, we propose the fourth hypothesis: high environmentalism individuals do not show significantly reduced heart rate when processing price information for pro-environmental products compared to non-environmental products. The fifth hypothesis posits that high environmentalism individuals also do not show significantly reduced β wave activity when processing price information for pro-environmental products compared to non-environmental products.

1.3 Directional Influences of Cardiac and Neural Attention Mechanisms

The neurovisceral integration model proposes a bidirectional influence relationship between the brain's nervous system and the heart (Thayer & Lane, 2009). Pardo-Rodriguez et al. (2021) found temporal sequence interrelationships between EEG band indicators and heart rate variability during controlled and spontaneous breathing tasks (Pardo-Rodriguez et al., 2021). Additionally, cardiac and neural indicators may exhibit unidirectional influences. For example, Hsueh et al. (2023) noted that heartbeat speed can significantly affect activation in brain regions related to emotion, while Patron et al. (2019) found that reduced δ waves in prefrontal regions during resting states can modulate heart rate decreases.

Although previous research has simultaneously examined the application of cardiac and neural indicators in consumer contexts, such as using them to measure individual preferences for food (Walsh et al., 2017) and preferences for advertisements (Baldo et al., 2022; Clark et al., 2018), to our knowledge, no study has explained the directional influences of cardiac and neural attention mechanisms in purchase decisions from the perspective of information processing temporal sequences. The temporal sequence of information processing in the purchase process provides a basis for directional hypotheses regarding cardiac and neural influences in the consumer domain (温忠麟 et al., 2024). Therefore, this study aims to explore how cardiac and neural indicators during the product information stage predict subsequent indicators during the price information stage. Specifically, the sixth hypothesis is: heart rate during the product information stage significantly predicts brain β waves in the subsequent price information stage, and brain β waves during the product information stage significantly predict heart rate in the subsequent price information stage.

1.4 The Current Study

This study aims to investigate the influence of natural sounds and environmentalism on pro-environmental purchase decisions (see Figure 1 [Figure 1: see original paper]). First, the study will analyze the impact of salient incentives (natural sounds) and specific populations (environmental activists) on pro-environmental product purchase rates. Second, the study will delve into how natural sounds and environmentalism influence cardiac and neural attention mechanisms during both product information and price information stages. Finally, this study will further examine how cardiac and neural attention indicators during the product information stage predict subsequent indicators during the price information stage, to explore the directional influences of cardiac and neural attention mechanisms throughout the information processing sequence.

Figure 1 Research framework of this study
Note: First, the red dashed arrow at the bottom indicates the first part of this study—the influence of natural sounds and environmentalism on pro-environmental purchase decisions. Second, the two red dashed boxes mark the second part of this study, examining how natural sounds and environmentalism influence the cardiac and neural attention mechanisms underlying pro-environmental purchase decisions during information processing. The intersecting red dashed arrows represent the third part of this study, focusing on the directional influences of cardiac and neural attention mechanisms during information processing.

2.1 Participants

G*Power recommended recruiting 24 participants (effect size f = 0.25, α = 0.05, $1 - \beta = 0.80$). To ensure adequate sample size, 30 participants were actually recruited from a local university. All participants had no history of mental illness, normal heart rate, normal or corrected-to-normal vision, and were right-handed. All participants provided written informed consent. Data from 4 participants were excluded due to equipment issues that prevented analysis. The final sample consisted of 26 participants (14 males, aged 19 to 27 years, mean age = 21.73 years, SD = 1.87). All participants received corresponding compensation and the items they obtained during the experiment. The research protocol was approved by the local ethics committee.

2.2 Experimental Design

A 2 (Sound type: natural, non-natural) × 2 (Environmental movement activism: high, low) × 2 (Product type: pro-environmental, non-environmental) mixed experimental design was employed. Environmental movement activism was a between-subjects variable, while sound type and product type were within-subjects variables. The dependent variables were purchase rate, heart rate, and brain β waves.

2.3 Experimental Materials

(1) Sounds

Natural and non-natural sounds rated for arousal levels from Liang et al. (2024) were used. Specifically, bird songs were selected as natural sounds (Spendrup et al., 2016), and factory machine operation sounds were selected as non-natural sounds (Koivisto et al., 2022). Each sound segment matched the maximum duration of a single trial, approximately 10.6 seconds. During the experiment, a Bluetooth speaker placed behind the computer screen played sounds continuously in a loop; the specific layout is shown in Figure 2 [Figure 2: see original paper]A. Adobe Audition software was used to set sound intensity at approximately 50 dB, with real-time monitoring using a decibel meter to ensure sound output remained around 50 dB. Specific sound materials are available at https://osf.io/3754a/?view_{only}=ad244ca019464580b18b07b50c7e71a0.

(2) Products

Fifty-four daily items rated for purchase likelihood and familiarity from Liang et al. (2024) were used. These products and their prices were obtained from JD.com (https://www.jd.com/), including daily necessities such as toothbrushes, towels, and umbrellas. Following previous research (Linder et al., 2010; Schwartz et al., 2020), each product had two versions: a green label (China Green Product, CGP, pro-environmental product) and a gray label (non-environmental product), as shown in Figure 2B. Following Griskevicius et al. (2010), pro-environmental products were described as performing better in environmental protection, with characteristics including lower resource and energy consumption, reduced pollutant emissions, and easy recyclability and reusability. Non-environmental products were described as excelling in performance, with high-standard materials, structure, and functionality, demonstrating superior practicality, efficiency, and reliability. Consistent with Liang et al. (2024) and Knutson et al. (2007), among the 54 products, 27 were "high-priced" (price $>$ 10 yuan) and 27 were "low-priced" (price $<$ 10 yuan). All products were discounted by 75% from their actual prices to encourage purchases, so the prices participants saw during the experiment ranged from 2 to 20 yuan.

(3) Environmental Movement Activism Scale

The Environmental Movement Activism Scale consists of 10 items, such as "I would like to join and actively participate in environmental organizations." Participants rated these 10 items on a scale where "1" indicated "strongly disagree" and "7" indicated "strongly agree." After reverse scoring, higher scores indicated higher environmental movement activism (Milfont & Duckitt, 2010). The scale's internal consistency coefficient was 0.85, demonstrating good reliability. Detailed information for all items is provided in Appendix 2.

(4) Manipulation Checks for Pro-Environmental and Practical Attributes

This study adopted the manipulation check items for pro-environmental and practical attributes proposed by Liang et al. (2024) to evaluate pro-environmental and non-environmental products. Pro-environmental attributes were assessed through three manipulation check items, such as "Products with this label are considered environmentally friendly." Practical attributes were similarly assessed through three items, such as "Products with this label have high practicality." Ratings used a scale where "1" indicated "strongly disagree" and "7" indicated "strongly agree," with higher scores indicating stronger attribute levels. For pro-environmental products, the internal consistency coefficient was 0.86 for pro-environmental attributes and 0.89 for practical attributes. For non-environmental products, the internal consistency coefficient was 0.87 for pro-environmental attributes and 0.99 for practical attributes. These results demonstrate good reliability of the scales used; specific items are detailed in Appendix 3.

(5) Arousal Manipulation Check

The arousal manipulation check from Liang et al. (2024) and Peng-Li et al. (2022) was used to assess the effects of natural versus non-natural sounds on participants. The specific item was "How did the sound you just heard make you feel?" On this item, "1" indicated "very relaxed" and "9" indicated "very tense," with higher scores indicating greater perceived tension.

2.3 Experimental Task

This experiment adopted the "Save Holdings Or Purchase (SHOP)" task adapted by Liang et al. (2024) from Knutson et al. (2007). The experimental program was designed and implemented using E-Prime 3.0 (Psychology Software Tools, Inc., Sharpsburg, PA). As shown in Figure 2B, after a fixation cross, participants entered the product information phase, where they viewed product images with green or gray labels and their names for 2 seconds without making any response. Participants then transitioned to the price information phase, which also lasted 2 seconds without requiring a response. Next, participants saw a "purchase vs. no purchase" selection screen, where they had 2 seconds to press the "F" key to purchase or the "J" key to not purchase (key assignments were counterbalanced; for half the participants, "F" indicated no purchase and "J" indicated purchase). If participants failed to respond within 2000 ms, a new trial was presented to ensure a valid choice. Additionally, if participants responded faster than 200 ms, the choice was considered too fast and the trial was repeated. To incentivize participation in the SHOP task, participants were informed that one of their purchase choices would be randomly selected for actual cash-out after the experiment. If no key was pressed during the selection phase or if the response was faster than 200 ms, that choice was invalidated, and participants would lose their 20-yuan principal and the right to purchase items. If the key press met requirements, participants who chose to purchase would receive the remaining principal minus the item price and the purchased item; those who chose not to purchase would receive their full principal.

Before the formal experiment, participants completed 4 practice trials (not recorded) to ensure they understood the experimental rules, after which they proceeded to the formal experimental phase.

Throughout the experiment, the 54 products were divided into two sets of 27 items each. Each set was balanced to appear equally often under natural and non-natural sound conditions. To ensure experimental balance, products in each set appeared with equal frequency across sound conditions. Participants completed six task blocks, including three non-natural sound blocks and three natural sound blocks. In each sound condition, participants repeated one product set three times. In each block, participants were presented with 27 pro-environmental and 27 non-environmental products, with presentation order randomized within each block to prevent expectancy effects (Zhang et al., 2021). After the first sound condition, participants completed the arousal manipulation check. They then proceeded through the same procedure for the second sound condition. After all experimental recordings, participants answered manipulation check questions about pro-environmental and practical attributes and completed the environmental movement activism scale. The detailed experimental procedure is shown in Figure 2C.

Figure 2 Trial examples, experimental flowchart, and recording schematic for the SHOP task
Note: ISI = interstimulus interval.

2.4 EEG Recording and Processing

Raw EEG data were collected using a 32-channel electrode cap based on the international 10–20 system (Neuroscan, Neurosoft Labs, Inc., Sterling, USA). Vertical electrooculogram signals were recorded from electrodes placed above and below the left eye socket, while horizontal electrooculogram signals were monitored from electrodes placed at the left and right outer canthi (Wang et al., 2021), as shown in Figure 2A. The sampling rate was 1000 Hz, and electrode impedance was maintained at approximately 10 kΩ. Collected data were offline preprocessed in MATLAB 2019 using EEGLAB, referenced to bilateral mastoids, filtered between 0.01 and 30 Hz, and downsampled to 500 Hz. Trials with artifacts exceeding $±$100 V were rejected. The average rejection rate for the 26 participants was 9.81%. Preprocessed data were used for time-frequency analysis. EEG epochs were segmented into product and price phases, extracting signals from 200 ms pre-stimulus to 1500 ms post-stimulus. Based on visual inspection and relevant research (Xie et al., 2022), β waves of interest (13–18 Hz) were examined at frontal left, middle, and right electrodes FC3, FCz, and FC4. Specifically, β wave data for the product phase were extracted from 900 ms to 1200 ms, while β wave data for the price phase were extracted from 1100 ms to 1200 ms.

2.5 ECG Recording and Processing

Electrocardiogram (ECG) data were recorded using two electrodes placed on the left (anode) and right (cathode) sides of the chest, approximately 5 cm below the center of the clavicles (Gebodh et al., 2021), as shown in Figure 2A. ECG data were filtered between 0.05 Hz and 35 Hz (Parrotta et al., 2024), and R-wave peak intervals were detected using the Pan-Tompkins algorithm (Sedghamiz, 2014) to calculate heart rate; an example of this algorithm is provided in Appendix 4. In this study, data from both the product information and price information phases were segmented, with time windows ranging from 800 ms pre-stimulus to 2200 ms post-stimulus.

2.6 Statistical Analysis

Behavioral data, derived ECG data, and EEG data were statistically analyzed using SPSS 21. When the sphericity assumption for repeated measures was violated, Greenhouse–Geisser correction was applied. All multiple comparisons used Bonferroni correction. All data used for analysis are available at: https://www.scidb.cn/anonymous/WlpWQkp6.

3.1 Manipulation Checks

For arousal, participants' self-reports indicated that they felt significantly more relaxed in the natural sound environment than in the non-natural sound environment, Mnatural $\pm$ SD = 2.31 $\pm$ 1.32, Mnon-natural $\pm$ SD = 5.54 $\pm$ 1.14,

$t(25) = –9.54$, $p < 0.001$, Cohen's $d = 2.61$. For pro-environmental attributes, products with green labels were rated significantly higher on pro-environmental attributes than those with gray labels, Mgreen label ± SD = 5.72 ± 1.00, Mgray label ± SD = 2.18 ± 0.77, $t(25) = 12.28$, $p < 0.001$, Cohen's $d = 3.90$. For practical attributes, green label products were rated significantly lower than gray label products, Mgreen label ± SD = 3.31 ± 1.09, Mgray label ± SD = 4.95 ± 1.49, $t(25) = –4.45$, $p < 0.001$, Cohen's $d = 1.23$. These results indicate successful manipulation of sound type and product type.

3.2 Environmental Movement Activism

Following the methodology of Fu et al. (2022) and 王益文 et al. (2017), the 26 participants' environmentalism scores were ranked from low to high and divided into high and low environmentalism groups using the median as the cutoff. Specifically, 13 participants (9 males) were classified into the high environmentalism group, while the remaining 13 participants (5 males) were classified into the low environmentalism group. Results showed that the high environmentalism group had significantly higher mean scores than the low environmentalism group, Mhigh ± SD = 51.00 ± 7.37, Mlow ± SD = 36.54 ± 6.02, $t(24) = 5.48$, $p < 0.001$, Cohen's $d = 2.15$.

3.3 Purchase Rate

A mixed ANOVA on purchase rate with participant sex as a covariate revealed a marginally significant three-way interaction, $F(1, 23) = 3.32$, $p = 0.082$, $^2 = 0.13$. Simple effects analysis showed that in the high environmentalism group, the effect of sound type was significant for pro-environmental products, $F(1, 23) = 6.92$, $p = 0.015$, $^2 = 0.23$. The purchase rate for pro-environmental products under natural sounds was significantly higher than under non-natural sounds, Mnatural ± SD = 0.49 ± 0.16, Mnon-natural ± SD = 0.40 ± 0.18, $p = 0.015$, 95% CI = [0.020, 0.16]. The effect of sound type was not significant for non-environmental products, $F(1, 23) = 0.01$, $p = 0.926$, $^2 < 0.001$, Mnatural ± SD = 0.36 ± 0.15, Mnon-natural ± SD = 0.37 ± 0.18. In the low environmentalism group, the effect of sound type was not significant for pro-environmental products, $F(1, 23) = 1.85$, $p = 0.187$, $^2 = 0.07$, Mnatural ± SD = 0.36 ± 0.15, Mnon-natural ± SD = 0.31 ± 0.15. However, the effect of sound type was significant for non-environmental products, $F(1, 23) = 4.32$, $p = 0.049$, $^2 = 0.16$. The purchase rate for non-environmental products under natural sounds was significantly higher than under non-natural sounds, Mnatural ± SD = 0.32 ± 0.16, Mnon-natural ± SD = 0.24 ± 0.12, $p = 0.049$, 95% CI = [0.00, 0.16]. See Figure 3 [Figure 3: see original paper] for detailed results. The main effect of environmentalism was marginally significant, $F(1, 23) = 3.07$, $p = 0.093$, $^2 = 0.12$. The purchase rate was higher in the high environmentalism group than in the low environmentalism group, Mhigh ± SD = 0.41 ± 0.12, Mlow ± SD = 0.31 ± 0.12, $p = 0.093$, 95% CI = [–0.19, 0.02]. The main effect of product type was significant, $F(1, 23) = 4.70$, $p = 0.041$, $^2 = 0.17$. Post-hoc comparisons showed that the purchase rate for pro-environmental products was significantly higher than for non-environmental products, Mpro-environmental ± SD = 0.39 ± 0.16, Mnon-environmental ± SD = 0.32 ± 0.14, p = 0.022, 95% CI = [0.01, 0.12]. No other effects were significant, $ps > 0.1$.

Figure 3 Three-way interaction on purchase rate. (A) shows purchase rates for the high environmentalism group across conditions, (B) shows purchase rates for the low environmentalism group across conditions.
Note: Violin plots in each condition represent relative frequency, with wider shapes indicating more data points at that value. Gray dots represent each participant's purchase rate in that condition, while black dots represent the mean purchase rate. The middle gray line indicates the median, and the gray lines at both ends mark the range of the axis.

3.4.1 Heart Rate During Product Information Stage

A mixed ANOVA on heart rate during the product information stage with participant sex as a covariate revealed a marginally significant three-way interaction, $F(1, 23) = 4.29$, $p = 0.050$, $^2 = 0.16$. Simple effects analysis showed that in the high environmentalism group, the effect of sound type was marginally significant for pro-environmental products, $F(1, 23) = 3.43$, $p = 0.08$, $^2 = 0.13$. Heart rate when viewing pro-environmental product information under natural sounds was marginally lower than under non-natural sounds, Mnatural ± SD = 74.98 ± 9.31, Mnon-natural ± SD = 76.49 ± 9.24, p = 0.077, 95% CI = [–4.59, 0.25]. The effect of sound type was not significant for non-environmental products, $F(1, 23) = 0.21$, $p = 0.655$, $^2 = 0.01$, Mnatural ± SD = 75.28 ± 10.14, Mnon-natural ± SD = 76.44 ± 8.65. In the low environmentalism group, the effect of sound type was marginally significant for pro-environmental products, $F(1, 23) = 3.18$, $p = 0.09$, $^2 = 0.12$. Heart rate when viewing pro-environmental product information under natural sounds was marginally higher than under non-natural sounds, Mnatural ± SD = 81.16 ± 9.06, Mnon-natural ± SD = 79.73 ± 6.86, p = 0.088, 95% CI = [–0.33, 4.51]. The effect of sound type was not significant for non-environmental products, $F(1, 23) = 0.11$, $p = 0.748$, $^2 = 0.01$, Mnatural ± SD = 79.36 ± 10.06, Mnon-natural ± SD = 79.38 ± 7.92. See Figure 4 [Figure 4: see original paper] for detailed results. The main effect of sound type was marginally significant, $F(1, 23) = 4.25$, $p = 0.051$, $^2 = 0.16$. However, post-hoc comparisons found no significant difference between heart rate under natural versus non-natural sounds, Mnatural ± SD = 77.94 ± 9.66, Mnon-natural ± SD = 78.01 ± 8.06, p = 0.937, 95% CI = [–1.77, 1.64]. No other effects were significant, $ps > 0.1$.

Figure 4 Three-way interaction on heart rate during the product information stage. (A) shows heart rates for the high environmentalism group across conditions, (B) shows heart rates for the low environmentalism group across conditions.
Note: Violin plots in each condition represent relative frequency, with wider shapes indicating more data points at that value. Gray dots represent each par-

ticipant's heart rate in that condition, while black dots represent the mean heart rate. The middle gray line indicates the median, and the gray lines at both ends mark the range of the axis.

3.4.2 Heart Rate During Price Information Stage

A mixed ANOVA on heart rate during the price stage with participant sex as a covariate revealed a significant two-way interaction between environmentalism and product type, $F(1, 23) = 15.60$, $p = 0.001$, $^2 = 0.40$. In the high environmentalism group, the product type effect was not significant, $F(1, 23) = 2.93$, $p = 0.100$, $^2 = 0.11$, Mpro-environmental ± SD = 75.68 ± 9.03, Mnon-environmental ± SD = 76.15 ± 9.26. In the low environmentalism group, the product type effect was significant, $F(1, 23) = 16.09$, $p = 0.001$, $^2 = 0.41$. Heart rate when viewing pro-environmental product prices was significantly higher than when viewing non-environmental product prices, Mpro-environmental ± SD = 80.00 ± 8.34, Mnon-environmental ± SD = 78.59 ± 7.44, $p = 0.001$, 95% CI = [0.80, 2.51]. See Figure 5 [Figure 5: see original paper] for detailed results. The main effect of product type was significant, $F(1, 23) = 7.72$, $p = 0.068$, $^2 = 0.41$. However, post-hoc comparisons indicated no significant difference in heart rate between viewing pro-environmental versus non-environmental product prices, Mpro-environmental ± SD = 77.84 ± 8.80, Mnon-environmental ± SD = 77.37 ± 8.32, $p = 0.109$, 95% CI = [0.80, 2.51]. No other effects were significant, $ps > 0.1$.

Figure 5 Two-way interaction between environmentalism and product type on heart rate during the price information stage. (A) shows heart rates for the high environmentalism group across conditions, (B) shows heart rates for the low environmentalism group across conditions.
Note: Violin plots in each condition represent relative frequency, with wider shapes indicating more data points at that value. Gray dots represent each participant's heart rate in that condition, while black dots represent the mean heart rate. The middle gray line indicates the median, and the gray lines at both ends mark the range of the axis.

3.5.1 Beta Waves During Product Information Stage

Separate mixed ANOVAs on β waves at frontal electrodes FC3, FCz, and FC4 were conducted with a 2 (Sound type: natural, non-natural) × 2 (Environmentalism: high, low) × 2 (Product type: pro-environmental, non-environmental) design. At electrode FC4, the three-way interaction was marginally significant, $F(1, 23) = 3.95$, $p = 0.059$, $^2 = 0.15$. Simple effects analysis showed that in the high environmentalism group, the sound effect was marginally significant for pro-environmental products, $F(1, 23) = 3.02$, $p = 0.096$, $^2 = 0.12$. β waves under natural sounds were higher than under non-natural sounds, Mnatural ± SD = –0.38 ± 1.09, Mnon-natural ± SD = –0.81 ± 0.99, $p = 0.096$, 95% CI = [–0.08, 0.86]. The sound effect was not significant for non-environmental products, $F(1, 23) = 1.59$, $p = 0.220$, $^2 = 0.07$, Mnatural ± SD = –0.91 ± 1.00, Mnon-natural ± SD = –0.53 ± 1.05. In the low environmentalism group, the sound effect was not significant for pro-environmental products, $F(1, 23) = 0.01$, $p = 0.906$, $^2 = 0.001$, Mnatural ± SD = –0.17 ± 0.61, Mnon-natural ± SD = –0.16 ± 1.08. The sound effect was also not significant for non-environmental products, $F(1, 23) = 1.23$, $p = 0.280$, $^2 = 0.05$, Mnatural ± SD = –0.08 ± 0.92, Mnon-natural ± SD = –0.41 ± 1.11. See Figure 6 [Figure 6: see original paper] for details. No other effects were significant, $ps < 0.1$.

At electrode FC3, the interaction between environmentalism and product type was marginally significant, $F(1, 23) = 3.41$, $p = 0.078$, $^2 = 0.15$. No product type effect was found in the high environmentalism group, $F(1, 23) = 0.76$, $p = 0.392$, $^2 = 0.03$, Mpro-environmental ± SD = –0.89 ± 0.97, Mnon-environmental ± SD = –0.89 ± 0.95. In the low environmentalism group, a product type effect emerged, $F(1, 23) = 3.26$, $p = 0.084$, $^2 = 0.12$. Post-hoc comparisons indicated that β wave power for pro-environmental products was marginally lower than for non-environmental products, Mpro-environmental ± SD = –0.41 ± 0.70, Mnon-environmental ± SD = –0.31 ± 0.74, $p = 0.084$, 95% CI = [–0.46, 0.03].

At electrode FCz, no significant effects were found, $ps < 0.1$.

Figure 6 Three-way interaction on β waves during the product information stage. (A) shows β wave power for the high environmentalism group across conditions. (B) shows β wave power for the low environmentalism group across conditions. (C) shows time-frequency analysis at electrode FC4 when the high environmentalism group viewed pro-environmental products under natural sounds. (D) shows time-frequency analysis at electrode FC4 when the high environmentalism group viewed non-environmental products under natural sounds. (E) shows time-frequency analysis at electrode FC4 when the high environmentalism group viewed pro-environmental products under non-natural sounds. (F) shows time-frequency analysis at electrode FC4 when the high environmentalism group viewed non-environmental products under non-natural sounds. (G) shows time-frequency analysis at electrode FC4 when the low environmentalism group viewed pro-environmental products under natural sounds. (H) shows time-frequency analysis at electrode FC4 when the low environmentalism group viewed non-environmental products under natural sounds. (I) shows time-frequency analysis at electrode FC4 when the low environmentalism group viewed pro-environmental products under non-natural sounds. (J) shows time-frequency analysis at electrode FC4 when the low environmentalism group viewed non-environmental products under non-natural sounds.
Note: Violin plots in each condition represent relative frequency, with shape width reflecting data point density. Gray dots represent each participant's β wave power in that condition, while black dots represent the mean β wave power. The middle gray line indicates the median, and gray lines at both ends mark the axis range. Black boxes in time-frequency plots demarcate the region of interest from 900 ms to 1200 ms and 13 to 18 Hz, with black lines pointing to the FC4

electrode location in the EEG montage.

3.5.2 Beta Waves During Price Information Stage

Mixed ANOVAs on β waves at frontal electrodes FC3, FCz, and FC4 were conducted with the same 2 × 2 × 2 design. At electrode FC4, the three-way interaction was marginally significant, $F(1, 23) = 3.00$, $p = 0.097$, $^2 = 0.12$. However, simple effects analysis revealed no significant results. Specifically, in the high environmentalism group, the sound effect was not significant for pro-environmental products, $F(1, 23) = 0.11$, $p = 0.747$, $^2 = 0.005$, Mnatural ± SD = –0.98 ± 1.28, Mnon-natural ± SD = –1.21 ± 0.80. The sound effect was also not significant for non-environmental products, $F(1, 23) = 1.01$, $p = 0.326$, $^2 = 0.04$, Mnatural ± SD = –0.89 ± 1.25, Mnon-natural ± SD = –1.34 ± 1.12. In the low environmentalism group, the sound effect was not significant for pro-environmental products, $F(1, 23) = 0.11$, $p = 0.739$, $^2 = 0.005$, Mnatural ± SD = –1.12 ± 0.97, Mnon-natural ± SD = –1.13 ± 0.88. The sound effect was also not significant for non-environmental products, $F(1, 23) = 0.57$, $p = 0.456$, $^2 = 0.02$, Mnatural ± SD = –1.53 ± 0.89, Mnon-natural ± SD = –1.16 ± 1.03. The interaction between environmentalism and product type was significant, $F(1, 23) = 3.17$, $p = 0.088$, $^2 = 0.19$, $p = 0.666$, $^2 = 0.12$. Simple effects showed no product type effect in the high environmentalism group, $F(1, 23) = 0.01$, Mpro-environmental ± SD = –1.10 ± 0.73, Mnon-environmental ± SD = –1.11 ± 0.89. In the low environmentalism group, the product type effect was significant, $F(1, 23) = 4.60$, $p = 0.043$, $^2 = 0.17$. β waves when viewing pro-environmental product prices were significantly higher than when viewing non-environmental product prices, Mpro-environmental ± SD = –1.13 ± 0.75, Mnon-environmental ± SD = –1.34 ± 0.86, $p = 0.043$, 95% CI = [0.01, 0.58]. See Figure 7 [Figure 7: see original paper] for details. The main effect of product type was marginally significant, $F(1, 23) = 4.07$, $p = 0.056$, $^2 = 0.15$. However, post-hoc comparisons indicated no significant difference in β wave power between viewing pro-environmental versus non-environmental product prices, Mpro-environmental ± SD = –1.11 ± 0.73, Mnon-environmental ± SD = –1.23 ± 0.86, $p = 0.228$, 95% CI = [–0.08, 0.31]. No other effects were significant, $ps > 0.1$.

At electrode FC3, the main effect of product type was significant, $F(1, 23) = 6.29$, $p = 0.020$, $^2 = 0.22$. However, post-hoc comparisons indicated no significant difference in β wave power between viewing pro-environmental versus non-environmental product prices, Mpro-environmental ± SD = –1.11 ± 0.63, Mnon-environmental ± SD = –1.19 ± 0.84, $p = 0.465$, 95% CI = [–0.13, 0.28]. No other effects were significant, $ps > 0.1$.

No significant effects were found at electrode FCz.

Figure 7 Interaction between environmentalism and product type on β waves during the price information stage. (A) shows β wave power for the high environmentalism group across conditions. (B) shows β wave power for the low

environmentalism group across conditions. (C) shows time-frequency analysis at electrode FC4 when the high environmentalism group viewed pro-environmental product prices. (D) shows time-frequency analysis at electrode FC4 when the low environmentalism group viewed pro-environmental product prices. (E) shows time-frequency analysis at electrode FC4 when the high environmentalism group viewed non-environmental product prices. (F) shows time-frequency analysis at electrode FC4 when the low environmentalism group viewed non-environmental product prices.
Note: Violin plots in each condition represent relative frequency, with shape width reflecting data point density. Gray dots represent each participant's β wave power in that condition, while black dots represent the mean β wave power. The middle gray line indicates the median, and gray lines at both ends mark the axis range. Black boxes in time-frequency plots demarcate the region of interest from 1100 ms to 1200 ms and 13 to 18 Hz, with black lines pointing to the FC4 electrode location in the EEG montage.

3.6 Regression Analysis of Heart Rate and Beta Waves

With sex and age as control variables, a linear regression was conducted with heart rate during the product information stage as the independent variable and β waves during the price information stage as the dependent variable. The results showed a marginally significant regression, $\beta = -0.39$, $t = -1.97$, $p = 0.062$. Similarly, with sex and age as control variables, a linear regression was conducted with β waves during the product information stage as the independent variable and heart rate during the price information stage as the dependent variable. The results showed a non-significant regression, $\beta = 0.21$, $t = 1.02$, $p = 0.319$. See Figure 8 [Figure 8: see original paper] for details.

Figure 8 Regression analysis results showing how cardiac and neural indicators during the product information stage predict subsequent indicators during the price information stage. (A) shows the prediction of price-stage β waves by product-stage heart rate. (B) shows the prediction of price-stage heart rate by product-stage β waves.

4.1 Natural Sounds and Environmentalism Influence Pro-Environmental Purchase Decisions

This study found that in a purchase decision incentive mechanism with random cash-out, natural sounds significantly promoted pro-environmental purchase decisions among high environmentalism individuals, thereby validating the first hypothesis. Consistent with previous research, natural sounds indeed have a nudging effect on pro-environmental purchase decisions (Liang et al., 2024). The current findings further extend this literature by demonstrating that this nudging effect is particularly pronounced among high environmentalism individuals. Meanwhile, the results showed that low environmentalism individuals were more inclined to purchase non-environmental products with strong practical attributes under the influence of natural sounds. This finding indicates that when encouraging pro-environmental purchasing behavior, natural sounds only produce positive effects for high environmentalism individuals who are more environmentally concerned. This may be because natural sounds, as external stimuli, can evoke pro-environmental thoughts in high environmentalism individuals. For low environmentalism individuals, although natural sounds provide pleasant sensory experiences, they fail to stimulate environmental concern, which is related to their lower environmental attention. This result aligns with the evolutionary-constructivist perspective, which suggests that when the brain is exposed to natural stimuli, it generates top-down positive states (Koivisto et al., 2022). Only when individuals endorse environmentalist values will they be aroused by these positive stimuli to make pro-environmental purchase decisions. Therefore, by examining the nudging influence of natural sounds as a salient incentive on a specific population (i.e., high environmentalism individuals), this study extends the limitations of nudge theory when discussing the nudging effects of salient incentives and further clarifies the conditions under which natural sounds promote pro-environmental purchase decisions.

4.2 Natural Sounds and Environmentalism Influence Attention-Related Heart Rate During Purchase

This study's results indicate that natural sounds and environmentalism have differential effects on heart rate during product and price information stages. First, during the product information stage, natural sounds significantly reduced heart rate among high environmentalism individuals when viewing pro-environmental products, supporting the second hypothesis. This finding is consistent with prior research showing that decreased heart rate reflects enhanced attention (Corcoran et al., 2021; Lansink & Richards, 1997). Compared to noisy non-natural sounds, natural sounds can effectively reduce individuals' heart rates (Song et al., 2023). This phenomenon suggests that the positive psychological state induced by natural sounds in high environmentalism individuals during pro-environmental product information processing manifests as enhanced attention through cardiac signals. However, low environmentalism individuals, due to their lower environmental concern, showed lower heart rate responses to pro-environmental products in non-natural sound environments, further demonstrating that the influence of natural sounds on individuals is top-down in nature. Second, during the price information stage, low environmentalism individuals showed significantly lower heart rates for non-environmental products than for pro-environmental products, while high environmentalism individuals showed no significant differences between the two product types, supporting the fourth hypothesis. Consistent with previous research, non-prosocial individuals show attention to price information through activation in brain regions including the anterior cingulate cortex, cerebellum, and inferior frontal gyrus (Medina et al., 2020). We observed similar reactions in low environmentalism individuals' heart rates, extending existing literature findings. Overall, to our knowledge, previous research on the physiological mechanisms underlying nudges for pro-environmental purchase decisions has not examined attention-related heart rate indicators, as shown in Appendix 1. The current findings provide a new perspective for exploring the physiological mechanisms behind nudging pro-environmental decisions, revealing the importance of heart rate in this process.

4.3 Natural Sounds and Environmentalism Influence Attention-Related Brain Beta Spectral Power During Purchase

Natural sounds and environmentalism showed different patterns of influence on β waves during product and price information stages. First, during the product information stage, natural sounds significantly enhanced β wave power activity among high environmentalism individuals when viewing pro-environmental products, supporting our third hypothesis. Previous research indicates that β waves enhance their power activity when individuals engage in attentional control (Prinsloo et al., 2013). Natural sounds promote increased β waves in the brain (Li et al., 2021). This study found that during pro-environmental purchase decisions, natural sounds help high environmentalism individuals process pro-environmental product information more effectively, leading to increased β wave activity. This suggests that the top-down positive state experienced by high environmentalism individuals when influenced by natural sounds is reflected as enhanced attention through EEG signals. Second, during the price information stage, low environmentalism individuals showed significantly higher β wave activity for pro-environmental products than for non-environmental products, while high environmentalism individuals showed no significant differences between the two product types, supporting our fifth hypothesis. The current study reveals that low environmentalism individuals are more sensitive to price information in β wave activity, extending Medina et al.'s (2020) findings. Interestingly, this study also found that in heart rate indicators, low environmentalism individuals showed more pronounced attentional control for non-environmental product prices, whereas in β wave activity, they showed stronger attentional control for pro-environmental product prices. This phenomenon may be due to differences in measurement time windows between heart rate and β wave indicators; heart rate requires calculating R-peak intervals throughout the entire price information presentation period, while β waves focus on the 1000 ms to 1100 ms period after price information presentation, reflecting stage-specific processing differences. Therefore, the results indicate that across the entire price information stage, heart rate evidence shows low environmentalism individuals attend more to non-environmental product prices, whereas EEG evidence in the middle-to-late price stage shows they attend more to pro-environmental product prices. This suggests that although low environmentalism individuals focus more on pro-environmental product prices during mid-to-late cognitive processing, they may tend to attend to non-environmental product prices throughout the overall price stage. In summary, by reviewing previous research on promoting pro-environmental purchase decisions (see Appendix 1), we note that prior studies have not adequately considered brain spectral indicators related to attention. Therefore, this study's findings provide new brain spectral activity indicators for understanding the physiological mechanisms of this decision-making process.

4.4 Heart Rate During Product Information Stage Predicts Brain Beta Spectral Power During Price Information Stage

Although the current study did not find that β waves during the product information stage predicted heart rate during the price information stage, it is noteworthy that we observed a significant predictive effect of product-stage heart rate on price-stage β waves, partially supporting our sixth hypothesis (see Figure 9 [Figure 9: see original paper]). These findings align with previous perspectives on how cardiac activity influences brain function (Al et al., 2023; Hsueh et al., 2023). Specifically, the results suggest that during information processing in purchase decisions, heart rate changes may serve as a physiological feedback mechanism that modulates nervous system activity, thereby influencing the brain's response patterns to information. This feedback mechanism enables individuals to rapidly generate brain responses when receiving price information. By conducting regression predictions of cardiac and neural indicators across information processing stages in purchase decisions, this study extends existing literature on physiological relationships between heart and brain in consumer contexts (Baldo et al., 2022; Clark et al., 2018), providing further empirical evidence for how cardiac states influence brain activity. These findings enrich the connections between cardiac and neural mechanisms involved in nudge theory, offering new perspectives for understanding the physiological basis of consumer decision-making.

Figure 9 Schematic diagram of heart rate influencing β waves during purchase information processing
Note: The red arrow indicates that heart rate during the product information stage significantly predicts brain β wave spectral power during the subsequent price information stage.

4.5 Limitations and Future Directions

The current study has several limitations. First, this study only used natural sounds as a salient incentive from natural environments; other salient incentives related to natural environments require further validation. Future research should explore additional salient incentive factors related to natural environments, such as natural landscape images (Gamble et al., 2014) and natural environment audio materials (Laumann et al., 2003), and compare the effectiveness of different salient incentives in nudging pro-environmental purchase decisions. Second, this study used non-portable physiological recording equipment, requiring participants to sit fixedly in the laboratory for purchase decisions, which may limit ecological validity. Future research could employ portable EEG devices to conduct real purchase decisions in more flexible environments, enhancing external validity. Additionally, the directional influences of cardiac and neural attention mechanisms require further verification. Considering participant fatigue, the experimental design allowed rest after each sound condition, which may have caused discontinuity in recordings and limited the use of time-series data for more advanced analyses. Future studies should optimize experimental designs to enable richer analyses of directional cardiac and neural influences in purchase decisions, such as using Granger causality tests (Pardo-Rodriguez et al., 2021). Finally, this study's sample size calculation based on G*Power used a medium effect size, resulting in a sample size that yielded mostly marginally significant results. Future research could set a higher effect size for sample size calculation to detect stronger effects.

This study investigated the influence of natural sounds and environmentalism on pro-environmental purchase decisions. The results showed that natural sounds significantly promoted pro-environmental behavior among high environmentalism individuals at the behavioral level. At the physiological mechanism level, natural sounds enhanced attention-related cardiac and neural mechanisms among high environmentalism individuals. Furthermore, the study found that heart rate changes in ECG signals during the product information stage could predict β wave power activity in EEG signals during the subsequent price information stage. These findings not only enrich the application of nudge theory in pro-environmental purchase decisions but also reveal the underlying physiological mechanisms, providing scientific evidence and important insights for promoting pro-environmental purchasing behavior.

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Appendix 1 Studies Using Neuroscience Techniques to Explore Nudging Pro-Environmental Purchase Decisions

Author (Year)	Salient Incentive	Population	Brain Region/Indicator	EEG Time Domain
Linder et al. (2010)	German organic food label (yes, no)	-	Ventromedial striatum, right dorsolateral prefrontal cortex	-
Vezich et al. (2017)	-	-	Ventromedial prefrontal cortex, ventromedial striatum	-
Casado–Aranda et al. (2018)	Advertising type (green, non-green)	-	Anterior cingulate cortex	P2
Jin et al. (2018)	Eco-label (yes, no)	-	-	N2
王财玉 et al. (2018)	Temporal reference (recent, distant)	-	-	P2
Lee et al. (2020)	Information presentation (priming, explicit intervention); Global Organic Textile label (present, absent)	-	-	N2
Zubair & Wang et al. (2020)	Message framing (positive, negative, neutral)	-	-	LPC
Zubair & Iqbal et al. (2020)	Message framing (positive, negative); Emotion type (pride, guilt)	-	Ventromedial striatum, anterior cingulate cortex, superior parietal lobule, bilateral lingual gyrus	P1, P3

Author (Year)	Salient Incentive	Population	Brain Region/Indicator	EEG Time Domain
Mehlhose & Risius (2021)	Rearing environment (free-range, indoor intensive); Label (no antibiotics, antibiotics label, no label)	-	-	N1, P2
Gómez–Carmona et al. (2022)	Advertising description (positive, neutral)	Environmental concern (high, low)	Anterior cingulate cortex, ventromedial prefrontal cortex, amygdala, insula	N2, N4
Jing et al. (2022)	Empathy with nature (priming, no priming)	-	Prefrontal cortex, nucleus accumbens	P2, P3
Sawe et al. (2022)	Energy Star label (present, absent); Energy cost (high, low); Price (high, low)	-	-	P2, P3
Yin et al. (2022)	Image priming (extreme weather images, control)	-	-	LPP
Zhang et al. (2022)	Green product type (self-benefit, other-benefit); Message framing (loss, gain)	-	-	N2, N4

Author (Year)	Salient Incentive	Population	Brain Region/Indicator	EEG Time Domain
Li et al. (2023)	Beneficiary (family, acquaintance, stranger); Social context (observed, not observed)	-	Frontal cortex, temporoparietal junction	P3, N4
Wei et al. (2023)	Product attributes (hedonic, utilitarian); Premium (0, 10%, 35%)	-	-	LPP
Yin & Lee (2023)	Image priming (extreme weather images, control)	-	-	N2, N4
Zhang et al. (2023)	Green product type (self-benefit, other-benefit); Message framing (loss, gain); Anticipated pride (present, absent)	-	-	P3
Zhong et al. (2024)	Social context (observed, not observed)	Socioeconomic status (high, low)	-	N2, N4
Liang et al. (2024)	Sound type (natural, non-natural)	-	-	P2, N4
Current Study	Sound type (natural, non-natural)	Environmental movement activism (high, low)	-	-

Note: 1. This literature review was guided by: (1) Searching for publications before October 2024 with keywords "nudge" + "pro-environmental purchase decision" or + "EEG" or "ERP" or "neural" or "fMRI" or "heart rate." (2) References and citations of literature identified through keyword searches. (3) Literature retrievable from Web of Science and CNKI. 2. These references are arranged chronologically.

Appendix 2 Environmental Movement Activism Scale

To what extent do you agree with the following statements? (1 = strongly disagree; 2 = disagree; 3 = somewhat disagree; 4 = neutral; 5 = somewhat agree; 6 = agree; 7 = strongly agree)

1. If I had extra income, I would donate some money to environmental organizations.
2. I would like to join and actively participate in environmental organizations.
3. I don't think I would help raise funds for environmental protection. (R)
4. I would not participate in environmental organizations. (R)
5. Environmental protection costs a lot of money. I am prepared to help in fundraising efforts.
6. I don't want to donate money to support environmental causes. (R)
7. I would not go out of my way to help with recycling activities. (R)
8. I often try to persuade others that the environment is important.
9. I want to support an environmental organization.
10. I would never try to persuade others that environmental protection is important. (R)

Note: (R) indicates reverse scoring.

Appendix 3 Manipulation Checks for Green Attributes

To what extent do you agree with the following statements? (1 = strongly disagree; 2 = disagree; 3 = somewhat disagree; 4 = neutral; 5 = somewhat agree; 6 = agree; 7 = strongly agree)

Pro-environmental attributes: - Q1: Products with this label are environmentally friendly products. - Products with this label are green products. - Products with this label are beneficial to the environment.

Practical attributes: - Products with this label have high practicality. - Products with this label have high efficiency. - Products with this label have strong reliability.

Appendix 4 Example of Heart Rate Analysis

Note: This is a schematic diagram of 3-second ECG data extraction. The Pan–Tompkins algorithm was used to detect R-peak intervals, obtaining the duration between three R-peaks. The average of these three intervals was calculated, *and 60 was divided by this average to obtain the heart rate for this segment, approximately 77.5 BPM.*

Note: Figure translations are in progress. See original paper for figures.