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Green and black: the implicit color metaphor of environmental concepts and its impact on pro-environmental behavior

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This study aims to examine the impact of background colors on pro-environmental behavior surveys in both Chinese and English. A total of 146 unbalanced bilingual undergraduate students (individuals with higher proficiency in Chinese, L1, than in English, L2) in China were randomly assigned to either the green or black background versions of the survey. Prior to the survey, an Implicit Association Test (IAT) was administered to another group of 46 unbalanced bilingual undergraduates to assess implicit associations between green and black colors and environmental concepts in both languages. The IAT results showed that green was implicitly associated with environmental protection and black with pollution in both languages, with a stronger association in Chinese than in English. The questionnaire survey further revealed that a green background significantly promoted pro-environmental behaviors, whereas a black background had a somewhat inhibitory effect. These findings suggest that color metaphors associated with environmental concepts can influence pro-environmental behaviors.

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Introduction

Embodied cognition theory posits that human cognitive activities are not solely reliant on the brain but are deeply intertwined with bodily interactions and external entities (Barsalou 2008; Niedenthal 2007). This theory highlights the essential role of sensorimotor experiences in concept processing (Jamrozik et al. 2016). However, this poses a challenging question: if concepts are fundamentally grounded in sensorimotor experiences, how do individuals process abstract ideas such as love or truth— concepts that are not directly tied to physical experiences?

Conceptual metaphor theory offers a compelling framework to address this question. Proposed by Lakoff and Johnson (1980), this theory suggests that connections between concrete and abstract concepts are established through metaphorical mapping. Metaphors function by projecting knowledge from a source domain, typically concrete and familiar, onto a target domain, which is often abstract and complex. For example, in the metaphor "UNDERSTANDING IS GRASPING," "grasping" serves as the source domain, and "understanding" is the target domain. The physical experience of holding or grasping objects with our hands is systematically mapped onto the abstract concept of comprehension, enabling people to understand intellectual processes through familiar, embodied sensorimotor experiences. Linguistic expressions like "I can't quite grasp that concept" or "She firmly grasped the main ideas" reflect this systematic mapping, showcasing how people often use the framework of concrete physical experiences to make sense of abstract cognitive processes. Conceptual metaphors are not only ubiquitous in daily life but also play a significant role across diverse linguistic and cultural systems, shaping not just language but also cognitive and behavioral processes (Yang et al. 2024; 2023). Motivated by this deeper understanding of metaphorical cognition, this study aims to examine the impact of background colors on pro-environmental behavior surveys in both Chinese and English contexts.

Literature review

Colors not only possess visual attributes but also carry rich symbolic meanings (Elliot and Maier 2012). Color terms transcend mere hue description, reflecting deeper cultural significance. For instance, red symbolizes enthusiasm and celebration in Chinese culture (Tham et al. 2020). This is evident in Chinese expressions like "红红火火" (meaning prosperous and vibrant) and "张灯结彩" (decorating with red lanterns and colorful ribbons for celebrations). Moreover, the connection between colors and abstract concepts frequently manifests through color metaphors. In color metaphors, color serves as the source domain, representing abstract concepts in the target domain through metaphorical mapping. For instance, Wu et al. (2018) demonstrated that the color red is implicitly associated with social status in both the United Kingdom and China. Their research shows how colors carry powerful symbolic meanings that influence our cognitive processing and perceptions. Examples also include black and white colors symbolizing integrity behaviors (Zhang et al. 2022), red and gray colors symbolizing love status (Yang et al. 2024), and gold and gray colors symbolizing power status (Yang et al. 2015), demonstrating the metaphorical mappings of abstract concepts through color.

Color metaphors are essential for the understanding of environmental concepts. These color metaphors provide powerful frameworks for environmental communication. For example, the metaphor of "green economy" links green with a low-carbon economy, allowing people to understand and express environmentally friendly economic models more intuitively through this metaphor. In academia, environmental concepts have both broad and narrow definitions. Broadly speaking, environmental concepts can be defined as fundamental ideas, principles, and phenomena that describe and explain the relationship between human activities and the natural environment. However, researchers often tend to focus on specific types of environmental protection behaviors, leading to a more specific definition of environmental concepts. These specific environmentally friendly behaviors can be categorized based on different research fields, including pro-environmental purchasing behavior (McDonald et al. 2012), pro-environmental recycling behavior (Goldstein et al. 2008), and energy-saving behavior (Dwyer et al. 2015), among others. Thus, while the narrow concept of environmental concepts focuses on specific behaviors, it allows for a more detailed and in-depth study of the concept of environmental protection.

Recently, environmental protection issues have garnered widespread attention across various sectors of society, and green metaphors are commonly used in many languages. For instance, environmentally friendly products are often referred to as green products, and environmentally friendly behaviors are equated with green behaviors. This association exemplifies the way green has been specifically adopted as a marketing tool for environmentally conscious consumption through learned associations rather than inherent properties of the color itself. It is noteworthy that in many advertisements containing the term "green," it does not refer to the actual color but rather implies environmental characteristics. This semantic extension is also evident in concepts such as green food (Zhu et al. 2013), green energy (Hartmann and Apaolaza-Ibáñez 2012), and green economy (Estrada et al. 2025). In addition, the selection of green as an organizational image element stems from management's desire to improve corporate reputation and the widely recognized association between the color green and environmental protection (Rafaeli and Vilnai-Yavetz 2004). Escobedo et al. (2019) traced the evolution of environmental discourse through several key metaphors, including ecosystem services, green infrastructure, and nature-based solutions, which emerged over time as frameworks for translating complex environmental concepts into accessible forms of public understanding. At the same time, black is also a primary color metaphor used to represent environmental pollution. The black metaphor emphasizes the severity and harmfulness of environmental pollution, raising public awareness of environmental issues, as seen in concepts like black pollution and black waste. Polluted environments often appear black, such as polluted rivers, uncollected garbage, and gray-black skies on smoggy days (Cheng 2018). These impressions are deeply ingrained, making black a metaphorical mapping of environmental pollution (Cheng 2018). A question worth exploring is whether the presentation of green and black colors can activate the corresponding environmental concept metaphors and subsequently influence pro-environmental behaviors.

Only a few studies have focused on the psychological connections between environmental concepts and color metaphors. Müller (2014) was the first to explore the impact of questionnaire color on measuring environmental protection attitudes, finding that the color of the questionnaire had no significant effect on the scores of environmental protection attitudes. In contrast, Barone and Winterich (2016) discovered that a green background increased consumers' tendency to choose discount promotions, although this effect was weakened among consumers with strong environmental consumption values. Cheng (2018) systematically examined the association between green/black colors and environmental concepts from the perspectives of lexical processing and consumer behavior. The study found that when environmental

protection words were presented in green, the reaction times of participants were significantly shorter than when presented in other colors, indicating that green, as a visual cue, facilitated the processing of environmental protection words. In a purchasing decision experiment, participants using a green background survey were more inclined to select pro-environmental products, while those using a black background survey did not show a significant intention to purchase pro-environmental products (Cheng 2018). This suggests that visual green color may influence consumers' pro-environmental purchasing behavior (Cheng 2018).

Despite the preliminary exploration of the green-black color metaphor related to environmental concepts and its impact on purchasing behavior in the aforementioned studies, further research can be conducted in the following areas: First, while Cheng's (2018) study focused solely on pro-environmental purchasing behavior when examining the potential influence of color metaphors on pro-environmental actions, this approach has notable limitations. Pro-environmental purchasing behaviors typically represent private sphere decisions involving personal and household products whose individual environmental impact is relatively small (Stern 2000), whereas energy-saving behaviors constitute routine, socially visible actions (e.g., taking the subway, bicycling) with direct and more substantial impact on carbon emissions. By 2016, the energy consumption of Chinese residents for daily activities reached 540.9 million tons of standard coal, comprising 12.44% of China's total energy usage—nearly double the amount from 2005 (CNBS 2020). With "carbon peak" and "carbon neutrality" established as key objectives in China's pollution control strategy during the 14th Five-Year Plan (Zhao et al. 2022). Individual behaviors hold significant potential for contributing to energy conservation and emissions reduction through lifestyle choices. The present research therefore expands the scope to include energy-saving behaviors, providing a more comprehensive examination of how color metaphors influence different categories of pro-environmental behaviors.

Second, this study will investigate the potential differences in the impact of background colors on pro-environmental behavior surveys in both Chinese and English contexts. Importantly, environmental concepts likely involve distinct cultural schemas and emotional resonance that could affect metaphor processing. For example, Li and Ye (2017) found that while green metaphors are common in both English and Chinese to emphasize eco-friendliness and promote environmental protection, their usage and connotations differ significantly. In English, "green" can carry both positive and negative attributes depending on context and extends metaphorically into domains such as politics and finance, whereas in Chinese, "green" metaphors generally maintain positive associations and primarily focus on environmentalism (Li and Ye 2017). Moreover, Chinese contains a wealth of English environmental signage, necessitating metaphor research across languages. These signs, often displayed on green boards, feature rich cultural expressions beyond simple information transfer. For example, English environmental signage in China includes metaphorical phrases like "When you conserve water, you conserve life!" (personifying water as life), "The earth is sick, save the earth" (portraying the planet as a living being), and direct instructions like "Please don't leave rubbish" (Li 2017). Furthermore, some studies indicate that there is a delay in the metaphor comprehension process during second language processing compared to the native language (Heredia and Cieślicka 2015; Vaid et al. 2015). This difference in metaphor processing between L1 and L2 can be explained by the Revised Hierarchical Model (RHM) (Kroll and Stewart 1994), which posits that bilinguals have separate lexical stores but share a conceptual system, with stronger L1-concept links than L2-concept links. This structural asymmetry can lead to delayed or weakened activation of conceptual metaphors when processing in L2, resulting in reduced sensitivity to metaphorical associations. Therefore, it is necessary to explore whether the cognitive mechanisms of color metaphors are consistent when unbalanced Chinese-English bilinguals process environmental concepts in Chinese and English.

The present study. Based on conceptual metaphor theory, this study aims to explore the green-black color metaphor of environmental concepts among unbalanced bilingual undergraduate students in China and further investigate the impact of color metaphors on pro-environmental purchasing and energy-saving behaviors. Specifically, this study defines "unbalanced bilinguals" as individuals who exhibit significantly higher proficiency in their first language (Chinese) than in their second language (English). This characterization is based on their academic background and self-reported language proficiency. To this end, the study was conducted in two parts. The first part utilized an Implicit Association Test (IAT) to examine whether participants implicitly associate green with environmental protection and black with pollution. As the Implicit Association Test functions as a measurement protocol designed to evaluate differences between individuals in their unconscious cognitive processes (Anikin and Johansson 2019; Chen et al. 2015; Foroni and Bel-Bahar 2010; Parise and Spence 2012). We hypothesized that if participants' reaction times for categorizing environmental protection words with green squares and environmental pollution words with black squares are significantly shorter than for the opposite categorization task, it would demonstrate the existence of a green-black color metaphor for environmental concepts. The second part consisted of a Pro-Environmental Behavior Survey that operationalized environmental concepts into pro-environmental purchasing and energy-saving behaviors, using a 2 (Language Group: Chinese, English) × 2 (Background Color: Green Background, Black Background) between-subjects design to investigate whether the green-black color metaphor can influence Pro-environmental behaviors in both languages.

IAT assessment

Research questions. Are the Colors Green and Black Implicitly Associated with Environmental Concepts in Chinese and English?

Participants. G-power version 3.1 was used to estimate the required sample size. Based on the effect size $d = 0.39$ from related research (Ruba et al. 2021, Experiment 3), the statistical method was set to paired sample t-test, with the software settings of $1\text{-}\beta = 0.8$, $\alpha = 0.05$, resulting in an expected sample size of 43 participants. A total of 49 undergraduate students from Zhejiang Gongshang University were recruited (mean age = 22, range = 19–26), 4 males and 45 females, of whom 3 were removed from the data analysis. All participants were native speakers of Chinese and had proficiency in Chinese as their dominant language, with English as their second language. All participants were able to read simplified Chinese and English fluently. They were all born in China and resided in China at the time of the assessment. The language learning sequence for all participants was first learning Chinese and then learning English. Participants had normal vision without correction or corrected to normal vision, with no reading disabilities or color vision deficiencies. Participation in the assessment was voluntary, and participants received gifts upon completion. Among the participants, 5 had passed the Test for English Majors-Band 4 (TEM-4), a specialized English test designed for English major students in Chinese universities after approximately two years of university-

level English study, with an average score of 72 out of 100. The remaining 41 participants had passed the College English Test-Band 4 (CET-4), the standard English test required for non-English major university students in China, with an average score of 556 out of 710. All participants had received formal English education for a minimum of 9 years through the Chinese educational system.

Materials. The materials for the formal IAT assessment included color squares and target words. There were 35 green squares and 35 black squares, with all squares measuring approximately 10 cm by 5 cm. The target words were divided into environmental protection words and environmental pollution words, with 35 of each.

Before the formal IAT assessment, 13 participants who did not take part in the main study participated in a norming assessment. Participants were asked to rate each environmental word on two seven-point scales: one for the degree of environmental friendliness and the other for familiarity. The rating for environmental friendliness ranged from 1 (very harmful to the environment) to 7 (very beneficial to the environment), while the familiarity rating ranged from 1 (very unfamiliar) to 7 (very familiar). For the Chinese environmental words, the average environmental friendliness score for environmental protection words ($M = 6.14$) was higher than that for environmental pollution words ($M = 2.03$), $t(68) = 36.88$, $p < 0.001$. However, there was no significant difference in familiarity ratings between the two categories of words (5.56 vs. 5.51), $t(68) = 0.193$, $p = 0.847$, indicating that both categories of words were very familiar. Similarly, for the English environmental words, the average environmental friendliness score for environmental protection words ($M = 6.12$) was greater than that for environmental pollution words ($M = 1.89$), $t(68) = 47.44$, $p < 0.001$, but there was no significant difference in familiarity ratings (5.64 vs. 5.48), $t(68) = 0.623$, $p = 0.536$, with both categories of words being very familiar. This indicates that there is a difference in environmental friendliness among the selected two types of words, but no difference in familiarity. Importantly, the selection process for the environmental words aligns with the selection process from previous research (Sherman and Clore 2009; Yang et al. 2021), with some words sourced from Cheng (2018). The words used in the IAT assessment could be found at OSF link (https://osf.io/dmp4n/?view_only=e14414aa8ee94174baed8451744efbdd).

IAT assessment design. This IAT assessment employs the seven-step implicit association test designed by Greenwald et al. (1998). The third and sixth steps of the process serve as practice trials for the fourth and seventh steps, and data from the third and sixth steps are not recorded. The fourth and seventh steps constitute the formal assessment, during which data are recorded and analyzed. The IAT assessment tasks are divided into compatible categorization tasks and incompatible categorization tasks. The compatible categorization task involves categorizing compatible concept words and color squares; specifically, when environmental protection words and green squares appear, participants are required to press the "E" key, while when environmental pollution words and black squares appear, participants are instructed to press the "I" key. Conversely, the incompatible categorization task involves categorizing incompatible concept words and color squares; in this case, when environmental pollution words and green squares appear, participants were required to press the "E" key, while when environmental protection words and black squares appear, they are required to press the "I" key.

Procedure. The IAT assessment utilized a Lenovo monitor and employed E-Prime 2.0 software to present stimuli. All Chinese words were displayed in 30-point SimSun font, and all English words were displayed in 30-point Times New Roman font with target words in white (RGB: 255, 255, 255) and color squares in either green (RGB: 0, 176, 80) or black (RGB: 0, 0, 0). The background color of the IAT assessment was gray (RGB: 128, 128, 128). Each stimulus was presented in the center of the screen. The gray background with white text was chosen as a neutral control setting for the IAT procedure. Gray represents a neutral midpoint on the brightness spectrum, while the white text ensures optimal readability and contrast. The specific procedures and trials for IAT assessment are detailed in Table 1.

This IAT assessment adopted an implicit association test. Before the assessment commenced, participants were positioned approximately 50 centimeters from the screen and instructed to place their index fingers on the "E" and "I" keys, respectively. At the start of the assessment, participants first saw a white "+" fixation presented in the center of the screen for 500 ms, followed by the target stimulus, which was displayed for 3000 ms or until the participant made a key response. Participants were required to respond quickly and accurately to the target stimulus and press the corresponding key as instructed. The E-Prime software automatically recorded reaction times and accuracy rates. After the participant made a key response, the screen displayed the "+" fixation point again, continuing the aforementioned operational process until all target stimuli had been presented. Prior to the

Table 1 Example sequence of trial blocks for the color-environment IAT.

Blocks	Number of trials	Phase	Items assigned to key response	
			E Key	I Key
1	70	Practice	Environmental protection words	Environmental pollution words
2	70	Practice	Green color square	Black color square
3	140	Practice	Environmental protection words + Green color square	Environmental pollution words + Black color square
4	140	Test	Environmental protection words + Green color square	Environmental pollution words + Black color square
5	70	Practice	Environmental pollution words	Environmental protection words
6	140	Practice	Environmental pollution words + Green color square	Environmental protection + Black color square
7	140	Test	Environmental pollution words + Green color square	Environmental protection + Black color square

This study comprises two Implicit Association Tests (IATs), one presented in Chinese and another in English, using environmental protection/pollution words. The Chinese IAT block uses Chinese words, while the English IAT block uses English words.

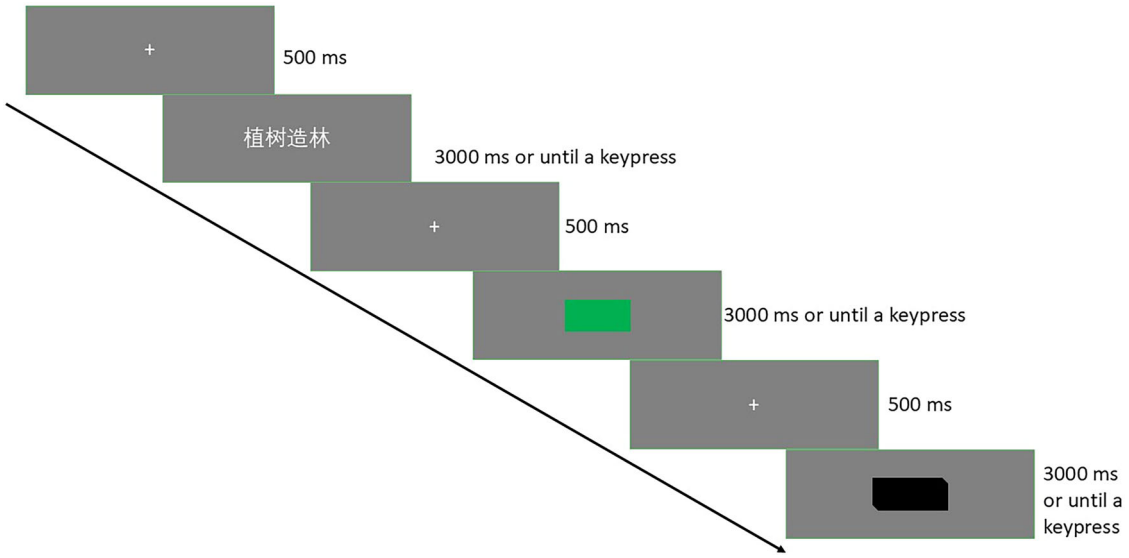

Fig. 1 IAT assessment setup and timeline of stimulus presentation.

Table 2 Mean reaction times (RTs, in Milliseconds) and percentage error rate with standard deviations in brackets under different conditions.

	Environmental protection words		Environmental pollution words	
	Reaction Times	Error rates	Reaction Times	Error rates
Chinese words				
Compatible	761 (97)	5.3 (5)	751 (92)	5.3 (4)
Incompatible	874 (155)	7.3 (7)	874 (155)	6.8 (7)
Difference	113	2.0	123	1.5
English words				
Compatible	1076 (189)	10.5 (9)	1094 (186)	12.2 (9)
Incompatible	1130 (205)	12.0 (10)	1140 (210)	11.6 (9)
Difference	54	1.5	52	−0.6

formal IAT assessment, participants were required to complete practice trials at the third and sixth steps, during which feedback on response accuracy was provided, whereas no feedback was given during the formal IAT assessment. More details of the IAT assessment procedure can be found in Fig. 1.

Results. Data analysis of the IAT assessment results was conducted using R language version 3.6.1. First, data from three participants with an accuracy rate below 80% were excluded. Next, reaction times less than 300 ms, reaction times exceeding three standard deviations from each participant's mean reaction time, and data from error trials (8.0% of the data) were excluded from the reaction time analysis. Table 2 presents the average reaction times and error rates of participants under different conditions.

According to the *d*-value calculation method proposed by Greenwald et al. (2003) (compatible categorization task mean reaction time - incompatible categorization task mean reaction time/standard deviation), the reaction time data were converted into *d*-values. A larger *d*-value indicates that the implicit association direction aligns with the experimental hypothesis. In the Chinese IAT assessment, a one-sample *t*-test showed that the *d*-value for environmental protection words ($M = 0.40$, $SD = 0.37$) was significantly greater than 0, $t(45) = 7.19$, $p < 0.001$, Cohen's $d = 1.06$, power = 1.00, indicating that participants had an implicit association between environmental protection words and the color green. The *d*-value for environmental pollution words ($M = 0.44$, $SD = 0.33$) was also significantly greater than 0, $t(45) = 8.97$, $p < 0.001$, Cohen's $d = 1.32$, power = 1.00, suggesting that participants had an implicit association between environmental pollution words and the color black. Finally, a paired sample *t*-test indicated that the strength of color-word associations for environmental protection words and environmental pollution words was similar, $t(45) = -0.90$, $p = 0.376$, Cohen's $d = -0.12$, power = 0.13.

In the English IAT assessment, a one-sample *t*-test revealed that the *d*-value for environmental protection words ($M = 0.15$, $SD = 0.35$) was significantly greater than 0, $t(45) = 2.98$, $p = 0.005$, Cohen's $d = 0.44$, power = 0.83, indicating that participants had an implicit association between environmental protection words and the color green. The *d*-value for environmental pollution words ($M = 0.13$, $SD = 0.40$) was significantly greater than 0, $t(45) = 2.29$, $p = 0.027$, Cohen's $d = 0.34$, power = 0.62, suggesting that participants had an implicit association between environmental pollution words and the color black. While this result reached statistical significance, we acknowledge that the post-hoc power (0.62) falls below the commonly accepted threshold of 0.80. This lower power indicates a greater risk of Type II error, and therefore the result should be interpreted with caution. Lastly, a paired sample *t*-test showed that the strength of color-word associations for environmental protection words and environmental pollution words was similar, $t(45) = 0.31$, $p = 0.756$, Cohen's $d = .05$, power = 0.06.

This study also conducted a further comparison of Chinese and English data. A paired sample *t*-test indicated that the *d*-value for environmental protection words in Chinese was significantly greater than in English, $t(45) = 3.26$, $p = 0.002$, Cohen's $d = 0.68$, power = 1.00. A paired sample *t*-test also showed that the *d*-value for environmental pollution words in Chinese was significantly greater than in English, $t(45) = 4.45$, $p < 0.001$, Cohen's $d = 0.83$, power = 1.00. In summary, Chinese-English bilinguals exhibited stronger color-word associations in Chinese than in English.

Pro-environmental behavior survey research questions. Do Green and Black Background Colors Influence Participants' Choices in Pro-Environmental Surveys?

Participants. Using G-Power software version 3.1 to estimate the required sample size, based on related research (Cheng 2018,

Experiment 3) with an effect size of $d = 0.66$, the statistical method was set to independent samples t-test, with the software configured for $1\text{-}\beta = 0.8$ and $\alpha = 0.05$. The anticipated sample size was 29 participants per group. A total of 146 undergraduate students from Zhejiang Gongshang University were recruited (mean age = 19, range = 18–22). All participants were native speakers of Chinese and had proficiency in English as a second language. All participants were able to read Simplified Chinese and English words fluently. They were all born in China and resided in China during the survey. The language learning sequence for all participants was to learn Chinese first, followed by English. Participants had normal vision without correction or corrected to normal vision, with no reading disabilities or color vision deficiencies. Participation in the survey was voluntary, and gifts were provided upon completion of the survey.

In the Chinese language survey, 70 participants (32 males and 38 females) were divided into two groups: the green background group and the black background group, with 35 participants in each group. The average score of the green background in the Chinese subject of the college entrance examination was 110; the average score of the black background was 110. An independent samples t-test was conducted to analyze the differences in Chinese scores between the two groups. The results indicated that there was no significant difference in Chinese scores between the green background ($M = 109.6$) and the black background ($M = 110.0$), $t(68) = 0.971$, $p = 0.827$.

In the English language survey, 76 participants (20 males and 56 females) were divided into two groups: the green background group and the black background group, with 38 participants in each group. All participants had received formal English education for a minimum of 9 years through the Chinese educational system. All participants in the green background had passed the College English Test Band 4 (CET-4), with an average score of 501; all participants in the black background had also passed the CET-4, with an average score of 491. An independent samples t-test was conducted to analyze the differences in CET-4 scores between the two groups. The results indicated that there was no significant difference in CET-4 scores between the green background ($M = 501.47$) and the black background ($M = 490.71$), $t(74) = 1.31$, $p = 0.195$.

Materials. The materials in both Chinese and English include reading tasks, a pro-environmental purchasing behaviors survey, and an energy-saving behaviors survey. The pro-environmental purchasing behaviors survey primarily references Mazar and Zhong (2010) and Cheng (2018). To extend the time participants are exposed to a specific color background, a neutral reading task is conducted before the survey begins. In this task, participants are asked to read an expository article about the working principles of electrical appliances. The article consists of approximately 400–500 words and takes about 2 min to read. After reading, participants are required to answer three questions.

In the pro-environmental purchasing behaviors survey, participants are first asked to select six products they wish to purchase, with a total price not exceeding 130 yuan. The shopping list contains 12 items, half of which are environmentally friendly and the other half not. The total price of the six environmentally friendly products is equal to the total price of the six non-environmentally friendly products, and the proportion of selected environmentally friendly products is statistically analyzed. In the product descriptions, the environmentally friendly products are primarily described in terms of the environmental properties of their materials (e.g., the body of each pen in the carbon-neutral series is made from recycled plastic derived from takeaway containers, which can reduce carbon emissions by ~2.3 g per pen), while the non-environmentally friendly products are described mainly in terms of their practicality (e.g., the disposable plastic cup features a smooth and transparent body, is thickened for heat resistance, and is not easily deformed. Made from food-grade materials, it is convenient to use and suitable for various occasions such as receptions, banquets, and restaurants).

Secondly, in the energy-saving behaviors survey, participants are asked to choose their mode of transportation. Six scenarios (e.g., on a sunny day, if you have 20 min to travel from your dormitory to the classroom building, please choose your mode of transportation) present participants with two energy-saving modes of transportation and two energy-consuming modes, from which they need to select one option from those four modes. The energy-saving modes are primarily described in terms of their environmental benefits (e.g., walking can protect the environment, reduce exhaust pollution, and strengthen the body), while the energy-consuming modes are mainly described in terms of speed and energy consumption (e.g., taxis can meet the personal transportation needs of passengers. Passengers do not have to worry about routes, parking spaces, or costs).

Survey design. This survey employs a 2 (Language Group: Chinese, English) × 2 (Background Color: Green Background, Black Background) between-subjects design, with the dependent variables being the proportion of participants' pro-environmental purchasing behaviors and energy-saving behaviors.

Procedure. The Pro-Environmental Behavior Survey distributed the questionnaire through the Questionnaire Star platform. Participants were randomly assigned to either the green background group or the black background group. Both groups first reporting demographic information such as age, gender, and language background experience. They then sequentially completed reading tasks, a pro-environmental purchasing behavior survey, and an energy-saving behavior survey. The difference between the green background group or the black background group lies in the background color used throughout the survey: the Green Background group completed the questionnaire with a green background (RGB: 0, 176, 80), while the black background group used a black background (RGB: 0, 0, 0) for the entire survey. White text white (RGB: 255, 255, 255) was used in all surveys to ensure optimal readability across both green and black background versions.

Results. The statistical analysis of Pro-Environmental Behavior Survey data was conducted using R language version 3.6.1. Before running the model, the default contrast in R was changed to a sum-to-zero contrast (Singmann and Kellen 2019). In the GLMM model, Language and Group were set as fixed effects, while Subject was set as a random effect to explore the combined impact of these factors on the proportions of pro-environmental purchasing and energy-saving behaviors (Bates et al. 2015; Lo and Andrews 2015). Post-hoc tests were conducted using the emmeans package to further analyze the significant differences between different condition levels (Russell 2020).

The analysis of pro-environmental purchasing behavior indicated that, as shown in Table 3, the main effect of Background Color was significant, ß = −0.66, $SE = 0.20$, $z = -3.35$, $p = 0.001$, suggesting that within the total price limit of 130 yuan, the proportion of pro-environmental products purchased by the green background group under a green background (56%) was higher than that of the black background group under a black background (43%). The main effect of Language Group was not significant, ß = −0.08, $SE = 0.20$, $z = -0.41$, $p = 0.680$. Furthermore, the interaction between

Table 3 Proportion of pro-environmental purchasing behavior (%) and energy-saving behavior (%) with standard deviations in brackets under different conditions.

Condition	Proportion
Pro-environmental purchasing behavior	
Questions in Chinese with green background	55.7 (17)
Questions in Chinese with black background	42.9 (14)
Questions in English with green background	56.1 (19)
Questions in English with black background	45.2 (20)
Energy-saving behavior	
Questions in Chinese with green background	72.4 (18)
Questions in Chinese with black background	61.9 (17)
Questions in English with green background	69.3 (17)
Questions in English with black background	61.4 (16)

Language Group and Background Color was also not significant, ß = −0.15, $SE = 0.20$, $z = -0.79$, $p = 0.432$. In post hoc analyses of the color effect, it was found that the color effect was significant in the Chinese survey ($z = -2.74$, $p = 0.006$) and marginally significant in the English survey ($z = -1.94$, $p = 0.052$).

The analysis of energy-saving behaviors showed that, as indicated in Table 3, the main effect of Background Color was significant, $ß = -0.64$, $SE = 0.19$, $z = -3.33$, $p = 0.001$. The proportion of energy-saving behaviors made by the green background group under a green background (71%) is higher than that of the black background group under a black background (62%). The main effect of Language Group was not significant, ß = −0.07, $SE = 0.19$, $z = -0.37$, $p = 0.715$. Furthermore, the interaction between Language Group and Background Color was also not significant, ß = −0.11, $SE = 0.19$, $z = -0.59$, $p = 0.555$. In post hoc analysis of color effects, it was found that the color effect is significant in the Chinese survey ($z = -2.70$, $p = 0.007$) and also significant in the English survey ($z = -1.99$, $p = 0.047$).

Discussion

This study, based on conceptual metaphor theory, explores the green-black color metaphor of environmental concepts among unbalanced bilingual undergraduate students in China, and examines its impact on pro-environmental purchasing and energy-saving behaviors.

Color metaphor of environmental concepts. This study first examines the black-green color metaphor of environmental concepts in both Chinese and English contexts. The results of the IAT assessment showed that participants exhibited significant implicit associations between environmental protection words and the green color, and between environmental pollution words and the black color, supporting conceptual metaphor theory (Lakoff and Johnson 1980). Green, as a common color in the natural environment, such as green vegetation and green mountains and rivers, often evokes images of vitality, health, and environmental friendliness. In contrast, black, as a consequence of industrial pollution, such as black smoke and black water, often conjures images of gloominess, dirtiness, and toxicity. Many languages associate green with environmental protection. For example, "going green" means becoming more environmentally friendly, and a "green pasture" signifies a new and better place (Lichtenfeld et al. 2012). The bodily experiences accumulated over time in specific cultural contexts lead to stable cross-domain mappings between green and environment protection concepts.

More importantly, this study finds that the strength of the black-green color metaphor of environmental concepts in Chinese is significantly higher than that in English. Over recent decades, "green" metaphors have grown significantly in both English and Chinese due to environmentalism (Li and Ye 2017). This concept extends beyond color hue to represent an ideology in diverse contexts, as seen in terms like "green economy," "green policy," and "going green," reflecting internationally accepted environmental values (Li and Ye 2017). Conversely, "black" is often used to denote dirtiness and illegality, as seen in terms like "黑乎乎" (English translation equivalents: Dark and murky), "黑帮" (English translation equivalents: Gang) and "黑社会" (English translation equivalents: Underworld) which align with the characteristics of environmental pollution (Li 2012; Zhang 2011).

The observed differences in color-word associations between Chinese and English can be interpreted from multiple perspectives. First, this aligns with the Revised Hierarchical Model (RHM), which posits that bilinguals maintain separate lexical representations for their languages with asymmetrical connections to the conceptual system (Kroll and Stewart 1994). According to this model, the connections between L1 words and the conceptual system are substantially stronger and more direct than those between L2 words and the conceptual system. This theoretical framework provides a compelling explanation for why Chinese environmental words yielded larger color-word associations when processed in L1 (Chinese). Additionally, as Harnad (1990) emphasized, newly acquired L2 concepts frequently borrow sensorimotor groundings from previously established L1 symbols. Given the presence of the green-environmentalism metaphor in both Chinese and English, a plausible interpretation is that participants had already internalized this metaphorical mapping during their English language acquisition process, with the association transferring directly from their L1. For instance, when Chinese learners encounter English expressions such as "green economy" or "green technology," they likely activate pre-existing conceptual associations between green and environmental protection established in Chinese, rather than constructing entirely new conceptual networks in English. This interpretation is further supported by Türker (2016), who demonstrated that bilinguals most effectively comprehend L2 metaphors more effectively when they align with existing L1 mappings, suggesting reliance on L1 knowledge structures during metaphor processing in L2. Although the statistical power for the English IAT on environmental pollution words was relatively low (0.62), the observed small effect (Cohen's $d = 0.34$) was consistent with the study's overall pattern and theoretical expectations. Nonetheless, this result should be interpreted with caution, and future studies with larger samples are needed to confirm the effect's reliability.

The impact of green-black color metaphors on environmental behavior. The key contribution of this study is the incorporation of multiple pro-environmental behavior indicators, specifically examining both pro-environmental purchasing and energy-saving behaviors. Unlike previous research that often focused on single-type environmental behavior (such as pro-environmental purchasing), our results provide a more comprehensive understanding of how color metaphors influence different types of environmental behaviors. The consistent pattern of color effects in both pro-environmental purchasing and energy-saving behaviors strengthens the case for color metaphors' importance in environmental contexts. These findings suggest that while green-environmental protection behaviors and black-environmental pollution behaviors associations exist in both languages, they may manifest more strongly in participants' native language. This aligns with our IAT results showing stronger associations in Chinese than English contexts.

This finding is consistent with existing research and supports the notion that color serves as a psychological cue in behavior regulation (Elliot 2015; Elliot and Maier 2014). Numerous studies indicate that even when individuals are not consciously aware, color cues can still activate specific psychological representations, thereby influencing attitudes, judgments, and behaviors. For instance, red is often associated with the danger of failure (e.g., incorrect answers are commonly marked in red ink), which can undermine an individual's performance in challenging intellectual tasks in achievement contexts (Shi et al. 2015). Conversely, in human sports competitions, athletes wearing red uniforms have a higher probability of winning (Hagemann et al. 2008).

Why do the green-black color metaphors of environmental concepts affect individual decision-making regarding environmental behavior? There may be three psychological mechanisms at play. First, the color effect arises from the repeated pairing of colors with specific concepts, information, and experiences. Through long-term association, individuals form strong (often implicit) color connections, such that merely perceiving a certain color can evoke corresponding emotions, cognitions, and behaviors (Elliot and Maier 2014). Mahnke and Mahnke (1987) suggest that modifying the colors of ceilings, walls, and floors can alter the spatial character of an environment, subsequently influencing individuals' reactions and behaviors. Similarly, in the Pro-Environmental behavior survey, the green background of the questionnaire may have preferentially activated participants' conceptual metaphor mappings related to environmental protection, leading them to focus more on the eco-friendly attributes of products in subsequent purchasing and energy-saving surveys. In contrast, the black background may have triggered conceptual metaphor mappings related to environmental pollution, ultimately resulting in a decrease in the proportion of pro-environmental purchasing and energy-saving behaviors. Similar color effects have been observed in other studies. For example, in the context of fashion retail, blue interiors may create a more positive and pleasant atmosphere than orange interiors, enhancing customers' willingness to purchase (Babin et al. 2003).

Secondly, in addition to paying attention to cues, the emotional experiences underlying color metaphors may also play an important role in environmental behaviors. Numerous studies have shown that even when individuals are exposed to specific colors unconsciously, their emotional states can change. Cross-cultural research by Adams and Osgood (1973) found consistent patterns in color-emotion associations across diverse cultures, with GREEN and BLUE generally perceived as "good," while BLACK was associated with "bad, strong, and passive" qualities. Moreover, Kaya and Epps (2004) found that college students tend to associate green with relaxation and comfort, which may stem from the inherent connection between green and natural environments. Hanada (2018) also discovered that green is associated with emotions of peace, soothing, and healing, a connection that may be based on the fact that plants typically present in green, which could form the foundation for the link between green and a sense of tranquility.

In contrast, black often evoke negative emotions such as gloom and depression (Hanada 2018). This color-emotion association parallels Adams and Osgood's (1973) observation that black is generally perceived as "bad". Emotional changes triggered by color may influence motivation and goal-setting, thereby regulating individuals' environmental behaviors. Previous research has found that both positive and negative emotions can affect an individual's willingness to engage in environmentally friendly behaviors. For instance, negative emotions (such as anger or frustration) can decrease people's willingness to use public transportation and participate in household recycling (Carrus et al. 2008). Additionally, studies have shown that positive emotions (such as happiness or optimism) are significant predictors of green product purchasing behavior (Koenig-Lewis et al. 2014). Recent research by Kawai et al. (2023) further explores color-emotion associations, examining both explicit and implicit associations between colors and emotions across different cultural contexts. Interestingly, Zentner (2001) demonstrated that these color-emotion associations develop early in life, finding that children as young as 3 years old can detect consistent relationships between colors and facial expressions of emotions.

However, explanations based on the positive or negative valence of emotions associated with colors may be insufficient to fully account for the green versus black opposition observed in our study. Research by Simmons (2011) demonstrated that both green and black colors can be associated with negative emotions in English language contexts. For example, green is associated with negative emotions through expressions like "green with envy". Another possible explanation can be found in the structural characteristics of these colors, particularly their brightness levels. Lakens et al. (2011) proposed that the relationship between brightness and positivity is only present when the relationship between darkness and negativity is simultaneously activated. This brightness-valence relationship creates a grounded representation where opposing concepts (light-dark, positive-negative) become conceptually linked. In this study, although participants were only exposed to either a green or a black background, the differential responses may still reflect this brightness-valence mechanism. Specifically, the green background, being perceptually brighter, may have implicitly evoked more positive affect and thus promoted stronger pro-environmental behaviors, whereas the darker black background may have induced negative affect and thus inhibited such behaviors.

In summary, a green background may generally evoke positive emotions associated with natural environments and environmental protection, thereby encouraging pro-environmental purchasing and energy-saving behaviors. In contrast, a black background may trigger negative emotions linked to environmental pollution. The structural brightness contrast between these colors likely plays a crucial role in reinforcing these associations and shaping subsequent environmental behavior.

Conclusion

This study examines the green-black color metaphor and its influence on pro-environmental behavior among unbalanced Chinese-English bilingual undergraduates. Our Pro-Environmental Behavior questionnaire demonstrated that background colors significantly affected environmental behaviors: green backgrounds promoted pro-environmental purchasing and energy-saving behaviors, whereas black backgrounds suppressed pro-environmental behaviors. IAT results confirmed the underlying mechanism, showing that green was implicitly associated with environmental protection while black was implicitly associated with environmental pollution in both Chinese and English, with stronger associations in Chinese. These findings suggest that environmental color metaphors influence behavior through attentional cues, emotional experiences, and the brightness-valence relationship. Despite these meaningful results, the study has three limitations that should be addressed in future research. First, while we utilized IAT to assess color-word associations in both Chinese and English, it is important to acknowledge that this methodology is not well-suited for investigating bilingual processing specifically, as the IAT measures automatic associative processes but does not require genuine bilingual processing. Second, the study was conducted in a laboratory setting, which may differ from real-life environmental decision-making (Zhang and Ren 2024). Lastly, the research did not account for individual

differences (such as environmental awareness and color sensitivity) that may moderate the effects of color metaphors.

Data availability

All data generated or analyzed during this study are included in the OSF link (https://osf.io/dmp4n/?view_only=e14414aa8ee94174baed8451744efbdd), further inquiries can be directed to the corresponding author.

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Author contributions

All authors contributed to the study's conception and design. All authors revised and approved the final manuscript.

Competing interests

The authors declare no competing interests.

Ethical approval

This study's protocol was approved by the Research Ethics Committee of the Foreign Languages Department at Zhejiang Gongshang University (Approval No: [ZJGSU-2021-12-20]; Date of Approval: December 20, 2021). The scope of the approval covered all experimental procedures involving human participants as described in the study protocol. All research was performed in accordance with the ethical principles for medical research involving human subjects outlined in the Declaration of Helsinki and its later amendments.

Informed consent

Written informed consent was obtained from all participants prior to their inclusion in the study. The experimental sessions were conducted between June 2022 and June 2023. Before each session, the researcher provided an information sheet and verbally explained all relevant aspects of the study. This process ensured participants were fully informed about: (a) the purpose and procedures of the experiment; (b) the voluntary nature of their participation and their right to withdraw at any time without penalty; (c) the confidential handling of their data and assurance of anonymity; (d) any foreseeable risks, which were deemed minimal and not exceeding those of everyday life; and (e) the potential for anonymized data to be used in academic publications. The scope of the written consent explicitly covered participation, data use for analysis, and consent to publish. All participants were over the age of 18.

Additional information

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