

Visual attention and memory retention of cannabis warning labels: an eye-tracking experiment with young adults

Jiaying Liu, PhD^{1, }, Ranran Z. Mi, PhD², Moonson Jeon, MA^{3, }, Jessica L. Fabbriatore, PhD⁴, Rebekah Wicke, MS^{5, }, Lauren Raquel Cojulan, MA⁶, Sijia Yang, PhD^{*7, }

¹Department of Communication, University of California Santa Barbara, Santa Barbara, CA 93106, United States

²Department of Communication, Media and Journalism, Kean University, Union, NJ 07083, United States

³Department of Communication, Michigan State University, East Lansing, MI 48824, United States

⁴School of Communication, East Carolina University, Greenville, NC 27858, United States

⁵Department of Communication, Cornell University, Ithaca, NY 14853, United States

⁶Department of Communication, University of Georgia, Athens, GA 30602, United States

⁷School of Journalism and Mass Communication, University of Wisconsin-Madison, Madison, WI 53706, United States

*Corresponding author: Sijia Yang, PhD, School of Journalism and Mass Communication, University of Wisconsin-Madison, Madison, WI 53706, United States (sijia.yang@alumni.upenn.edu).

Author Contributions: Drs J. Liu and R.Z. Mi shared first authorship.

Abstract

Background: Cannabis use is rising among young adults, while their perceived risks are declining. Existing cannabis warning labels (CWLs), often dense, generic, and text-only, struggle to sustain attention or promote effective risk recognition. Drawing on construal-level theory, this study investigates whether the concreteness of textual and pictorial elements improves CWL effectiveness.

Purpose: This study examines how specific (vs. generic) text related to health consequences and the addition of pictograms or vivid imagery influence sustained attention to CWLs and recognition of cannabis-related health risks.

Methods: In an eye-tracking experiment, 163 young adult participants were randomly assigned to view CWLs featuring: (1) generic text, (2) specific text, (3) specific text with pictogram, or (4) specific text with vivid imagery. Attention was measured via fixation duration, and recognition was assessed using a post-exposure memory test with signal detection scores.

Results: CWLs with specific text significantly outperformed generic text in sustaining attention and enhancing general risk recognition. Adding vivid imagery further enhanced attention but did not significantly improve recognition beyond specific text alone. CWLs with pictograms also led to greater attention than generic text, though less than vivid imagery, and similarly did not improve recognition.

Conclusions: Cannabis warnings should prioritize concrete, specific text to optimize both attention and recognition. For raising awareness, incorporating vivid imagery can be beneficial. However, for educational goals centered on enhancing recognition, pictorial elements may be unnecessary if the text is sufficiently concrete. These findings offer practical guidance for designing effective warnings to curb cannabis use among young adults.

Key words: cannabis use; warning messages; young adults; attention; recognition; eye-tracking

Lay Summary: Cannabis use is increasing among young adults in the United States, yet many do not fully recognize its health risks. Warning labels on cannabis products are meant to inform people about these risks, but current labels are often long, vague, and difficult to read. This study tested whether making warning messages more concrete and adding visuals could improve their effectiveness. We conducted an experiment with 163 young adults who viewed different types of cannabis warning labels while their eye movements were tracked. Some labels used generic, abstract text, while others used specific, detailed text. A subset of the specific-text labels also included either simple pictograms or vivid images. After viewing, participants completed a memory test about the health risks shown. The results showed that labels with specific text were better than generic ones at holding attention and helping participants remember health risks. Adding vivid images drew even more attention, though they did not improve memory beyond the effect of specific text alone. These findings suggest that cannabis warnings should use clear, specific language to improve risk recognition, and vivid imagery can be added when the goal is to maximize attention.

Introduction

Cannabis is the most commonly used psychoactive drug among young adults in the United States¹ and as of 2024, nonmedical (recreational) use of cannabis has been legalized in 24 states as well as the District of Columbia.² In the years following these policy changes, the availability and potency of cannabis

products have increased significantly.³ Despite substantial evidence linking cannabis use to serious mental and physical health consequences,^{4,5} public perceptions of its risks have declined.⁶ This shift in perception is particularly noticeable among adolescents and young adults, who report daily or near-daily use, often of high-potency products containing

Received: June 5, 2025. Accepted: November 4, 2025

© Oxford University Press 2025. All rights reserved. For commercial re-use, please contact reprints@oup.com for reprints and translation rights for reprints. All other permissions can be obtained through our RightsLink service via the Permissions link on the article page on our site—for further information please contact journals.permissions@oup.com.

elevated levels of delta-9-tetrahydrocannabinol (THC), with an earlier onset of use.³

Cannabis warning labels (CWLs) play a crucial role in informing consumers about the potential risks of cannabis use.^{6–8} However, CWLs currently mandated in the United States vary widely, and the regulatory landscape is rapidly changing. As of 2024, among the 20 states that mandate warning labels on packaging for retail nonmedical cannabis products, 8 require statements about general health risks, while the remaining 12 vary in their mandated warnings of specific health risks, with the top 3 pertaining to child protection, pregnancy and breastfeeding, and impaired driving.⁹ Importantly, only 2 states require the rotation of multiple specific-risk warnings, and no state has mandated the use of pictorial warnings.⁹ Most states have faced criticism for their dense, generic, text-only designs, which often combine multiple health risk messages into a single label using hard-to-read fonts.¹⁰ This heterogeneity in warning requirements and the lack of alignment with best practices in tobacco warning label design¹⁰ pose the risk that these warnings might be ineffective in capturing consumer attention, a prerequisite for successfully delivering targeted risk information. This highlights the need for research examining alternative warning label designs, such as rotating single-risk statements, larger fonts, and visual enhancements, that may enhance warning label efficacy.

Health warnings are considered effective to the extent that they capture and sustain consumer attention and facilitate memory of the risks involved, as these proximal outcomes can set the stage for subsequent emotional, cognitive, and behavioral responses.^{11,12} The Message Impact Framework, grounded in tobacco warning research, suggests that strengthening warnings increases attention, stimulates deeper message processing, and enhances perceptions of warning effectiveness, which in turn influences how individuals think about and respond to health risks.¹³ In today's digital media environment, where consumers are exposed to a flood of competing information online, sustaining attention is critical for breaking through the clutter and ensuring that risks are noticed. Equally important, however, is to ensure that warnings are recognized and remembered over time. Recognition memory has been shown to mediate the relationship between warning exposure and outcomes such as risk perception and quit intentions.¹⁴ Thus, achieving both momentary attention and durable recognition through stronger, engaging warnings is essential for fulfilling their educational and preventive functions.

Research on textual warning design has primarily focused on factors such as readability and rotating themes to examine their effect on attention and recognition.^{7,15} In this study, we draw on the construal-level theory (CLT) of psychological distance,¹⁶ a recently emerged framework that has been used to inspire and guide persuasion research.¹⁷ According to CLT,¹⁸ specific, concrete messages—those with a low-construal level—are often perceived as more personally relevant and immediate, making them more persuasive. In contrast, generic, abstract messages, or those with a high-construal level, are perceived as more distant and less personally engaging, thus less persuasive. A study on a daily texting intervention for student cannabis users found that participants preferred concrete and straightforward messaging over abstract or academic language.¹⁹ However, there remains a lack of empirical research

comparing concrete versus abstract language specifically in the context of CWL design.

Beyond textual design, another key aspect of designing warning messages is the inclusion of pictorial elements. Visualizing the warning label is crucial, as it competes with branding imagery for the consumer's attention.²⁰ From a CLT perspective, visual depictions can make health risks feel more tangible and immediate, offering a concrete representation that enhances perceived relevance compared to text-only messages.¹⁷ However, current mandates for CWLs do not require pictorial warnings on packaging with branding imagery.²¹ Experimental research has demonstrated that pictorial warnings can enhance attention and recognition.⁷ Additionally, young adults perceive CWLs with pictorial visuals as more believable and effective than text-only warnings.^{12,22} Vividness also plays an important role, as research indicates that it corresponds with a low-level construal²³ and is linked to increased engagement²⁴ and threat appraisal.²⁵ Nevertheless, it remains unclear how the inclusion of pictorial elements, particularly varying levels of vividness, may impact these key outcomes in the CWL context.

To address these gaps, this study examines whether the concreteness of textual and pictorial elements in CWLs impacts sustained attention to the warnings and recognition of cannabis-related health risks. Because sustained attention is a central proximal outcome, we employed eye-tracking, which provides an objective and fine-grained assessment of where and for how long participants look. Prior tobacco warning studies have established eye-tracking as a reliable method for evaluating how design features capture attention and have shown that greater visual attention predicts stronger emotional reactions, improved recall, and reduced susceptibility to future use.^{26–29} Accordingly, an eye-tracking experiment was conducted using a between-subjects design with 4 conditions: generic text only, specific text only, specific text with a pictogram, and specific text with vivid imagery. We hypothesized that CWLs with specific text only (1), specific text with pictogram (2), and specific text with vivid imagery (3) would lead to greater attention (H1) and better general risk recognition (H2) than generic text. We also explored whether attention (RQ1) and specific risk recognition (RQ2) varied among the 3 specific-text conditions. Understanding these effects can inform public health initiatives and regulatory policies aimed at mitigating cannabis-related harms.

Method

Participants

Participants were undergraduate students recruited from the University of Georgia (Athens, GA, USA) in 2021. Eligible participants were 18 years or older. The study was approved by the University's Institutional Review Board. Of the 218 participants who signed up, 14 failed the eye calibration test, resulting in 204 completions. Forty participants were excluded for being assigned to a condition that tested a composite text-only CWL, modeled after the version used in California as of early 2025.^{30,31} This condition was designed to support an auxiliary analysis rather than testing the main hypotheses and research questions of the present study (more details in the Results section). One additional participant was removed for lack of attention to stimuli during quality control, yielding a final sample of 163 participants. An *a priori* power analysis

using G*Power indicated that a total sample of 128 participants (32 per group) would provide 80% power to detect a medium effect size (Cohen's $f=0.30$) in a 4-group design (as detailed below) at $\alpha = .05$. Our final analytic sample of 163 participants (37–44 per group) exceeded this threshold, ensuring adequate power to detect the main effects of interest. It is important to note that, due to state laws at the data collection site, where recreational cannabis use was illegal and possession, purchase, manufacture, or sale of cannabis constituted a criminal offense, we were not permitted to include survey questions assessing participants' prior cannabis use. Although medical cannabis use was legal in limited forms in the state, these restrictions still prevented us from collecting such information. However, given the randomized experimental design, the absence of individual cannabis use data is unlikely to introduce systematic bias to the results.

Experimental design

The study employed a 4 (message feature, between-subject factor) \times 6 (message theme, within-subject factor) mixed factorial design. Participants were randomized to 4 experimental conditions varying CWL message features: generic text only, specific text only, specific text with pictogram, and specific text with vivid imagery. Within each condition, participants viewed 6 CWLs, each corresponding to a different established health consequence associated with cannabis use,^{32–38} presented on the same fictitious product. The 6 message themes were: (1) baby (ie, harms to babies); (2) chemicals (ie, health problems caused by inhaling toxic chemical constituents found in cannabis products); (3) driving (ie, risk of impaired driving under the influence of cannabis use); (4) early use (ie, irreversible damage to brain development if used early in life); (5) mental health (ie, mental health issues); and (6) vomiting (digestive discomfort caused by consumption of cannabis). Except for the message on digestive discomfort and vomiting, all other themes are addressed in a bill to redesign warning labels in California.³⁹ The sequence of the themes was randomized for each participant to account for potential order effects. Example stimuli are provided in [Figure 1](#).

The generic text-only condition included abstract text information (eg, "Consumption of cannabis impairs users' ability to drive and operate machinery"). The specific text condition provided more concrete details (eg, "Driving high is dangerous. Cannabis slows down your reaction time and causes drowsiness. Driving after using cannabis can double your risk of a car crash"). In the specific text with pictogram or vivid imagery conditions, the same concrete text is paired with either an illustrative pictogram (eg, an abstract black-and-white image of a car crash) or a graphic image (eg, a vivid photo of a car crash).

Procedure and lab setting

Prior to the eye-tracking session, participants provided informed consent and completed a brief pre-experiment survey to report demographic information. Trained research assistants administered the eye-tracking sessions in a dedicated research lab. Participants were told they would view images of product packaging, but were unaware of the product type.

All participants were seated about 60–65 cm from the display of a laptop computer (15.6-inch Dell XPS 15 with a screen resolution of 1920 \times 1080 pixels). Their eye movements were

tracked by a Tobii Pro Nano screen-based eye-tracker with a sampling rate of 60 Hz. At the beginning of the eye-tracking session, participants were guided through a standardized onscreen calibration process, using a set of 5 calibration points covering the entire screen. Calibrations were checked and verified to ensure that the average error in eye position was <0.5 degrees and 6.3 mm. Participants who failed to meet the validation criteria for 5 calibrations were considered ineligible for the study. Once calibration was completed, participants were instructed to avoid body and head movement throughout the session.

Following validation, participants viewed 6 CWLs presented in a randomized order. Each warning label was displayed for 20 seconds, followed by a blank screen with a fixation cross at the center for 15 seconds before presenting the next stimulus. The warning area of interest was identified a priori (see [Figure 1](#)). After viewing all 6 CWLs, participants completed a post-experiment survey where the recognition outcomes were assessed. The entire study session took approximately 30 minutes to complete.

Measures

Attention

Participants' attention was measured using total fixation duration (ie, dwell time, recorded in seconds) by the eye-tracker, with longer durations indicating greater sustained attention. A fixation is a period when the eyes hold the central foveal vision in place (ie, no eye-movement), which exceeds a predetermined velocity (ie, pixel by milliseconds) threshold, to take in detailed information of an area.⁴⁰ This measure was collected for each CWL (ie, at the per-message level).

Recognition

Participants' recognition of the risks was assessed through a memory test after their exposure to all stimuli. They were presented with a list of potential risks, including a mixture of correct general risks ($n=6$; e.g., "brain development problems," "cognitive and motor dysfunction"), correct specific risks ($n=17$; "irreversible IQ loss," "drowsiness"), and incorrect foil items ($n=15$; "lung cancer," "kidney disease"). They were asked to select only the health risks mentioned in the CWLs they had viewed. This recognition-based task differs from free (unaided) recall in that participants selected risks from a provided list rather than generating them spontaneously, thereby reducing retrieval demands and minimizing vulnerability to floor effects.^{41,42} Both general and specific risk recognition were measured using the "sensitivity" score from signal detection theory,⁴³ which assesses participants' ability to discern true risks. This score was calculated by subtracting the standardized false alarm rate from the standardized hit rate. The hit rate represented the proportion of true risks correctly identified, while the false alarm rate reflected the proportion of false risks mistakenly identified as true. The 2 recognition measures were collected for each participant (ie, at the per-person level).

Demographics

Participants reported their age, biological sex, race, and ethnicity in a pre-experiment survey administered prior to the eye-tracking task.



Figure 1. Experimental conditions, example stimuli and area of interest. *Note.* The area of interest (AOI) consists of the contents of the black box at the bottom of each image.

Analytical strategy

Given that each participant viewed 6 CWLs and attention was measured at the per-message level, we fitted a linear mixed-effects model to examine attention differences across conditions. The model included random intercepts for participants to account for individual differences in baseline attention. Estimated marginal means were then calculated for each message condition, followed by pairwise comparisons adjusted using Tukey's method to assess differences in mean attention between message conditions. Recognition for both general and specific risks was assessed at the per-person level. We analyzed recognition using a linear regression model with robust standard errors to account for potential heteroscedasticity. Estimated marginal means were calculated for each message

condition to compare general risk recognition across all message conditions, and specific risk recognition among the 3 specific text conditions. Pairwise comparisons, adjusted using Tukey's method, were then conducted to evaluate differences in mean recognition between message conditions.

Results

Sample characteristics

The final analytical sample consisted of 163 participants. The average age was 19.40 years ($SD = 1.20$), with 56.7% ($N = 93$) self-identifying as female. Most participants identified as White ($N = 126$, 76.8%), followed by Asian or Pacific Islander ($N = 18$, 11.0%), African American ($N = 10$, 6.1%), multiracial

or other ($N=9$, 5.5%), and American Indian or Alaskan Native ($N=1$, 0.6%). Fourteen participants (8.5%) were of Hispanic or Latino origin.

Attention (fixation duration)

Descriptive statistics for key outcome variables, including attention and recognition measures, are presented in Table 1. Results from the linear mixed-effects model indicated that message features significantly influenced fixation duration, $F(3, 159) = 24.51$, $P < .001$. Message theme also had a significant main effect, $F(5, 795) = 6.55$, $P < .001$, although its interaction with message feature was not significant, $F(15, 795) = 1.09$, $P = .36$. Given our primary interest in how specific message features affect attention, we then conducted multiple pairwise comparisons of fixation duration among different message feature conditions after averaging across 6 themes. Results showed that compared to generic text only, specific text only ($\Delta=2.38$, $SE=0.52$, $P < .001$), specific text with pictogram ($\Delta=3.27$, $SE=0.51$, $P < .001$), specific text with vivid imagery ($\Delta=4.20$, $SE=0.51$, $P < .001$) all produced significantly greater fixation duration. Thus, H1a, H1b, H1c were supported.

To test whether the longer fixation durations in the specific text conditions were merely the result of greater content volume or complexity (ie, having more words to read), we carried out a post-hoc auxiliary analysis drawing on data from an additional condition not included in the primary analyses. As briefly noted earlier, this condition featured a composite text-only CWL modeled after California's current label, consisting of a dense, all-caps block of 73 words describing multiple health risks simultaneously. This word count was substantially higher than the 13–20 words in the generic text condition and the 21–30 words in the specific text conditions used in the current study, not to mention the added complexity of full capitalization. Despite the increased text length and visual density, the average fixation duration in this composite condition was $M=7.99$ ($SD=3.34$), nearly identical to that of the specific text-only condition ($M=7.97$, $SD=3.38$; $P = .98$). This suggests that increased text length alone does not necessarily lead to longer visual attention. However, because this composite message also differed in format (eg, all-caps presentation) and may have introduced message fatigue, this comparison should be interpreted cautiously. Taken together, the findings suggest that the increased attention in the specific text conditions cannot be attributed solely to greater content volume, but other message characteristics beyond length may also play a role.

To address RQ1, multiple pairwise comparisons among 3 specific text conditions were conducted. Results showed that specific text with vivid imagery produced significantly higher mean fixation duration than specific text only ($\Delta=1.82$,

$SE=0.50$, $P < .001$), but the estimated difference of mean fixation duration only trended significance between specific text only and specific text with pictogram ($\Delta=0.89$, $SE=0.50$, $P = .074$), and between specific text with pictogram and specific text with vivid imagery ($\Delta=0.92$, $SE=0.49$, $P = .061$).

Recognition

Results showed that compared to generic text only, specific text only ($\Delta=0.71$, $SE=0.28$, $P = .014$), specific text with pictogram ($\Delta=0.59$, $SE=0.27$, $P = .028$), specific text with vivid imagery ($\Delta=0.72$, $SE=0.28$, $P = .011$) all produced significantly better recognition of general risks. Thus, H2a, H2b, H2c were supported. For RQ2, no significant differences in specific risk recognition were found among these conditions.

Discussion

Cannabis use is rising among young adults, a vulnerable group whose perceptions of cannabis risk are declining. This trend highlights the need for more effective CWLs to achieve 2 crucial outcomes: sustaining attention and enhancing recognition of health risks. In this eye-tracking experiment, we evaluated different message features to determine which best sustained attention and facilitated recognition. Specifically, we compared CWLs with concrete, detailed information (specific text) to those with abstract, less detailed content (generic text). Additionally, we assessed whether supplementing specific text with a pictogram or vivid imagery would further influence these outcomes.

Our findings suggest that warning messages with specific text are more effective than those with generic text in sustaining attention and enhancing recognition of cannabis-related risks. However, the effects of adding a pictorial element alongside specific text were mixed. Among specific-text conditions, adding vivid imagery significantly increased fixation duration, making it the most attention-holding design. In contrast, the addition of a pictogram did not significantly improve attention relative to specific text alone, though it trended toward significance. Importantly, while all specific-text conditions improved recognition of general risks compared to generic text, neither the pictogram nor vivid imagery provided additional recognition benefits beyond those achieved by specific text alone.

The findings of this study offer clear implications for the design of CWLs. First, replacing generic text with more concrete, specific language may significantly enhance their effectiveness. Our results show that specific text is more successful in sustaining attention and enhancing risk recognition, both of which are critical for impactful health communication. When the primary goal of a warning message is to hold attention and

Table 1. Descriptives of fixation duration and recognition.

	All	Generic text only	Specific text only	Specific text with pictogram	Specific text with vivid imagery
	N, mean (\pm SD)	N, mean (\pm SD)	N, mean (\pm SD)	N, mean (\pm SD)	N, mean (\pm SD)
Fixation duration	978, 8.13 (\pm 3.75)	222, 5.58 (\pm 3.09)	240, 7.97 (\pm 3.38)	264, 8.86 (\pm 3.44)	252, 9.78 (\pm 3.75)
Recognition: general risks	163, 0.05 (\pm 1.21)	37, -0.46 (\pm 1.27)	40, 0.24 (\pm 1.21)	44, 0.12 (\pm 1.08)	42, 0.26 (\pm 1.19)
Recognition: specific risks	163, 0.04 (\pm 1.30)	37, -1.69 (\pm 0.96)	40, 0.44 (\pm 1.00)	44, 0.55 (\pm 0.77)	42, 0.66 (\pm 0.89)

Note. Fixation duration was measured at the message level (N = number of participants \times 6 themes). Recognition was measured at the participant level (N = number of participants).

raise awareness, incorporating vivid imagery is the most effective strategy, as it significantly enhances the message's ability to maintain attention for meaningful processing of the message. However, when the objective is to enhance recognition and fulfill an educational purpose, adding a pictorial element may be less crucial. As our results suggest, specific and concrete text alone is sufficient for improving recognition, without the need for supplementary imagery. This nuanced understanding highlights that different communication goals, such as sustaining attention versus promoting knowledge retention, can be achieved through different design approaches. Our findings also underscore the importance of treating both attention and recognition as key proximal outcomes in warning label research. As the Message Impact Framework notes, attention enables message encoding while recognition allows retrieval at decision points.¹³ Together, they shape downstream responses such as risk perceptions and intentions, highlighting how CWL design can influence both immediate processing and longer-term impact. Given that currently mandated CWLs in the United States are text only and small in font, and that many states only require general risk statements while very few require rotating warnings,⁹ our findings support redesigning CWLs to include concrete information on specific risks, rotate single-risk warnings, and strategically employ visual elements such as pictograms and vivid imagery to enhance attention and recognition. These results can inform ongoing regulatory discussions to better follow best practices in health warning label design⁶ as legalization of recreational cannabis expands and the urgency for effective CWLs heightens.

Our study provides evidence-based recommendations for policymakers and public health practitioners that are both actionable and pragmatically incremental, recognizing the challenges of implementing sweeping changes to warning label policies, especially given potential resistance from the cannabis industry. For instance, in the context of social media public health campaigns where the primary goal is to capture and hold attention, the use of vivid imagery remains essential. On the other hand, when negotiating regulations, where drastic changes face strong opposition, focusing on improving text specificity may be a more achievable goal. This approach can enhance recognition and internalization of health risks without requiring a complete overhaul of existing labels. By advocating for these incremental changes, policymakers can make meaningful progress in enhancing CWLs, allowing for gradual improvements while navigating the complex landscape of industry regulations and resistance to change.

This study has several limitations that open avenues for future research. First, our predominantly young adult, college sample may limit the generalizability of our findings, particularly to younger populations like teenagers and to more diverse groups in terms of race, education, and health literacy. Relatedly, the study was conducted in Georgia, a state without legalized recreational cannabis,⁴⁴ and legal restrictions prevented us from assessing participants' cannabis use behaviors. While random assignment ensured valid comparisons across conditions, the absence of user-status data limits our ability to examine whether cannabis users and non-users may respond differently to warning messages. Future research should directly test these potential differences. In addition, conducting the study in a prohibition context may limit generalizability to states where cannabis is legal and more normalized. Nonetheless, young adults report substantial levels of use even in

prohibition states,⁴⁵ and risk perceptions continue to decline nationally,⁴⁶ underscoring the broader relevance of these findings for prevention and policy. Beyond issues of sample composition, while the current sample provided adequate power to detect medium-sized effects, it may have been underpowered to detect smaller differences among the specific-text conditions, which should be examined in larger samples in future research. Additionally, the artificial environment of an eye-tracking experiment may not accurately capture the real-world exposure to CWLs, suggesting a need for studies in more naturalistic settings to improve ecological validity.

Moreover, our study focused on a specific combination of package design features (eg, patterns, colors), product type (ie, pod), and warning themes, which may have influenced participants' interpretations and limited the generalizability of findings to other packaging contexts. While the design principles identified here are likely to extend beyond the tested conditions, future research could expand the range of package styles, product formats, and textual and pictorial warning elements. In particular, employing fully crossed factorial designs would enable systematic testing of interactions between these elements, such as whether pictorial components differentially affect attention or recognition when paired with generic versus specific text. We acknowledge that our design did not include all possible combinations (eg, pictograms with generic text), which limits our ability to isolate potential interactions between text specificity and visual elements. At the same time, our study was designed with a focus on ecologically relevant combinations that reflect how message specificity and visual salience are often implemented together in practice. Rather than isolating the independent effects of each element, our aim was to assess how these theoretically grounded design enhancements perform in tandem. Future research employing factorial designs could build on this work to further clarify how specific message components interact to influence attention, recognition, and other outcomes. Finally, this study focused on short-term outcomes such as immediate attention and recognition. Although the pictorial warnings did not significantly enhance recognition, they may still influence other meaningful outcomes not assessed here, such as beliefs about cannabis-related risks and perceived message persuasiveness.^{7,12} Future research should examine these broader attitudinal and behavioral effects, as well as long-term outcomes like delayed recognition,¹³ to fully capture the impact of warning designs over time.

In conclusion, this research enhances our understanding of how textual specificity and imagery in warning messages can be strategically employed to achieve different communication objectives, offering a tailored approach to public health messaging in the context of cannabis use.

Author contributions

Jiaying Liu (Conceptualization [lead], Data curation [lead], Formal analysis [lead], Funding acquisition [lead], Investigation [lead], Methodology [lead], Project administration [lead], Resources [lead], Software [lead], Supervision [lead], Validation [lead], Writing—original draft [lead], Writing—review & editing [lead]), Ranran Z. Mi (Data curation [lead], Formal analysis [lead], Software [lead], Validation [lead], Visualization [lead], Writing—original draft [lead], Writing—review & editing [lead]), Moonsun Jeon (Investigation [supporting], Methodology [supporting], Project administration [supporting],

Writing—review & editing [supporting]), Jessica L. Fabbriatore (Investigation [supporting], Methodology [supporting], Project administration [supporting], Writing—review & editing [supporting]), Rebekah Wicke (Investigation [supporting], Methodology [supporting], Project administration [supporting], Writing—review & editing [supporting]), Lauren Raquel Cojulun (Investigation [supporting], Methodology [supporting], Project administration [supporting], Writing—review & editing [supporting]), and Sijia Yang (Conceptualization [supporting], Data curation [supporting], Formal analysis [supporting], Funding acquisition [supporting], Investigation [supporting], Methodology [supporting], Project administration [equal], Resources [supporting], Software [supporting], Supervision [equal], Validation [supporting], Writing—original draft [supporting], Writing—review & editing [supporting])

Funding

Data collected in this study were supported by a Faculty Seed Grant from the Department of Communication Studies at the University of Georgia. The funder had no role in study design, data collection, analysis, interpretation, manuscript preparation, or the decision to publish.

Conflicts of interest

All authors have no financial disclosures to report.

Open science and transparency statement

This study was not formally registered. The analysis plan was not formally pre-registered. De-identified data from this study, the analytic code used to conduct the analyses, and study materials are available in a public archive: https://osf.io/k97xh/?view_only=9db8f9c1276b48eebf907b38236f4a1.

Statement of conflict of interest and adherence to ethical standards

All authors declare no potential or actual conflicts of interest. All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

References

- Samhsa. Substance Abuse and Mental Health Services Administration, 2024, Contract No.: July 29.
- Bryan K. Report Cannabis Overview. National Conference of State Legislatures 2024 [cited 2024]. Accessed August 1, 2025. <https://www.ncsl.org/civil-and-criminal-justice/cannabis-overview>.
- Hammond CJ, Chaney A, Hendrickson B, Sharma P. Cannabis use among U.S. adolescents in the era of marijuana legalization: a review of changing use patterns, comorbidity, and health correlates. *Int Rev Psychiatry*. 2020;32:221–234. <https://doi.org/10.1080/09540261.2020.1713056>
- Scott JC, Slomiak ST, Jones JD, Rosen AFG, Moore TM, Gur RC. Association of cannabis with cognitive functioning in adolescents and young adults: a systematic review and meta-analysis. *JAMA Psychiatry*. 2018;75:585–595. <https://doi.org/10.1001/jamapsychiatry.2018.0335>
- Marconi A, Di Forti M, Lewis CM, Murray RM, Vassos E. Meta-analysis of the association between the level of cannabis use and risk of psychosis. *Schizophr Bull*. 2016;42:1262–1269. <https://doi.org/10.1093/schbul/sbw003>
- Popova L, Massey ZB, Giordano NA. Warning labels as a public health intervention: effects and challenges for tobacco, cannabis, and opioid medications. *Annu Rev Public Health*. 2024;45:425–442.
- Kim SJ, Minich M, Tveleneva A, et al. Textual and pictorial enhancement of cannabis warning labels: an online experiment among at-risk U.S. young adults. *Drug Alcohol Depend*. 2022;237:109520. <https://doi.org/10.1016/j.drugalcdep.2022.109520>
- Massey ZB, Hammond D, Froeliger B. A systematic review of cannabis health warning research. *Prev Med Rep*. 2024;37:102573. <https://doi.org/10.1016/j.pmedr.2023.102573>
- Meek CJ, Ranney LM, Clark SA, Jarman KL, Callanan R, Kowitz SD. Regulatory landscape of cannabis warning labels in US states with legal retail nonmedical cannabis, 2024. *Am J Public Health*. 2024;114:S681–S684. <https://doi.org/10.2105/ajph.2024.307722>
- Goodman S, Leos-Toro C, Hammond D. The impact of plain packaging and health warnings on consumer appeal of cannabis products. *Drug Alcohol Depend*. 2019;205:107633. <https://doi.org/10.24095/hpcdp.41.7/8.01>
- Noar SM, Hall MG, Francis DB, Ribisl KM, Pepper JK, Brewer NT. Pictorial cigarette pack warnings: a meta-analysis of experimental studies. *Tob Control*. 2016;25:341–354. <https://doi.org/10.1136/tobaccocontrol-2014-051978>
- Leos-Toro C, Fong GT, Meyer SB, Hammond D. Perceptions of effectiveness and believability of pictorial and text-only health warning labels for cannabis products among Canadian youth. *Int J Drug Policy*. 2019;73:24–31. <https://doi.org/10.1016/j.drugpo.2019.07.001>
- Noar SM, Francis DB, Bridges C, Sontag JM, Ribisl KM, Brewer NT. The impact of strengthening cigarette pack warnings: systematic review of longitudinal observational studies. *Soc Sci Med*. 2016;164:118–129. <https://doi.org/10.1016/j.socscimed.2016.06.011>
- Peters E, Shoots-Reinhard B, Evans AT, et al. Pictorial warning labels and memory for cigarette health-risk information over time. *Ann Behav Med*. 2019;53:358–371. <https://doi.org/10.1093/abm/kay050>
- Thrasher JF, Brewer NT, Niederdeppe J, et al. Advancing tobacco product warning labels research methods and theory: a summary of a grantee meeting held by the US National Cancer Institute. *Nicotine Tob Res*. 2019;21:855–862. <https://doi.org/10.1093/ntr/nty017>
- Trope Y, Liberman N. Construal-level theory of psychological distance. *Psychol Rev*. 2010;117:440–463. <https://doi.org/10.1037/a0018963>
- Lee SJ. The role of construal level in message effects research: a review and future directions. *Communication Theory*. 2019;29:231–250. <https://doi.org/10.1093/ct/qty030>
- Qin Y, Chen J, Namkoong K, Ledford V, Lim JR. Increasing perceived risk of opioid misuse: the effects of concrete language and image. *Health Commun*. 2022;37:425–437. <https://doi.org/10.1080/10410236.2020.1846323>
- Laursen D. Counseling young cannabis users by text message. *J Comput Mediat Commun*. 2010;15:646–665. <https://doi.org/10.1111/j.1083-6101.2009.01510.x>
- Leos-Toro C, Fong GT, Hammond D. The efficacy of health warnings and package branding on perceptions of cannabis products among youth and young adults. *Drug Alcohol Rev*. 2021;40:637–646. <https://doi.org/10.1111/dar.13240>
- Orenstein DG, Glantz SA. Regulating cannabis manufacturing: applying public health best practices from tobacco control. *J Psychoactive Drugs*. 2018;50:19–32. <https://doi.org/10.1080/02791072.2017.1422816>
- Yang S, Cotter LM, Lu L, et al. Countering online marketing and user endorsements with enhanced cannabis warning labels: an online experiment among at-risk youth and young adults. *Prev Med*. 2024;180:107877. <https://doi.org/10.1016/j.ypmed.2024.107877>

23. Amrhein PC, McDaniel M, Waddill P. Revisiting the picture-superiority effect in symbolic comparisons: Do pictures provide privileged access? *J Exp Psychol Learn Mem Cogn*. 2002;28:843–857. <https://doi.org/10.1037/0278-7393.28.5.843>
24. Ophir Y, Brennan E, Maloney EK, Cappella JN. The effects of graphic warning labels' vividness on message engagement and intentions to quit smoking. *Commun Res*. 2019;46:619–638. <https://doi.org/10.1177/0093650217700226>
25. Nabi RL, Roskos-Ewoldsen D, Dillman Carpentier F. Subjective knowledge and fear appeal effectiveness: implications for message design. *Health Commun*. 2008;23:191–201. <https://doi.org/10.1080/10410230701808327>
26. Klein EG, Quisenberry AJ, Shoben AB, et al. Health warning labels for smokeless tobacco: the impact of graphic images on attention, recall, and craving. *Nicotine Tob Res*. 2017;19:1172–1177. <https://doi.org/10.1093/ntr/ntx021>
27. Meernik C, Jarman K, Wright ST, Klein EG, Goldstein AO, Ranney L. Eye tracking outcomes in tobacco control regulation and communication: a systematic review. *Tob Regul Sci*. 2016;2:377–403. <https://doi.org/10.18001/trs.2.4.9>
28. Byrne S, Kalaji M, Niederdeppe J. Does visual attention to graphic warning labels on cigarette packs predict key outcomes among youth and low-income smokers? *Tob Regul Sci*. 2018;4:18–37. <https://doi.org/10.18001/trs.4.6.3>
29. Liu J, Phua J, Krugman D, Xu L, Nowak G, Popova L. Do young adults attend to health warnings in the first IQOS advertisement in the U.S.? An eye-tracking approach. *Nicotine Tob Res*. 2021;23:815–822. <https://doi.org/10.1093/ntr/ntaa243>
30. Informational Panel Labeling Requirements, 4 Cal Code Regs. Sect. § 17406 (2025).
31. Silver LD, Naprawa AZ, Padon AA. Assessment of incorporation of lessons from tobacco control in city and county laws regulating legal marijuana in California. *JAMA Netw Open*. 2020;3:e208393-e. <https://doi.org/10.1001/jamanetworkopen.2020.8393>
32. Gunn JKL, Rosales CB, Center KE, et al. Prenatal exposure to cannabis and maternal and child health outcomes: a systematic review and meta-analysis. *BMJ Open*. 2016;6:e009986. <https://doi.org/10.1136/bmjopen-2015-009986>
33. Moir D, Rickert WS, Lévassieur G, et al. A comparison of mainstream and sidestream marijuana and tobacco cigarette smoke produced under two machine smoking conditions. *Chem Res Toxicol*. 2008;21:494–502. <https://doi.org/10.1021/tx700275p>
34. Rogeberg O, Elvik R. The effects of cannabis intoxication on motor vehicle collision revisited and revised. *Addiction*. 2016;111:1348–1359. <https://doi.org/10.1111/add.13347>
35. Meier MH, Caspi A, Ambler A, et al. Persistent cannabis users show neuropsychological decline from childhood to midlife. *Proc Natl Acad Sci USA*. 2012;109:E2657–E2664. <https://doi.org/10.1073/pnas.1206820109>
36. Moore THM, Zammit S, Lingford-Hughes A, et al. Cannabis use and risk of psychotic or affective mental health outcomes: a systematic review. *Lancet*. 2007;370:319–328. [https://doi.org/10.1016/S0140-6736\(07\)61162-3](https://doi.org/10.1016/S0140-6736(07)61162-3)
37. Sorensen CJ, DeSanto K, Borgelt L, Phillips KT, Monte AA. Cannabinoid hyperemesis syndrome: diagnosis, pathophysiology, and treatment—a systematic review. *J Med Toxicol*. 2017;13:71–87. <https://doi.org/10.1007/s13181-016-0595-z>
38. National Academies of Sciences Engineering, and Medicine, Health and Medicine Division, Board on Population Health and Public Health Practice, Committee on the Health Effects of Marijuana: An Evidence Review and Research Agenda. *The Health Effects of Cannabis and Cannabinoids: The Current State of Evidence and Recommendations for Research*. Washington (DC): National Academies Press (US); 2017.
39. An Act to Add Sections 26070.3 and 26121 to the Business and Professions Code, Relating to Cannabis, SB 1097, California Legislature 2021–2022 Regular Session, (2022).
40. Yzer M, Han J, Choi K. Eye movement patterns in response to anti-binge drinking messages. *Health Commun*. 2018;33:1454–1461. <https://doi.org/10.1080/10410236.2017.1359032>
41. Tulving E. Memory and consciousness. *Can Psychol*. 1985;26:1.
42. Yonelinas AP. The nature of recollection and familiarity: a review of 30 years of research. *J Mem Lang*. 2002;46:441–517. <https://doi.org/10.1006/jmla.2002.2864>
43. Hautus MJ, Macmillan NA, Creelman CD. *Detection theory: a user's guide*. Routledge; 2021. ISBN: 1003203639.
44. Ga Code Ann Sect. § 16-13-1. 2024.
45. Goodman S, Wadsworth E, Leos-Toro C, Hammond D, Team ICPS. Prevalence and forms of cannabis use in legal vs. illegal recreational cannabis markets. *Int J Drug Policy*. 2020;76:102658.
46. Terry-McElrath YM, Pang YC, Patrick ME. Historical change in associations between perceived risk, disapproval, and use of cannabis among young adults ages 19–30, 2011–2022. *Addict Behav*. 2025;160:108185.