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RESEARCH ARTICLE

ALCOHOL CLINICAL & EXPERIMENTAL RESEARCH

Impact of text-only versus large text-and-picture alcohol warning formats: A functional magnetic resonance imaging study in French young male drinkers

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Abstract

Background: Although the World Health Organization recommends visible and clear warning labels about the risks of alcohol consumption on containers and advertising, many of the currently used labels are too small to be visible. This study investigated the brain activity (using fMRI) and alcohol consumption intentions of French young men exposed to two warning formats displayed on alcoholic beverage advertisements: a small Text-only Alcohol Warning (TAW) currently used in many countries, and a larger text-and-picture alcohol warning (PAW).

Methods: Seventy-four eligible 18–25-year-old male drinkers completed a face-to-face individual visit with a physician expert in addiction medicine. This was followed by the fMRI session during which they viewed 288 stimuli [96 alcohol advertisements with TAWs, the same 96 advertisements with PAWs, and 96 water advertisements (controls)] for 3 s each. If the advertisement made participants want ("yes")/do not want ("no") to consume the product, they pressed the corresponding button (self-report responses). The number of "yes" responses was compared between advertisement types with a paired sample *t*-test. Whole-brain and region-of-interest (ROI) analyses of the fMRI data were performed.

Results: Whole-brain BOLD fMRI highlighted contrasting effects of PAWs and TAWs. Compared with TAWs, PAWs elicited more activation in the precuneus, angular gyrus, occipital, frontal and temporal areas, and less activation in the nucleus accumbens, ventral tegmental areas, and putamen areas (regions of the reward circuit). The ROI analysis confirmed less activation in the reward circuit (left and right ventral tegmental areas, left and right nucleus accumbens) when viewing PAWs than TAWs. Analysis of the self-report responses indicated that the desire to consume the advertised alcohol product was lower when PAWs were viewed (compared with TAWs) ($T = 8.18, p < 10^{-11}$).

Conclusions: This is the first fMRI study to assess the effect of different alcohol warning formats. Our findings show that compared with TAWs, stronger PAWs in advertisements elicited less activity in key regions of the reward system. This suggests that the effects may influence the desire to consume alcohol products (self-report response analysis). These results could help policymakers who are interested in developing more effective labeling measures that target young people.

KEYWORDS
alcohol, fMRI, neuroimaging, warnings, youth

INTRODUCTION

Worldwide, alcohol consumption is responsible for 3 million deaths each year as well as diseases (liver cirrhosis, cancers) and other social costs (injuries, road accidents) (World Health Organization [WHO], 2022). The European Region is particularly concerned because the level of alcohol consumption per capita is very high (9.8 L of pure alcohol per year) (Jané-Llopis et al., 2020).

To tackle this problem, the WHO recommended warning labels about the risks of alcohol consumption on containers and advertising (WHO, 2018). In 2021, the European Commission proposed the introduction of mandatory cancer warning labels on alcoholic beverages, as part of the Beating Cancer plan (European Commission, 2021, p. 10). However, few countries implemented strong and mandatory warning policies, unlike what is done for tobacco (Neufeld et al., 2020). It has been shown that many of the currently used warnings do not increase knowledge and do not promote alcohol decrease because of their format (small text-only messages) (Coomber et al., 2018; Dossou et al., 2017) and wear-out effect (Hankin et al., 1996). Moreover, literature reviews indicate that their effects remain unclear on risk perception, attention, comprehension and behavioral compliance (Clarke, Pechey, Kosīte, et al., 2021; Dimova & Mitchell, 2022).

It is not precisely known whether and how different warning formats on alcohol advertisements (small text-only alcohol warnings—TAW—currently used in many countries vs. larger text-and-picture alcohol warnings—PAW—) can influence their effectiveness. Very few studies compared the impact of PAW and TAW labels and their conclusions are unclear. Hall et al. (2020) concluded that images were more effective than TAW to elicit thoughts about the harms and to decrease the appeal of alcohol products. They also generated greater reactance, but were considered less believable. Clarke, Pechey, Mantzari, et al. (2021) highlighted that compared with no label, alcoholic drink choice was lower and defensive reactions (i.e., avoidance, threat denial) were higher when image-and-text, text-only and image-only warnings were displayed on alcoholic packs. PAW increased fear arousal and reduced the likelihood of selecting an alcoholic drink, compared with TAW, but increased it compared with the image-only label. In addition, image-only warnings had the largest effect on the measured outcomes. Other studies did not find any difference between PAW and TAW. Wigg and Stafford (2016) observed an increase in fear arousal with both formats compared to no warning, but no difference between labels on consumption intentions. Stafford and Salmon (2017) found that both formats reduced the speed and amount of alcohol consumption compared to no warning. Staub et al. (2022) tested two label formats (TAW and PAW) and no warning on wine bottles. Compared with no warning, labels increased the risk perception (small effect), but without difference between formats. Clarke, Blackwell, De-loyde, et al. (2021) carried out a study in a naturalistic shopping laboratory. They did not find any clear difference in the three consumer groups (PAW, TAW, no warning) on the choice of drinks (with vs. without alcohol). However, negative emotional arousal was higher and product acceptability was lower in the PAW group than TAW group. To sum up these studies, uncertainty remains on the added-value of the pictorial format in the context of alcohol. Based on what is known in the tobacco context (pictorial warnings are more effective than textual messages for changing smoking behaviors, Noar et al., 2016), we hypothesized that PAW will decrease significantly the desire to consume alcohol products promoted in advertisements compared with TAW (based on the self-report responses) (H1).

Most studies that compared different alcohol warning formats used self-report measures that have several limitations, such as capturing only conscious reactions and misreporting or underestimating alcohol consumption and risks. To avoid this problem, some researchers used eye tracking to assess the attention devoted to alcohol warnings (Diouf et al., 2023; John et al., 2022; Lacoste-Badie et al., 2022; Pham et al., 2018; Sillero-Rejon et al., 2018). Traditional self-report measures can be completed and supplemented by neuroimaging methods to measure cognitive and affective reactions that may play a key role in explaining the effect of such labels. Functional magnetic resonance imaging (fMRI) analyzes changes in blood flow and blood oxygenation by measuring the blood oxygen-level-dependent (BOLD) contrast response in the brain regions involved when exposed to stimuli (Alsharif et al., 2021). This method was used successfully to provide insights into the neuroanatomical, cognitive and emotional mechanisms underlying tobacco warning processes. It was found that text-and-picture messages activate the visual association cortex (involved in visual tasks), insula (linked to disgust) and amygdala (that plays a prominent role in emotional processing) (Newman-Norlund et al., 2014). Compared with weak fear-appeal tobacco labels, stronger text-and-picture warnings increased activation of brain regions that mediate emotional memory (amygdala, hippocampus, inferior frontal gyri and insulae). Wang et al. (2015), Riddle et al. (2016) and Rüther et al. (2018) also highlighted that pictorial health warnings on tobacco products activate brain areas associated with emotions (amygdala) and cognitive reactions (ventromedial prefrontal cortex) that predict smoking cessation. To our knowledge, fMRI has not been used to compare different alcohol warning labels. Based on what is known from fMRI findings in the tobacco context, we hypothesized that PAW displayed on alcohol advertisements will elicit significantly lower brain activation in the reward circuit than TAW (H2).

To provide insights into the process generated by different alcohol warning formats, the aims of our study were to determine whether: (i) activation of brain regions differed when the warning displayed on alcohol advertisements was a TAW, as done in many countries (including France where this study took place) or a PAW; and (ii) brain activation patterns were linked to self-report measures on alcohol drinking intentions.

MATERIALS AND METHODS

This study was ethically approved by the "Comité de protection des personnes" (Committee for the Protection of Persons – an institutional review board) Ouest III in Poitiers (ID-RCB 2018-A00219-46). All the data were anonymized, and all participants gave their written consent.

The tested warnings

The tested TAW was very similar to the current French warning label. Since 1991, the message "Alcohol abuse is harmful" must be displayed at the bottom of all alcohol advertisements (French Evin law). As size and prominence are not specified in the law, the message is generally small and barely visible. To avoid familiarity with and pre-exposure to the French current warning label, a new TAW label to target young people was created. A preliminary study was performed in 127 male students aged 17–25 years (excluded from the final fMRI study) to select an effective label that influences drinking behavior. The message "One out of four drivers killed in a drink-driving accident is 18 to 24-year-old person" was selected and displayed on the tested advertisements in a similar way as done with the current warning (TAW). The PAW combined the same text, but larger and colored in red, with a photo that depicts the bloody face of a young man after a car crash (Table 1). Here, to increase the study realism, advertisements and the PAW were designed and created by an advertising agency.

The two warnings were displayed on advertisements that showcase parties, sports or basic product-focused commercials of brands available in France for the most consumed alcohol categories by French young people (beer, vodka, whisky). In each advertisement, the size and placement of the bottle, of the brand logo and of the warnings displayed at the bottom were consistent. To compare the brain activity generated by alcoholic and nonalcoholic beverage (control) advertisements, water advertisements also were created without warnings. A total of 288 advertisements were designed on which the text-only or the larger text-and-picture warning was added: 96 alcohol advertisements with TAW, the same 96 alcohol advertisements but with PAW, and 96 water advertisements. Participants were exposed 96 times to each warning format (TAW or PAW). This allowed measuring brain reactions and being close to a real-life context where people are exposed many times to advertisements and warnings.

Sample population

Inclusion criteria for the fMRI study were: 18–25-year-old men with drinking status defined using the Alcohol Use Disorders Identification Test – consumption (AUDIT-C) (Bush et al., 1998), right-handed, affiliated to the French social insurance scheme, and who signed the written informed consent and agreement. Men in this age group were targeted because their alcohol use is high in France: in 2017, 66.2% of 18–24-year-old men reported at least one binge-drinking episode in the past 12 months (41.9% of 18–24-year-old women), and 13.4% had at least 10 binge-drinking episodes in the same period (7.3% of women) (Richard et al., 2019). Participants were all right-handed to limit differences in brain activation related to motor function that was not the focus of this study (left/right hand motions elicit activation of the contralateral primary motor area). All fMRI images were reviewed by a radiologist to confirm the absence of incidental findings. In case of incidental findings that needed additional exams, care would be covered by the French social security system. Therefore, all participants had to be affiliated to this system. Noninclusion criteria were: person at risk of alcohol addiction (identified by an AUDIT-C score >10), color blindness (unable to see the different colors in advertisements and warnings), user of psychoactive products except for tobacco (illicit drugs: cannabis, ecstasy, cocaine, crack, LSD, glue/solvents, heroin, hallucinogenic mushrooms, other illicit products not listed), not understanding French (written or spoken), and usual MRI contraindications. A positive alcohol breath test before the fMRI session (checked with an electronic breath analyzer) was an exclusion criterion.

Study design and setting

Participants were recruited through an e-mail sent to student mailing lists of the city of Rennes (where the experiment took place) and messages posted on social media (Facebook that was widely used by young people at the time). The messages described the purpose of the study (alcohol, no detail on the warning labels was given), without any commercial aim, data privacy, constraints (visiting a hospital twice), and incentive (50 €). If people were interested, they were invited to send an email to a dedicated address. Then, they were asked to fill in a short online questionnaire about their sex/gender, age, activities, education, alcohol consumption, use of cannabis and other substances (ecstasy, cocaine, crack, LSD, heroin, hallucinogenic mushrooms, other illicit products), and characteristics important for the current study (e.g., right-handedness, color vision deficiency, dental appliance user, pacemaker wearer). If they matched the inclusion criteria, people were contacted by telephone. If they confirmed their interest, a first face-to-face visit with a physician expert

TABLE 1 The two tested warning labels (TAW and PAW) displayed on the advertisements.

<table>
<tr><th>TAW: Alcohol advertisements with the current French health warning format but a new content</th><th>PAW: Alcohol advertisements with a larger, colored, text-and-picture health warning (the same as in the TAW)</th></tr>
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<tr><td colspan="2">"One out of four drivers killed in a drink-driving accident is a 18–24-year-old person"</td></tr>
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in addiction medicine was scheduled at the hospital. The aim was to check the inclusion criteria and provide more information on the fMRI session (e.g., duration, place, procedure). Participants were asked to read and sign an informed consent form. Their alcohol consumption was assessed with the AUDIT-C scale. If participants were still eligible, a second appointment for the fMRI scan at Rennes hospital Radiology Department was scheduled. The fMRI sessions were always planned between 3.30 p.m. and 8 p.m. during the week. Each session lasted about 2 h, including reception, familiarization with the task and the environment in a mock MRI scanner, fMRI scanning session, and completion of a questionnaire. The fMRI session lasted 1 h and comprised structural and functional (fMRI) image acquisition. A single task, which lasted 26 min, was performed. Participants were instructed to rest during the other sequences such as anatomical scans. The fMRI task followed a mixed block/event-related design implemented in EPrime Professional 2.0 with 288 trials in 48 blocks of six advertisements (trials) that displayed similar warnings (TAW or PAW) and lasting 25 s each. Stimuli were shown on a liquid-crystal display (LCD) screen placed at the back of the scanner, viewed via a mirror mounted on the head coil. The 48 blocks were presented in different orders, randomly assigned according to the participant number (even or odd). A trial consisted in (i) viewing an advertisement for an alcoholic beverage (with a TAW or PAW) or a water advertisement (without warning) (3 s), (ii) written question to self-report the participants' reaction: "Does this ad make you want to consume the product?" (0.2 s), leaving 1.2 s to answer by pressing a right-hand button (participants had to press the button with the thumb if "yes," or the button with the forefinger if "no"), (iii) short display of the selected answer (*yes* or *no*, 0.3 s), (iv) fixation cross (0.5 s) before the next trial (Figure 1). Six null events (fixation cross for 30 s in total) were interspaced in each block.

Following the fMRI session, participants completed a questionnaire on their current sociodemographic data and drinking patterns. Lastly, they were given information and a flyer on the risks of alcohol consumption. Participants left the hospital with the flyer, 50 €, and instructions on how to access their brain MRI images on a dedicated website.

Image acquisition and processing

Scanning was performed with a 3T MRI scanner (Magnetom Prisma, Siemens Healthineers, Erlangen, Germany) equipped with a 64-channel phased-array coil (software version VE11C). A 3D T1 MPRAGE sequence provided morphological data (TR/TI/TE = 1900/900/2.26 ms, parallel imaging GRAPPA 2, field of view = 256 × 256 mm^2, 176 slabs, voxel size = 1 mm^3). Functional data were obtained with a T2*-weighted single-shot spin-echo EPI multiband sequence (TR = 1.2 s, TE = 30 ms, field of view = 210 × 210 mm^2, 54 contiguous 2.5 mm axial

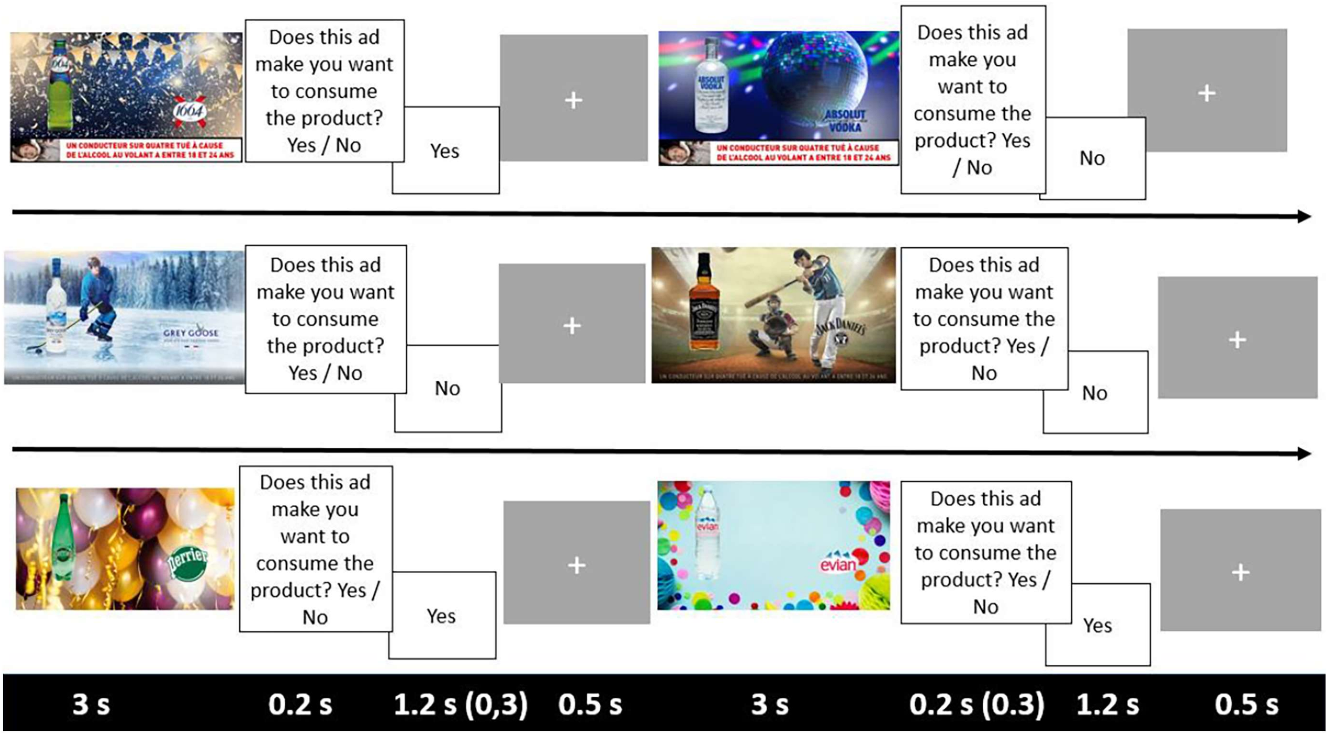

FIGURE 1 Representative example of one of the 48 blocks included in the fMRI task with the different steps. Each block included six advertisements displayed for 3 s each followed by a question. The self-report answer (yes or no) was displayed for 0.3 s. The advertisement-question-response sequences were separated by a fixation cross.

TABLE 2 Sample characteristics.

	Moderate-risk[a] drinkers (*n* = 20)		High-risk[a] drinkers (*n* = 54)		Total (*n* = 74)	
	n	%	*N*	%	*n*	%
Age (years)						
18			5	9.26	5	6.76
19	2	10	7	12.96	9	12.16
20	3	15	12	22.22	15	20.27
21	5	25	11	20.37	16	21.62
22	4	20	8	14.81	12	16.22
23	2	10	4	7.41	6	8.11
24	3	15	2	3.7	5	6.76
25	1	5	5	9.26	6	8.11
Student						
No	1	5	5	9.26	6	8.11
Yes	19	95	49	90.74	68	91.89

[a]Moderate risk (AUDIT-C score: 1–4) and high risk (AUDIT-C score: 5–10).

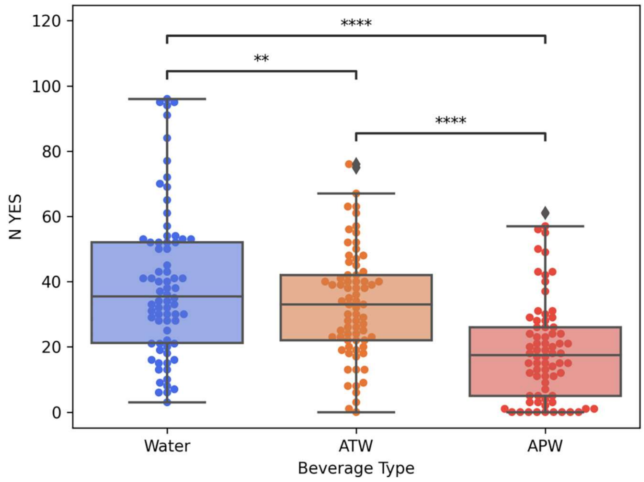

FIGURE 2 Distribution of the number of "yes" responses per participant to the question "Does this ad make you want to consume the product?" in function of the advertisement type (water, alcoholic product with TAW or PAW) (self-report responses). A paired sample *t*-test was used to compare "yes"/"no" responses according to advertisement (water/alcohol) and warning type (TAW/PAW). **: $0.001 < p < 0.01$; ****: $p < 0.0001$ (paired *t*-test). PAW, text-and-picture alcohol warning; TAW, text-only alcohol warning.

slices acquired parallel to the AC-PC line, matrix size 84×84, voxel size = 2.5×2.5×2.5 mm^3, multiband factor 3) for 25 min. Image pre-processing and analysis were done with SPM 12 (MATLAB) and Python packages (nilearn). The following pipeline was used for pre-processing: slice timing and motion correction of functional images (registering all volumes to the mean volume), co-registration to the morphological images, segmentation of morphological images, spatial normalization to a common reference Montreal Neurological Institute space, and smoothing using a 6 mm Gaussian kernel.

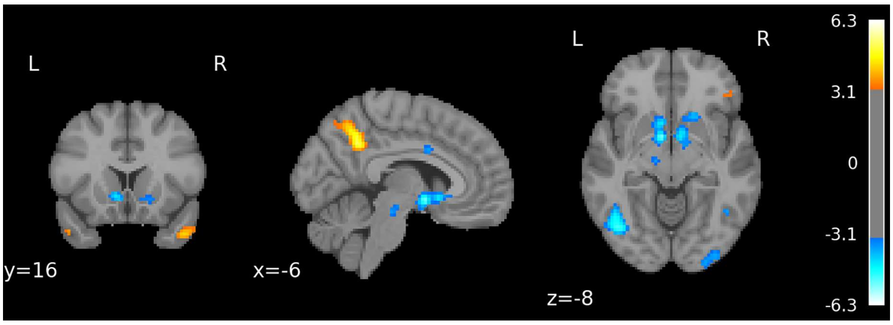

FIGURE 3 Comparison of neuronal responses during the presentation of advertisements with PAW or TAW (statistical map). Higher BOLD responses for PAW compared with TAW in yellow, Lower BOLD responses for PAW compared with TAW in blue. $p<0.001$, $k>10$.

Statistical analyses

For each participant, data were modeled using a general linear model. The regressors were divided in a factorial design with different factors: beverage type (alcohol/water), warning format (TAW/PAW) and other factors not presented here (e.g. advertisement content). The onsets were convolved with the canonical hemodynamic response function and used to build the regressors. Six motion parameters and a mean value of the sessions were entered in the model as covariates of no interest.

Whole-brain analysis was performed to extract the activation elicited by the different warning formats, different beverages, and other analyzed factors at the individual and group levels. To correct for multiple comparisons, all reported results were thresholded at $p<0.001$ with a spatial extent of 10 continuous voxels. This threshold was derived using Monte Carlo simulations to correct for Type I and Type II errors (Slotnick, 2017). The cluster size was determined following 10,000 iterations. The contrast of interest was the comparison of PAW to TAW.

Complementary region-of-interest (ROI) analyses were carried in regions known to correlate with real-world behaviors (alcohol, tobacco consumption) (McKenna et al., 2022; Schacht et al., 2013; Wagner et al., 2011). The following left and right ROIs were defined using the automated anatomical atlas 3 (AAL3) (Rolls et al., 2020): nucleus accumbens, caudate, ventromedial prefrontal cortex, amygdala, anterior cingulate cortex, ventral tegmental area, and putamen. For each ROI, the individual mean activation was extracted and tested for the contrast of interest; the mean ROI activation values were considered significantly different when $p<0.05/N$, after Bonferroni correction for the $N=14$ regions of interest (i.e. $p<3.57\times10^{-3}$).

Regarding self-report measures, the average reaction times per trial type and number of "yes" responses to the question "Does this ad make you want to consume the product?" were compared between trial types (water advertisements, alcohol advertisements with TAW and alcohol advertisements with PAW) with the paired sample t-test and results were considered significant when $p<0.05$.

RESULTS

Participants' characteristics

A total of 122 men who met the inclusion criteria and confirmed their interest by telephone were pre-recruited. Forty-four did not come to the face-to-face visit with the physician, and/or were not eligible after this interview, and/or did not come to the fMRI session. Seventy-eight participants completed the fMRI session. Four were excluded from the analyses because of excessive head motion during the scan (1), incidental finding (1), or technical issues (2). The final sample consisted of 74 right-handed 18–25-year-old male drinkers (mean age = 21.2 years, SD = 1.92) at moderate risk (AUDIT-C score: 1–4; $n=20$) or at high risk (AUDIT-C score: 5–10; $n=54$) of alcohol misuse (Table 2).

Behavioral intentions (self-report measures)

The results concerning the participants' responses per type of warning format (TAW or PAW) and beverage category (alcohol or water) are summarized in Figure 2. To the question "Does this ad make you want to consume the product?", participants responded "yes" more often to water advertisements than to alcoholic beverage advertisements with PAW (mean = 21, SD = 24.4, $T=7.19$, $p<10^{-9}$) and also with TAW (mean = 6.3, SD = 19.4, $T=2.77$, $p=0.007$). The desire to consume the alcohol products was significantly stronger when they were associated with TAW than with PAW (mean = 14.2, SD = 14.9, $T=8.18$, $p<10^{-11}$). The response reaction time did not differ among advertisements types and across time.

Functional MRI data: PAW versus TAW

The results concerning brain activation differences following exposure to PAW and TAW are summarized in Figure 3 and Table 3.

Compared with TAW, PAW elicited BOLD responses ($p<0.001$, $k>10$, listed in Table 3) with major activation clusters in the

TABLE 3 Brain regions influenced by the warning labels.

	MNI coordinates			Stat	Cluster size		
Brain region	x	y	z	Z	mm³	Voxels	BA
A. Increased BOLD responses for the PAW-TAW contrast (higher for PAW)							
Precuneus R	5.5	−52	50	6.29	15,390	985	7
Calcarine fissure R	15.5	−87	10	6.26	3468	222	
Inferior temporal gyrus R	53	3	−40	5.69	5906	378	20–21
Middle occipital gyrus R	48	−74.5	5	5.26	1906	122	19
Angular gyrus L	−49.5	−52	32.5	4.89	5625	360	
Cerebellar crus II L	−22	−79.5	−37.5	4.52	828	53	
Superior temporal gyrus R	58	−57	22.5	4.45	5937	380	39
Frontal Mid R	33	30.5	42.5	4.43	968	62	
Temporal Mid L	−59.5	−22	−15	4.39	531	34	21
Temporal Inf R	65.5	−17	−25	4.38	2078	133	
Frontal Mid R	38	5.5	55	4.04	843	54	6
Temporal Pole Mid L	−49.5	13	−32.5	3.99	406	26	
Temporal Mid R	63	−37	2.5	3.94	390	25	22
Frontal Mid L	−37	23	37.5	3.83	281	18	9
Frontal Inf Orb R	45.5	35.5	−10	3.72	234	15	
Frontal Sup Medial R	10.5	68	12.5	3.69	343	22	10
Temporal Inf L	−54.5	3	−37.5	3.65	156	10	
B. Decreased BOLD responses for the PAW-TAW contrast (lower for PAW)							
Cerebellum R	18	−54.5	−22.5	5.96	2953	189	
Postcentral gyrus L	−42	−32	45	5.75	16,750	1072	40
Ventral Striatum L	−7	3	−7.5	5.35	2593	166	34
Insula L	−37	−4.5	10	5.15	1000	64	
Inferior occipital gyrus L	−42	−69.5	−7.5	5.08	4296	275	37
Ventral striatum R	10.5	−7	−10	4.78	1671	107	
Precentral gyrus L	−49.5	5.5	27.5	4.76	1265	81	
Frontal Mid Orb L	−24.5	35.5	−17.5	4.64	781	50	
Cerebellum lobule VIII R	20.5	−62	−52.5	4.52	515	33	
Frontal Inf Tri L	−42	33	12.5	4.28	1828	117	46
Occipital Inf R	35.5	−92	−5	4.03	796	51	18
Putamen R	18	18	−7.5	4.02	468	30	
Cerebellum lobule VI L	−32	−47	−30	3.98	234	15	
Postcentral L	−37	−44.5	70	3.95	406	26	
Frontal Inf Tri R	48	40.5	10	3.89	234	15	
VTA L	−9.5	−19.5	−10	3.87	531	34	
Cingulum Mid L	−4.5	5.5	32.5	3.83	359	23	
Occipital Mid L	−27	−62	32.5	3.80	343	22	
Temporal Inf R	45.5	−57	−7.5	3.78	281	18	
VTA R	3	−19.5	−20	3.68	171	11	

Note: Reported clusters were thresholded at $p < 0.001$ with a spatial extent of 10 contiguous voxels.

Abbreviations: BA, Brodmann area; L, left; PAW, text-and-picture alcohol warning; R, right; TAW, text-only alcohol warning; VTA, ventral tegmental area.

precuneus, right calcarine fissure, right inferior temporal gyrus, right middle occipital gyrus, left angular gyrus, and right superior temporal gyrus. Conversely, PAW, compared with TAW, elicited lower BOLD responses in the nucleus accumbens (left and right), insula, right cerebellum, left postcentral gyrus, left inferior occipital gyrus and left precentral gyrus.

The ROI analysis focused on the reward circuit showed significantly lower activation in PAW than TAW in the left ($p = 3.6 \times 10^{-4}$) and right ($p = 2.62 \times 10^{-3}$) ventral tegmental areas, and in the left ($p = 7.93 \times 10^{-6}$) and right ($p = 5.09 \times 10^{-5}$) nucleus accumbens after Bonferroni correction for multiple comparisons. The difference observed in left amygdala ($p = 0.027$) and left putamen ($p = 0.0337$) did not survive the Bonferroni correction (Figure 4). No statistically significant difference was observed for the other ROIs.

DISCUSSION

This study assessed, using self-report measurements and fMRI, the effect of different warning formats on brain activation and on the desire to consume alcohol products in a sample of young French male drinkers. The aim was to bring neuroimaging-based evidence to design effective labeling measures and to support policy developments related to alcohol warnings.

According to the self-report responses, PAW significantly decreased the desire to consume the alcohol products promoted in the advertisements compared with TAW, which validated H1. This suggests that respondents were more sensitive to PAW. Moreover, the tested advertisements elicited more desire to consume the promoted product when they featured water brands (compared with alcohol brands).

Whole brain BOLD fMRI highlighted contrasting effect of PAW and TAW. PAW elicited increased BOLD activations in the precuneus, angular gyrus, occipital, frontal and temporal areas, and lower BOLD activations in the nucleus accumbens, ventral tegmental areas and putamen (regions of the reward circuit) (compared with TAW).

The precuneus is involved in episodic memory retrieval and self-mental imagery strategies (Cavanna & Trimble, 2006). This area is related to posterior medial regions with self-reflection guided by duties, obligations, and a more outward-directed, social or contextual focus (Johnson et al., 2006). The angular gyrus is considered a cross-modal hub involved in a variety of tasks (e.g. language-related functions, number processing, memory retrieval, spatial cognition, attention, social cognition and reasoning, from perception to action) (Seghier, 2013). More activation after exposure to PAW, compared with TAW, in the occipital regions (visual areas) was expected when visualizing advertisements with more salient pictorial warnings

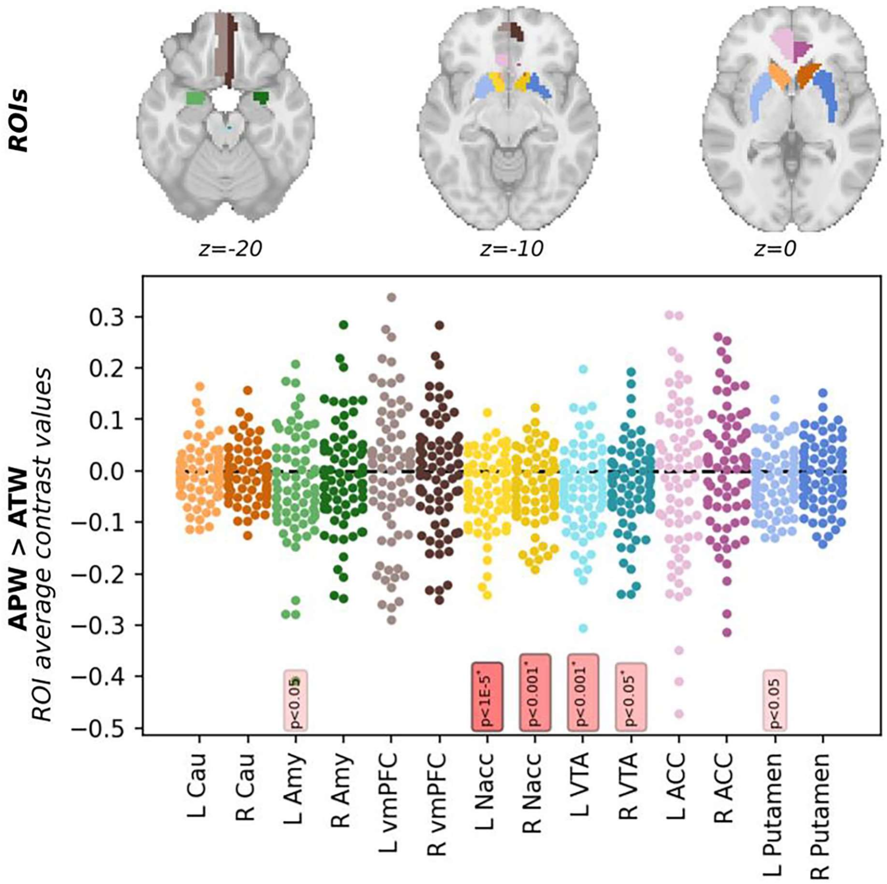

FIGURE 4 Regions of interest analyses (reward circuit): PAW compared to TAW. Upper panels: brain maps showing the different ROIs (color-coded as in the lower panel). Lower panel: mean contrast value for the indicated ROIs. ACC, Anterior Cingulate Cortex; Amy, Amygdala; Cau, Caudate; L, left, R: right; Nacc, Nucleus accumbens; PAW, text-and-picture alcohol warning; TAW, Text-only Alcohol Warning; vmPFC, ventromedial prefrontal cortex; VTA, Ventral Tegmental Area. A p-value label is shown when $p < 0.05$. An extra * symbol is added when the result is statistically significant after Bonferroni correction ($N = 14$ regions of interest).

compared with plainer textual messages. Temporal areas, usually involved in language and memory, were bilaterally elicited with a right predominance that may be related to the emotional processing of the PAW (Gainotti, 2021). Particularly, the anterior pole of the temporal lobe (Broadman Area 38) is involved in semantic memory, but has been linked also to the perception of emotionally salient stimuli (Strange & Dolan, 2006) and social and emotional information (Herlin et al., 2021; Wong & Gallate, 2012). This is coherent because pictorial warnings generate more emotional reactions than text-only labels.

An exploratory ROI-based analysis confirmed reduced activation in the reward circuit, particularly the nucleus accumbens and ventral tegmental area, when presenting PAW compared with TAW. The nucleus accumbens and ventral tegmental area results were maintained after the Bonferroni correction. These findings suggest that compared with TAW, PAW elicited less brain reactions and thus may reduce the persuasive effect of positive social contents displayed in some of the tested advertisements and the motivation to buy the promoted product. Indeed, the nucleus accumbens is involved in the pursuit of social rewards (Kohls et al., 2013), while the ventral tegmental area and substantia nigra have been related to reward behavior, motivation and addiction (Trutti et al., 2019). Therefore, displaying positive advertisement contents with negative warnings may reduce activation in this reward circuit.

In summary, our results demonstrate that compared with TAW, PAW displayed on realistic advertisements elicited less activation of the reward circuit. These findings suggest that stronger warnings (PAW) generated less activity of key regions of the reward system than TAW, and thus may explain the lower desire to consume alcohol declared by participants when viewing advertisements with a PAW. This validated H2. It is interesting to note that our findings are very similar to the brain activation patterns generated by tobacco warnings. Pictorial tobacco labels were associated with greater activation of brain regions involved in cognitive/affective decision-making, emotional reactions, and reward areas, leading to stronger self-reported motivation to reduce or stop smoking (Green et al., 2016; Riddle et al., 2016; Wang et al., 2015).

Despite its interests for public health, our study has some limitations. First, only one warning content, two formats (text/pictorial), and one "severity" level for the pictorial message were tested. Future studies should investigate whether other contents (e.g., cancer, damaged liver, social harm) combined with low/moderate/strong alcohol pictorial warnings differently influence brain activation, as already observed for self-report responses (Pechey et al., 2020; Sillero-Rejon et al., 2018). Second, due to material constraints linked to the use of fMRI methods, the sample size was relatively modest (74 participants). However, the effect size and the observed power were similar to those of previous studies that used such methods (40–70 participants in most studies) (Burnette et al., 2019; Maynard et al., 2017; Zhornitsky et al., 2019). Third, as no follow-up of the young participants was planned after the fMRI session, it is not possible to know whether PAW negative effect on the desire to consume alcohol products persisted after the session. Lastly, we took into account the use of illicit drugs (and excluded people who used them), but we did not ask participants about their use of tobacco, e-cigarettes or smoking cessation at the study time. This is a limitation because smoking and withdrawal can influence cerebral blood flow.

Despite these limitations, this first neuroimaging-based study on TAW and PAW brings new insights into the added-value of large and pictorial alcohol warning labels. It also provides evidence to justify the importance of changing the small textual labels currently used in many countries that have adopted alcohol warnings. The results may help public authorities to put in place effective measures and combat lobbying strategies by the alcohol industry to delay or oppose health warning implementation worldwide (Barlow et al., 2022).

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CONFLICT OF INTEREST STATEMENT

The authors have no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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