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Selective visual and crossmodal impairment in the discrimination of anger and fear expressions in severe alcohol use disorder

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ABSTRACT

Background: Severe alcohol use disorder (SAUD) is associated with impaired discrimination of emotional expressions. This deficit appears increased in crossmodal settings, when simultaneous inputs from different sensory modalities are presented. However, so far, studies exploring emotional crossmodal processing in SAUD relied on static faces and unmatched face/voice pairs, thus offering limited ecological validity. Our aim was therefore to assess emotional processing using a validated and ecological paradigm relying on dynamic audio-visual stimuli, manipulating the amount of emotional information available.
Method: Thirty individuals with SAUD and 30 matched healthy controls performed an emotional discrimination task requiring to identify five emotions (anger, disgust, fear, happiness, sadness) expressed as visual, auditory, or auditory-visual segments of varying length. Sensitivity indices (d') were computed to get an unbiased measure of emotional discrimination and entered in a Generalized Linear Mixed Model. Incorrect emotional attributions were also scrutinized through confusion matrices.
Results: Discrimination levels varied across sensory modalities and emotions, and increased with stimuli duration. Crucially, performances also improved from unimodal to crossmodal conditions in both groups, but discrimination for anger crossmodal stimuli and fear crossmodal/visual stimuli remained selectively impaired in SAUD. These deficits were not influenced by stimuli duration, suggesting that they were not modulated by the amount of emotional information available. Moreover, they were not associated with systematic emotional error patterns reflecting specific confusions between emotions.
Conclusions: These results clarify the nature and extent of crossmodal impairments in SAUD and converge with earlier findings to ascribe a specific role for anger and fear in this pathology.

1. Introduction

Severe alcohol use disorder (SAUD) is characterized by several cognitive deficits (Rolland et al., 2019; Stavro et al., 2013), but also significant emotional impairments, including a decoding deficit for facial and vocal emotional features (de Lima Osório and Donadon, 2014; Le Berre et al., 2017; Oscar-Berman et al., 2014; Uekermann et al., 2005). This deficit might play a key role in SAUD onset and maintenance, alcohol consumption being often used as a coping strategy to alleviate negative feelings or interpersonal problems (Baker et al., 2004; Carpenter and Hasin, 1999). Given the role of social interactions in everyday life, the inability to correctly interpret others' emotional states promotes social discomfort and negative emotions, leading to a vicious circle of persistent excessive consumption (Kornreich et al.,

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2002; Le Berre, 2019; Rupp et al., 2017). However, most previous studies on this topic (e.g., Hoffman et al., 2019; Lewis et al., 2019; Sorocco et al., 2010) used unimodal visual or auditory stimuli, thus exhibiting a limited ecological value in comparison with everyday life situations, where visual and auditory emotions are often presented simultaneously.

The extraction and decoding of emotional information can be conceptualized as a rapid network activity based on a fast refining of potential emotional matching candidates (Falagiarda and Collignon, 2019). While many emotions are activated when witnessing the very first emotional cues, the number of viable candidates quickly narrows down to one final option as more emotional information accumulates. Considering the added informative value of crossmodal emotional stimuli (i.e. when information from different sensory modalities are simultaneously available), such a model predicts that the correct emotion should be identified sooner when more congruent sensory cues are available. This proposal is supported by the fact that crossmodal integration leads to more efficient emotion recognition (i.e. faster and/or more accurate responses) in healthy control individuals (HC) (Calvert et al., 2001; Collignon et al., 2008; Jessen and Kotz, 2013). Nevertheless, this superiority of crossmodal stimulations over unimodal ones – or "crossmodal facilitation" – appears compromised among individuals with SAUD (Maurage et al., 2007, 2013), who might even be more impaired in crossmodal settings (classically auditory-visual ones) compared to unimodal situations in which they are presented with information from one single (auditory or visual) sensory modality (Brion et al., 2017; Maurage et al., 2007, 2008, 2013). Since SAUD is thus associated with a reduced ability to integrate multimodal emotional information into a unified percept, unimodal studies might not fully capture the extent of emotional disturbances in SAUD, which might be better appraised through the use of more ecological crossmodal stimuli.

Besides, crossmodal integration in HC is not a simple additive process but is rather related to specific integrative mechanisms involving reciprocal feedback between unimodal areas and additional specific cerebral regions (Calvert et al., 2001; Campanella and Belin, 2007; Davies-Thompson et al., 2018; Driver and Spence, 2000; Müller et al., 2012; Robins et al., 2009; Watson et al., 2014). In SAUD, impaired connectivity and lower cerebral activity have been documented within this specific neural network, as well as reduced connectivity between unimodal and crossmodal areas (Maurage et al., 2008, 2013). These cerebral changes further point towards an impaired crossmodal integration in SAUD.

However, studies exploring crossmodal processing in SAUD also presented low ecological value (Maurage and Campanella, 2013). First, they relied on static faces paired with dynamic voices, thus desynchronizing visual and auditory information. Consequently, they did not effectively mimic the dynamic unfolding of facial expressions, did not allow mouth movements to prepare the processing of auditory cues, and did not manipulate the amount of emotional content available. Yet, in daily living, individuals often have to decode emotions based on fragmented or low-intensity information. Second, previous work only explored the processing of anger, happiness, and neutral expressions, leaving open central questions regarding specific inter-emotional differences. Third, a ceiling effect was often observed at the behavioral level, these crossmodal tasks with low ecological validity thus being unable to reveal subtle emotional impairments (Maurage et al., 2007, 2008).

Accordingly, we assessed crossmodal emotional processing in SAUD through a new ecological audio-visual paradigm (Falagiarda and Collignon, 2019) manipulating the amount of emotional information available through a gating technique (Grosjean, 1980). Five basic emotions (anger, disgust, fear, happiness, and sadness, Ekman and Friesen, 1971) were selected. We hypothesized that patients with SAUD would display lower performance in emotional discrimination in all three sensory conditions, and particularly in the crossmodal one. We also expected that they would need more information (i.e. longer stimulus duration) to recognize emotions. Finally, we predicted a differential deficit across emotions as well as potential distinct patterns of emotional confusions (indicative of response biases) compared to HC, in line with previous results showing increased impairment for negative emotions, and especially those with a socially threatening content (Frigerio et al., 2002; Kornreich et al., 2001a; Philippot et al., 1999; Townshend and Duka, 2003). We thus expected that happiness would be globally more preserved than other emotions, all of negative valence, and that anger/disgust would be associated with more errors, possibly due to a tendency to misattribute socially threatening features to other emotions.

Capitalizing on the Signal Detection Theory (Macmillan and Creelman, 2004; Tanner and Swets, 1954), we computed dprimes (d') to get an unbiased measure of emotional discrimination. By simultaneously considering the proportion of "hits" (i.e. responses "A" in the presence of the emotion "A") and "false alarms" (i.e. responses "A" in the absence of the emotion "A"), dprime computations ensure that a high percentage of correct responses does not mask specific response biases or strategies. To further explore the presence of responses biases and spot repeated error patterns, we also analyzed participants' patterns of emotional misattribution through confusion matrices.

2. Material and methods

2.1. Participants

The sample included 30 patients with SAUD and 30 HC (see Table 1). Patients were diagnosed with severe alcohol use disorder according to DSM-5 criteria (American Psychiatric Association, 2013) and were all in their third week of an inpatient detoxification program at testing time (Saint-Luc University Hospital, Brussels, Belgium). They were all free of other psychiatric diagnoses (except nicotine use disorder) and had all abstained from alcohol for at least 14 continuous days. Alcohol consumption during the month preceding detoxification was assessed using the Timeline Followback (Sobell and Sobell, 1992). HC were free of past/present psychiatric disorders and substance abuse, expect nicotine use disorder. Their self-reported alcohol consumption

Table 1
Demographic measures, alcohol consumption data and psychopathological scores for Individuals with Severe Alcohol Use Disorders (SAUD) and Healthy Controls (HC): Mean (SD).

	SAUD (N = 30)	HC (N = 30)
Demographic measures		
Gender ratio (M/F) NS	18/12	17/13
Age (in years) NS	45.5 (9.0)	42.5 (11.0)
Education (in years since starting primary school) *	14.4 (4.0)	17.0 (4.0)
Alcohol and tobacco consumption		
Alcohol units per day ***	20.5 (12.8)	0.2 (0.3)
Years of SAUD	10.6 (9.3)	NA
Duration of abstinence (days)	16.8 (4.8)	NA
No. of previous detoxifications	1.5 (3.1)	NA
AUDIT score ***	28.4 (4.6)	2.1 (1.8)
No. of cigarettes per day ***	15.4 (14.8)	0.6 (2.8)
Psychopathological measures		
BDI-II ***	14.6 (8.8)	5.8 (6.3)
LSAS NS	35.7 (23.2)	36.4 (26.8)
IIP **	1.5 (0.5)	0.9 (0.6)
STAI-A (state) ***	39.4 (11.6)	28.5 (7.5)
STAI-B (trait) ***	50.4 (9.2)	36.7 (11.0)
TAS-20 **	49.6 (10.8)	40.3 (10.0)

AUDIT: Alcohol Use Disorders Identification Test; BDI-II: Beck Depression Inventory; LSAS: Liebowitz Social Anxiety Scale; IIP: Inventory of Interpersonal Problems; STAI-A and B: State and Trait Anxiety Inventory; TAS-20: 20-item Toronto Alexithymia Scale. NA: not applicable; NS: non-significant; *p < .05; **p < .01 ***p<.001.

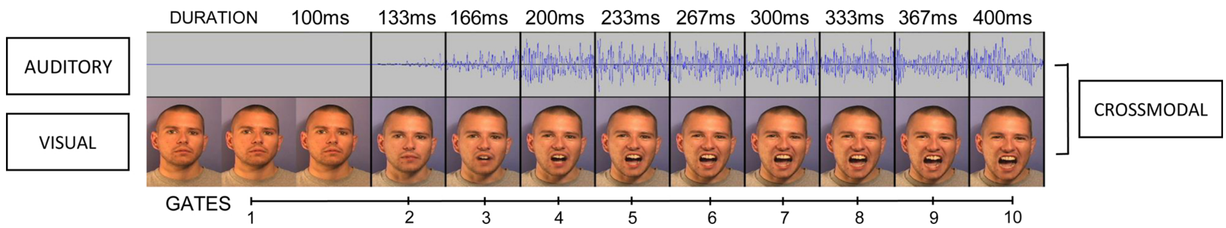

Fig. 1. Illustration of the content and duration of the ten gates for a male actor expressing anger.

was lower than ten standard alcohol units per week and never exceeded three units per day. They scored lower than 8 on the Alcohol Use Disorders Identification Test (AUDIT; Babor et al., 2001). HC were asked to abstain from alcohol for at least three days prior to testing and received monetary compensation for their participation. Tobacco use was not discontinued and the number of cigarettes smoked per day was collected for every participant. Exclusion criteria for both groups comprised major medical problems or neurological impairments. All participants reported normal hearing and normal or corrected-to-normal vision. Self-reported questionnaires assessed alexithymia (20-item Toronto Alexithymia Scale, TAS-20; Bagby et al., 1994), depression (Beck Depression Inventory, BDI-II; Beck et al., 1996), interpersonal problems (Inventory of Interpersonal Problems, IIP; Horowitz et al., 1988), state/trait anxiety (State and Trait Anxiety Inventory, form A and B, STAI-A and B; Spielberger et al., 1983) and social anxiety (Liebowitz Social Anxiety Scale, LSAS; Liebowitz, 1987). Higher scores reflected greater difficulties in each psychopathological dimension. The study was approved by the biomedical ethics committee of the UCLouvain and carried out according to the principles of the Declaration of Helsinki. Participants gave their written informed consent before starting the study.

2.2. Stimuli

Stimuli (available at http://osf.io/yedsz) were selected from a standardized set of dynamic emotional stimuli (Belin et al., 2008; Simon et al., 2008) where actors performed the prototypical faces/prosodies related to basic emotions (see Falagardia and Collignon, 2019 for the full description of the task). They consisted of short movie excerpts containing visual and/or auditory content of 4 actors (2 males and 2 females) expressing anger, disgust, fear, happiness, and sadness. Movies were divided into 10 segments or "gates" of increasing length. Starting from a first 100 ms long gate, composed of three static neutral frames (no auditory information), the following nine gates increased up to 400 ms with a 33 ms "gate size" or increment. The ten gates (respectively lasting 100-133-166-200-233-266-300-333-366-400 ms) depicted the natural unfolding of emotions (Fig. 1). This led to 600 stimuli: 4 actors x 3 sensory modalities x 5 emotions x 10 gates.

2.3. Task and procedure

The experiment was run with Matlab (Mathworks Inc., version R2017a) using the Psychotoolbox-3 extension and GStreamer (version 1.10.2) open-source multimedia framework on a 13-inch MacBookAir with iOSX 10.9.5 operating system. Visual stimuli were displayed centrally over a black background; auditory stimuli were presented binaurally at a fixed comfortable level. Participants performed a forced-choice emotional discrimination task (i.e. detecting the emotion expressed by pressing one of five labeled keyboard response keys). Participants had to respond as accurately as possible, irrespective of their certainty level, within a 6 s response interval. This prevented an absence of response for the shortest gates containing low or no emotional information. Responses and reaction times were recorded.

Participants underwent two experimental sessions carried out over two consecutive days and completed the self-report questionnaires in-between. Every session started with a 15-trial training phase offering written feedback. Each experimental session consisted of a fully randomized run of the 600 stimuli (around 45 min). Response keys were counterbalanced across participants but kept constant between sessions. Each session comprised 12 blocks (50 trials each) separated by breaks.

2.4. Data analysis

Statistical analyses were carried out in R 3.4.1. with a significance level set at 0.05. Between-group comparisons using parametric (Welch's t-test) and non-parametric (Chi-square and Mann-Whitney) tests were first performed on demographic and psychopathological variables depending on normality and homogeneity of variance assumptions. Presentation times were then checked to discard trials during which the on-screen duration of the stimulus exceeded a variation of 12 ms compared to what was theoretically expected. This slight variation in presentation timings was inherent to the refresh rate of the monitor (60 Hz). As suggested by the task developers (Falagiarda and Collignon, 2019) and in accordance with previous neuropsychological and psychophysical research (e.g., Kidd and Humes, 2015; Riesen et al., 2019; Uebel-von Sandersleben et al., 2017; Yamaguchi and Nishimura, 2019), trials associated with reaction times lower than 150 ms, or absence of an answer, were removed. In total, 672 trials (0.9%) were discarded (1.2% in patients with SAUD; 0.7% in HC).

Analyses focused on accuracy as instructions emphasized accuracy over speed. Sensitivity indices (d') were computed using the "sensR" package (Christensen and Brockhoff, 2018). Based on the Signal Detection Theory (Macmillan and Creelman, 2004; Tanner and Swets, 1954), the following formula was used: d' = z(hit rate)–z(false alarm rate). D' are not associated with any unit of measurement as they represent the difference between "Signal Present" and "Signal Absent" distributions. Accordingly, values of d' near zero reflect chance performance while larger positive values indicate a greater ability to discriminate the targets (i.e. a large proportion of hits and a limited proportion of false alarms). As no emotional information was provided during the first 100 ms of each stimulus, results from the first gate were removed from the analyses. Raw values of hits and false alarms rates, as well as the associated d', are available as supplementary material (Supplementary Table 1)[1] . The d' values from the remaining 9 gates were averaged across stimuli identities (actors) and experimental sessions, resulting in a 2 (group) x 3 (sensory modality) x 5 (emotion) x 9 (gate) mixed factorial design. A Generalized Linear Mixed Model (GLMM) was applied using the "lmerTest" package (Kuznetsova et al., 2017) with group, emotion, gate, and sensory modality as fixed effects and participants as random effect (random intercept). The random factor for participants took into account the dependence between our observations due to repeated measures while adjusting the intercept for each participant. Its significant contribution to the variance of the model was confirmed by a likelihood ratio test, ensuring model fit. Marginal and conditional R^2 values, which respectively represent the

[1] Importantly, the raw values provided in Supplementary Table 1 may not 100% converge with the values of the estimates of the GLMM as these estimates undergo a certain number of calculations and may be subjected to optimization.

proportion of the total variance explained by the fixed effects and by both the fixed and random effects, were calculated with the "piecewiseSEM" package (Lefcheck, 2016). An additional analysis of variance using the Satterthwaite degree of freedom approximation method was applied to the model to examine the global effects of each predictor. Bonferroni-corrected posthoc comparisons were performed when appropriate through the "emmeans" package (Lenth, 2019), by computing t-ratios based on the estimated marginal means from the GLMM fitted to all data. Confusion matrices were computed to assess error patterns. Mean proportions of responses related to each emotion were calculated across gates 2 to 10 in each sensory modality, and Wilcoxon rank-sum tests specifically compared the proportion of: (i) each of the 20 possible emotion confusion errors (5 emotions x 4 possible incorrect responses); (ii) incorrect responses for each emotion, irrespective of the correct one (e.g., the mean proportion of "anger" responses when anger was not presented). Bonferroni corrected p-values are reported according to the number of multiple comparisons. Finally, Pearson's and Spearman's correlations investigated the links between task performance and alcohol-related or psychological measures. These correlations are reported uncorrected due to their exploratory nature.

3. Results

3.1. Demographic and psychopathological measures

No significant group differences were observed for age (U = 378.0, p = .287), gender [$\chi^2(1) = 0.07$, p = .793] and social anxiety (U = 450.0, p = 1). As expected, patients with SAUD presented higher AUDIT scores (U = 0.0, p < .0001) and drank more alcohol units per day (U = 0.0, p < .0001). They also smoked more cigarettes per day (U = 177.5, p < .0001) and presented lower education level [t(57.997) = -2.537, p = .014] and higher depression (U = 140.0, p < .0001), state anxiety (U = 192.5, p = .0001), trait anxiety (U = 141.5, p < .0001), alexithymia (U = 231.0, p = .001) and interpersonal problem (t(57.065) = -3.595, p = .001) scores (Table 1).

3.2. Sensitivity indices (d')

Education level, depression, state/trait anxiety, alexithymia, and daily tobacco use were entered as covariates (fixed effects) in the GLMM as they differed between groups. These variables did not exert any direct effect on the d' (all ps > .098), but the results are presented with these variables controlled for. The marginal and conditional R^2 values of this final model reached respectively .71 and .78.

The GLMM yielded a significant main effect of group [F(152) = 4.25, p = .044], sensory modality [F(27,836) = 4463.11, p < .0001], emotion [F(47,836) = 477.30, p < .0001] and gate [F(87,836) = 1470.26, p < .0001][2] . As a whole, patients with SAUD exhibited lower d' than HC. Bonferroni-corrected pairwise post-hoc analyses showed a higher sensitivity for crossmodal stimuli than unimodal ones (crossmodal/visual, p < .0001; crossmodal/auditory, p < .0001), visual stimuli being also better discriminated than auditory ones (p < .0001). Comparisons across emotions revealed that fear was the best-discriminated emotion (fear/anger, p < .0001; fear/disgust, p < .0001; fear/happiness, p < .0001; fear/sadness, p < .0001), happiness the second-best (happiness/anger, p < .0001; happiness/disgust, p < .0001; happiness/sadness, p < .0001), followed by anger and sadness which did not significantly differ (anger/sadness, p = .068) but were better discriminated than disgust (anger/disgust, p < .0001; sadness/disgust, p < .0001). Sensitivity significantly improved with longer gate durations (all ps < .0001) (Fig. 2).

Analyses also yielded significant Group Sensory Modality [F(27,836) = 7.65, p = .0005], Group X Emotion [F(47,836) = 9.31, p < .0001] and Sensory Modality X Emotion [F(87,836) = 118.01, p < .0001] two-way interactions, as well as a critical three-way Group X Sensory Modality X Emotion interaction [F(87,836) = 5.47, p < .0001]. Bonferroni-corrected post-hoc comparisons revealed that differences across emotions followed the main effect (i.e. discrimination of disgust < sadness = anger < happiness < fear) in individuals with SAUD [all ps < .0001, except for fear/happiness (p = .035) and sadness/anger (p = 1)] while HC showed an extra difference between anger and sadness, with anger being better discriminated than sadness (all ps < .0001). The general hierarchy in sensory modality (i.e. discrimination for auditory < visual < crossmodal) also applied to all emotions in HC [all ps < .0001, except for visual/crossmodal sadness (p = .016)] and to all emotions except sadness in individuals with SAUD, with no difference between visual and crossmodal sadness [all ps < .0001, except for visual/crossmodal sadness (p = .082)]. Finally, patients with SAUD presented reduced discrimination for fear [in visual (p = .004) and crossmodal (p = .036) conditions] and anger [in crossmodal condition (p = .025)] compared to HC (Fig. 3). There was no significant two-way or three-way interaction involving group and gate (all ps > .112). Post-hoc pairwise contrasts for the main effects and interactions of interest, including 95% confidence intervals (CI) for the estimates are available in Supplementary Table 2. Pairwise comparisons showed a difference of -0.62 d' for visual fear, -0.51 d' for crossmodal fear and -0.53 d' for crossmodal anger in individuals with SAUD compared to HC, with 95% [-1.11, -0.13], [-1.00, -0.02] and [-1.02, -0.04] CIs, respectively.

While irrelevant to the goal of the present study, significant two-way interactions were also found between gate and emotion [F(32,7836) = 16.64, p < .0001], and gate and sensory modality [F(167,836) = 27.69, p < .0001]. The three-way Sensory Modality X Gate X Emotion interaction also reached significance [F(64,7836) = 3.96, p = < .0001]. Illustration of d' across gates for each emotion in the three sensory modalities is provided in Supplementary Figure 1.

3.3. Confusion matrices

Participants' ability to discriminate emotions differently improved across gates in the different sensory modalities (Fig. 4). In both groups, data condensed more quickly on the diagonal (correct identification) in the visual and crossmodal conditions. A systematic pattern of over-attribution for sadness was observed for the first gate in visual and crossmodal conditions (sadness constituting the default answer to neutral face presentation). Bonferroni-corrected multiple comparisons revealed that individuals with SAUD more often confused fear with disgust than HC in the visual condition (W = 687, p = .026, r = .455). No other group difference regarding two by two confusions emerged (all ps > .205). Individuals with SAUD did not display higher proportions of incorrect responses for one emotion compared to HC in any sensory modality (all ps > .701), indicating an absence of response bias or systematic response strategy.

3.4. Correlations

No significant correlation was found between d' aggregated across all conditions and alcohol-related measures in SAUD: AUDIT (r = .245, p = .190), SAUD duration (r_s = -.163, p = .388), abstinence duration (r_s = -.122, p = .520), number of DSM-5 criteria (r_s = .097, p = .612), number of previous detoxifications (r_s = -.156, p = .409) and number

[2] We performed complementary analyses on separate dprimes for each testing session to explore a potential Group x Session interaction. We ran the same GLMM model with session as an additional fixed effect. Results revealed a significant main effect of Group [F(1,52) = 4.16, p = .046] and Session [F(1,15934) = 100.57, p < .0001] but no significant Group X Session interaction [F(1,15934) = 0.04, p = .838]. Regardless of the session, HC outperformed patients with SAUD. Emotional discrimination improved from session 1 to session 2, but the magnitude of this improvement did not differ between groups, suggesting that unbalanced practice/exposure effects did not influence the results. The marginal and conditional R^2 of this model were respectively 0.62 and 0.68.

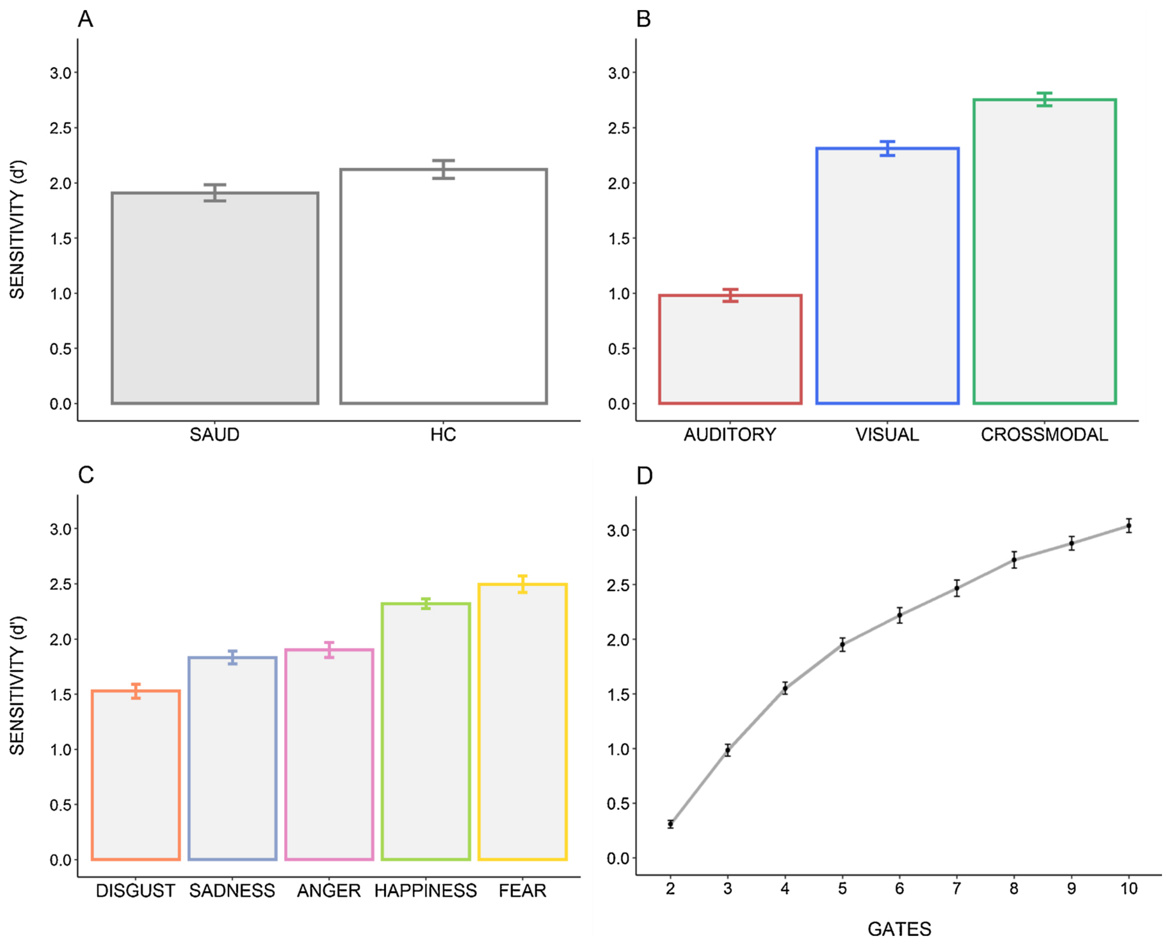

Fig. 2. Main effects. **A.** General difference in sensitivity between individuals with severe alcohol use disorder (SAUD) and healthy controls (HC). **B.** Global emotional discrimination across sensory modalities; **C.** Distinct discrimination levels across emotions; **D.** Improved discrimination over time/gates. Error bars represent the standard error of the mean.

of alcohol units per day (r_s = .005, p = .978), suggesting that the emotional deficit is independent of SAUD intensity, at least for the severity-related measures and specific sample of patients assessed here. When computed separately for each emotion, correlations remained not significant (all ps > .088), apart from an unexpected weak but significant positive correlation between AUDIT scores and d' for happiness (r = .374, p = .041). The intensity of interpersonal problems in SAUD did not correlate with d' [neither for the aggregated d' (r = -.122, p = .520); nor for the d' related to each emotion (all ps > .108)] when considering the total score of the IIP. Interestingly though, we did find a moderate negative link between the "Too Controlling" subscale of the IIP and d' for anger (r =-.431, p = .017) and sadness (r = -.481, p = .007). All other correlations between d' and IIP subscales were non-significant (all ps > .058).

4. Discussion

We assessed, for the first time, the discrimination of emotion expressions in SAUD through a new emotional discrimination task (Falagiarda and Collignon, 2019) relying on dynamic auditory, visual and audio-visual stimuli of varying durations. Results from the whole sample replicated earlier findings from the general population by exhibiting improved discrimination in crossmodal compared to unimodal conditions (Falagiarda and Collignon, 2019), and in visual compared to auditory conditions (Collignon et al., 2008). Moreover, significant differences emerged across emotions, consistent with the idea that some emotions are naturally easier to recognize. As predicted, performances also progressed linearly with stimulus duration but without a ceiling effect.

Irrespective of sensory modality, fear was the best-discriminated emotion by individuals with SAUD, followed by happiness, anger/sadness, and disgust. HC exhibited the same profile, except that they also showed an advantage for anger over sadness. It is likely that this advantage has been reduced in patients with SAUD due to their specific deficit for anger, as discussed below. The hierarchy in sensory modality also applied to all five emotions in both groups, except for sadness in individuals with SAUD. Contrary to previous crossmodal studies (Maurage et al., 2007, 2013), performance in SAUD patients improved from unimodal to crossmodal conditions and was thus associated with a crossmodal facilitation effect for all but one of the five emotions. This finding suggests that patients benefit from crossmodal facilitation more efficiently when ecological dynamic stimuli are presented. Unlike previous studies, the visual and auditory cues combined in crossmodal stimuli originated from the same individual, thus reducing inter-modality incoherence and potentially bolstering crossmodal integration in SAUD. This proposal is reinforced by previous results showing a specific difficulty to deal with incongruent crossmodal stimuli (Brion et al., 2017) and incoherent/dissociated information (Maurage et al., 2014). The impaired crossmodal facilitation effect systematically observed earlier might thus be related to the low ecological value of the paradigms used, generating auditory-visual mismatches. Conversely, emotional crossmodal facilitation appears more preserved in SAUD when crossmodal stimuli are coherent, as shown here. Regarding sadness, we did not highlight a difference between visual and crossmodal conditions in individuals with SAUD. This finding either suggests that crossmodal facilitation may genuinely be absent or reduced for this emotion in

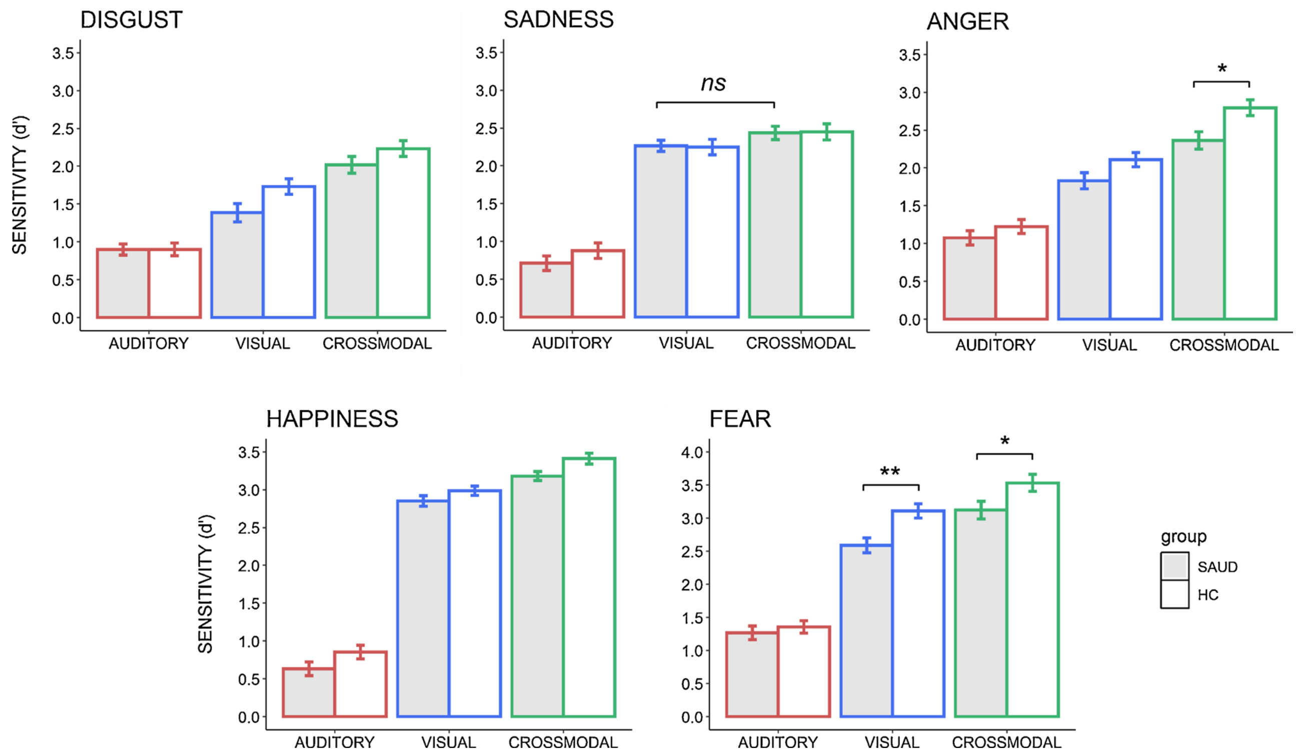

Fig. 3. Sensitivity (d') for each emotion in the three sensory modalities separately for individuals with severe alcohol use disorder (SAUD) and healthy controls (HC). In both groups, auditory < visual < crossmodal for each emotion, except for sadness in individuals with SAUD, with no difference between visual and crossmodal sadness. Individuals with SAUD performed lower than HC for crossmodal anger and crossmodal and visual fear only. Error bars represent the standard error of the mean. *ns*, non significant; **p* < .05; ***p*<.01.

SAUD, despite the dynamic signature of the task, or that we may have lacked the power to reveal a difference. In comparison with the four other emotions, discrimination only slightly improved from visual to crossmodal conditions for sadness in HC, suggesting that visual information already conveys almost all relevant emotional features and distinctive cues for this specific emotion. The absence of group difference for crossmodal sadness further suggests that patients with SAUD may have sufficiently benefited from facial (visual) information to discriminate it. From a qualitative perspective, and as clearly illustrated in Fig. 3, both groups thus displayed a very similar emotional processing profile.

Patients with SAUD nonetheless showed reduced discrimination for anger crossmodal stimuli and fear crossmodal/visual stimuli. Even though they displayed a crossmodal facilitation effect, they might less benefit from the simultaneous availability of auditory and visual input for these two specific emotions. The anger deficit converges with previous findings showing that this emotion is confusing for patients in unimodal (Bora and Zorlu, 2017; de Lima Osório and Donadon, 2014; Foisy et al., 2007; Kornreich et al., 2001a, b) and crossmodal (Brion et al., 2017; Maurage et al., 2007, 2008, 2013) conditions. The present deficit in discriminating anger specifically in the crossmodal condition –with no significant alterations for unimodal stimuli– suggests that SAUD are selectively impaired in the integration of audio-visual anger signals. The conjunction between the complexity of anger decoding, which shares common auditory-visual features with other emotions (Pell and Richards, 2011) and impaired integrative mechanisms in SAUD might have led to specifically reduced crossmodal performances. Deficits for fear processing are less frequently described in SAUD (e.g., Philippot et al., 1999; Kornreich, 2001a, b), but the ecological value of our paradigm and the absence of ceiling effect may have allowed the detection of more subtle deficits in visual and crossmodal conditions. Interestingly, the presence of a concurrent visual deficit might suggest that part of the lower crossmodal emotional integration effect observed in SAUD could be underpinned by a weakened visual input or visual processing. As visuoperceptive impairments are often reported in SAUD (Creupelandt et al., 2019; Crowe et al., 2019; Oscar-Berman et al., 2014; Stavro et al., 2013), patients might not process the most relevant visual cues to identify fear, and might thus base their crossmodal integration on degraded visual information. As such, vision might be particularly important in the framework of crossmodal predictions which posit that the brain continuously predicts incoming information from one modality based on information presented in another modality, to anticipate events and build a unified representation (Jessen and Kotz, 2013, 2015). These online predictions notably build on the natural temporal unfolding of facial/vocal cues and the natural gap between facial expression initiation and actual sound following these facial changes. Visual emotional information can thus influence subsequent auditory processing, resulting in improved affective decoding of multisensory stimuli (Jessen and Kotz, 2013; Kokinous et al., 2015). Such visuo-auditory predictions engage frontal networks (Ethofer et al., 2013; Jessen and Kotz, 2013; Talsma, 2015), known to be impaired in SAUD. Future studies should directly test crossmodal predictions in SAUD by manipulating the temporal gap between visual and auditory cues. Concerning fear, confusion matrices further showed that individuals with SAUD labeled fearful faces as disgusted ones more often than HC. Patients might thus more often interpret fear as a socially hostile cue directed at them (Freeman et al., 2018), probably due to their higher sensitivity to social exclusion (Maurage et al., 2012). The visual specificity of this error pattern however suggests that this hostile attribution might be reduced for dynamic crossmodal stimuli.

In contradiction with our hypothesis, SAUD deficits were not influenced by stimuli duration (i.e. by the quantity of emotional information available). While we expected predominant group differences during the first gates, with patients progressively catching up with HC's performances at longer ones, the gate factor did not influence any group effect. Patients thus need more information to discriminate crossmodal anger and visual/crossmodal fear, but this need was constant during the whole task, resulting in stable deficits throughout the

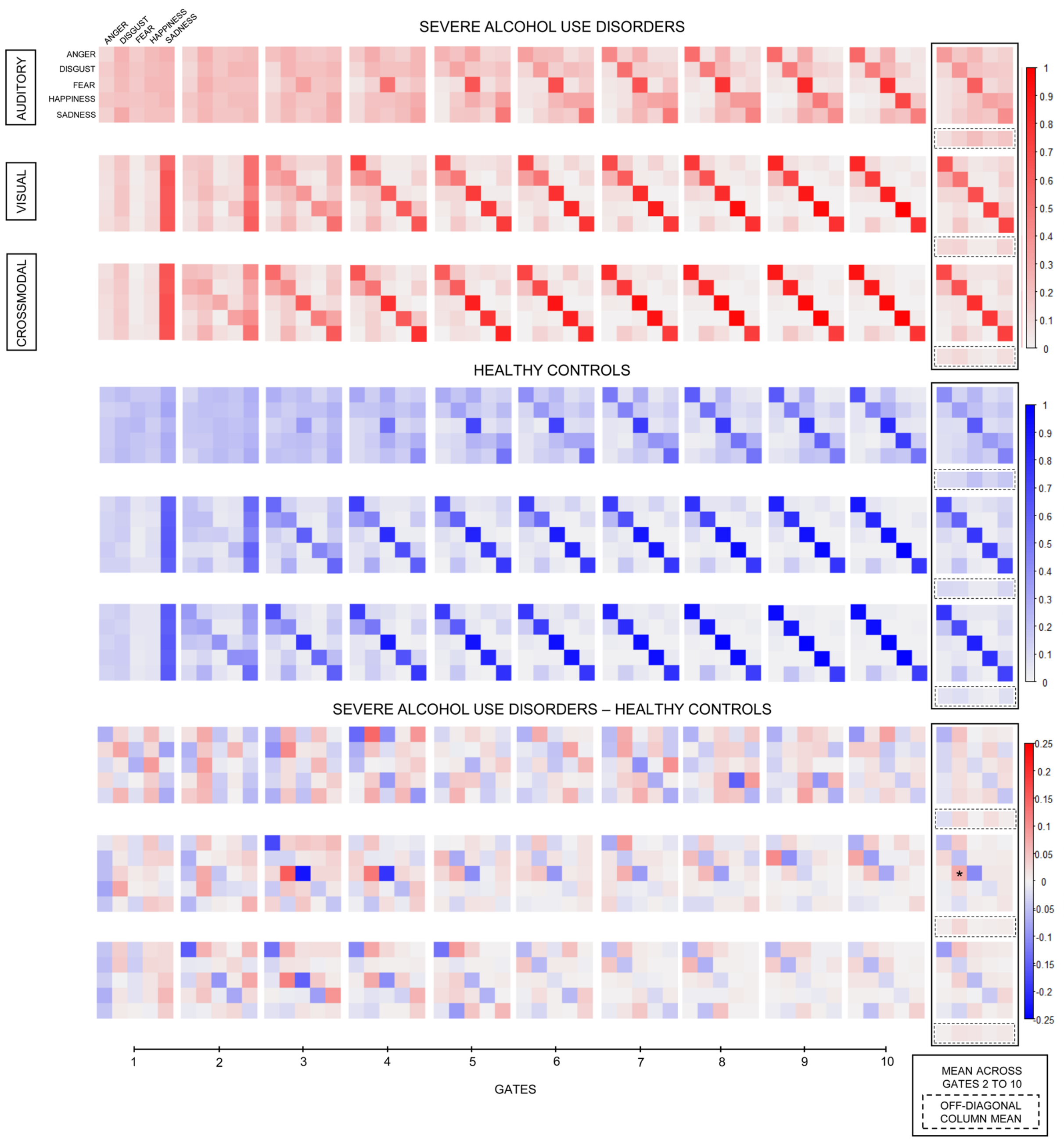

Fig. 4. Confusions matrices for individuals with severe alcohol use disorder (SAUD), healthy controls (HC), and group differences (SAUD − HC) in the three sensory modalities and ten gates. Lines indicate the emotion actually presented to the participants, columns indicate the five possible answers. Correct responses are located on the diagonal of the matrices so that off-diagonal data reflects incorrect responses, revealing which emotions were erroneously selected by participants, and in which proportion. Mean proportions of responses across gates 2–10 are shown in the boxes on the right. The scale of the difference matrices has been adapted to fit the range of differences in response proportions between groups, which never exceeded 0.25. Red cells in the difference matrices indicate higher proportions of responses in individuals with SAUD compared to HC. Blue cells indicate the opposite pattern. Group comparisons were performed on the off-diagonal mean data only. The cells in the dashed box represent the mean proportion of incorrect response for each emotion (off-diagonal column mean), which did not differ between groups. *$p < .05$ (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

gates. Another way to put it is that whatever the level of d' for crossmodal anger and visual/crossmodal fear, individuals with SAUD always needed a fixed extra amount of information (i.e. gate unit) to reach the level of performance of HC. This absence of temporal modulation of the deficits might be due to the fact that the task remained challenging for both groups even at the longest gates. Either way, the fact that anger and fear remained ambiguous even for longer presentation times in patients with SAUD has implications for crossmodal integration as this reflects a less effective network restriction process during emotion selection, leaving too much room for uncertainty and thus incorrect emotional candidates when faced with transitory emotions. In other words, patients might not efficiently reject irrelevant emotions, making them more at risk to select incorrect ones. Our findings are coherent with previous results showing that more intense emotional facial information is needed to attain the same level of correct facial emotional categorization than HC in SAUD (D'Hondt et al., 2015). Relying on a continuum paradigm requiring to categorize morphed faces with increasing emotional intensities, this study demonstrated that the categorical perception of facial expressions was overall preserved in SAUD, but characterized by a need for higher levels of emotional intensity (and thus more emotional information) to perform efficient discrimination.

Crucially, our results did not show a widespread emotional deficit in SAUD (Kornreich et al., 2013) and did not promote the idea that impairments can generalize to positive emotions when using complex tasks (D'Hondt et al., 2014). They rather revealed the presence of circumscribed deficits for specific negative emotions, with a preserved processing for happiness, as suggested earlier (Frigerio et al., 2002; Kornreich et al., 2001a; Townshend and Duka, 2003). This correct discrimination of happiness might nevertheless result from a mere valence saliency effect due to its status of unique positive emotion (D'Hondt et al., 2014). Contrary to previous studies (Freeman et al., 2018; Philippot et al., 1999), we did not record any response bias or overall pattern of emotional confusion in SAUD that generalizes across all emotions, as patients did not misselect a specific emotion more frequently than HC. We especially did not observe a higher tendency to label emotions as expressing anger. Their errors generally mimicked those of HC, except for the specific misinterpretation of fear for disgust, of moderate effect size.

These results bear significant implications for SAUD. Correct emotional interpretation requires rapidly grasping the most relevant sensory information to build a meaningful prediction percept. When crossmodal emotional integration processes are intact, this prediction exceeds a simple addition of unimodal inputs and benefits from redundant matching cues to narrow down the number of viable emotional candidates. Due to their lower crossmodal integration capacities for fear and anger, individuals with SAUD might misinterpret these emotions, increasing the risk of poor social interactions. While we did not find systematic correlations between task performance and interpersonal problems, a high tendency to be controlling towards other people (which may result in the use of manipulative and potentially aggressive behaviors) was associated with a low ability to discriminate anger and sadness. While this relationship must be interpreted with caution, it converges with previous work (Kornreich et al., 2002) suggesting that poorer emotional processing abilities are associated with more interpersonal problems in SAUD, with negative implications for treatment prognosis (Rupp et al., 2017). According to our results (see Supplementary Table 1), patients with SAUD in clinical settings display around 10.6% and 5.6% fewer correct discrimination of fear in the visual and crossmodal modality respectively. This number of incorrect discriminations approximates 8.7% for crossmodal angry stimuli. Considering the large number of emotional stimuli that we process daily, these percentages may have a real, tangible impact on everyday life functioning. Even the more so since we have to select the appropriate emotional interpretation among a much larger panel of candidates than the five emotions included in the study. Another interesting result is the apparent absence of a discrimination deficit in the auditory modality alone. Such potential preservation in the discrimination of vocal emotion expression might suggest that SAUD could selectively alter some sensory signals (visual and crossmodal but not auditory), which would provide a potential opportunity for rehabilitation. In this view, emotional training programs could thus benefit from the inclusion of dynamic crossmodal stimuli closely matching real-life stimulations, but could also capitalize on the auditory modality and pay specific attention to the role of potential visual alterations. Such a proposal would however require further investigation, especially since auditory cues were the most difficult to process for both individuals with SAUD and HC. As a result, unimodal auditory stimuli may simply have been too difficult for participants to identify, potentially masking group differences. Besides, Fig. 3 suggests that subtle deficits in the auditory condition might exist in SAUD (e.g., happiness or sadness), further advocating for additional testing, and stressing the need to increase the power of the analyses. Adapted versions of the task including fewer items will help to clarify these alternative interpretations, notably by removing the first gates at which neither individuals with SAUD nor HC are yet able to discriminate the emotions. Shortened variants specifically targeting the emotions found impaired in individuals with SAUD (such as anger and fear) could also serve clinical rehabilitation purposes, provided that they ensure an adequate learning potential and a positive learning transfer. To find the ideal fit, dedicated studies should examine how and to what extent patients' emotional discrimination abilities can improve through training sessions and identify which parameters may bolster persistent improvement, with the aim of reducing the risk of future relapse.

Several limitations must be considered. First, the absence of non-emotional crossmodal stimuli prevents any conclusion regarding the distinct contributions of emotional and crossmodal integration processes to the deficits. Second, to ensure the ecological value of the stimuli, we did not control for low-level visual and acoustic properties, and cannot ensure that every gate contained the same added amount of emotional information. We reasoned, however, that this natural inter-variability in emotional unfolding explains why some emotions are generally identified more quickly than others. Besides, the fact that group differences did not emerge for the emotions that were the most difficult to discriminate (e.g., disgust) suggests that other factors than perceptual ones might be at play. Finally, the absence of correlations between performances and alcohol-related data, except the positive link between AUDIT scores and discrimination of happiness, does not provide any cue regarding central drinking parameters. Beyond the limited validity of self-report measures, inter-individual differences probably contributed to masking such links. Future work should take into account the heterogeneity of emotional and interpersonal profiles since emotional decoding deficits, including crossmodal ones, may only concern part of the SAUD population (Maurage et al., 2017). In this regard, we examined a sample of individuals with SAUD free of additional psychiatric diagnoses, who especially did not present with polysubstance abuse. While this potentializes the possibility to identify SAUD-specific emotional correlates, it also hampers the generalization of the results to the whole SAUD population, which often displays multiple comorbidities.

In conclusion, we showed that patients with SAUD do not exhibit a generalized emotional deficit. The weakened discrimination of anger and fear suggests a specific role of these negative emotions in their emotional disturbances. Moreover, the alterations were limited to crossmodal (fear and anger) and visual (fear only) conditions, again pointing toward the specific nature of the deficit that is limited to vision and/or its integration with auditory emotional cues. This selectivity argues against the involvement of other general (e.g., motivational, attentional and executive) impairments (Brion et al., 2017; Crowe et al., 2019; Oscar-Berman et al., 2014; Stavro et al., 2013). Together, these results pave the way for additional work on crossmodal processing in SAUD and confirm that this novel paradigm is well suited to explore emotional deficits in psychiatric populations.

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Contributors

All authors contributed to draft the study design. FF and OC created the stimuli and paradigm. CC and PdT recruited the participants and collected the data. CC conducted the statistical analyses. CC, FD and PM drafted the manuscript and all authors provided critical revisions for important intellectual content. The final version of the manuscript was also approved by all authors.

Declaration of competing interest

No conflict declared.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi: https://doi.org/10.1016/j.drugalcdep.2020.108079.

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