



Crossmodal processing of emotions in alcohol-dependence and Korsakoff syndrome

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ABSTRACT

Introduction: Decoding emotional information from faces and voices is crucial for efficient interpersonal communication. Emotional decoding deficits have been found in alcohol-dependence (ALC), particularly in crossmodal situations (with simultaneous stimulations from different modalities), but are still underexplored in Korsakoff syndrome (KS). The aim of this study is to determine whether the continuity hypothesis, postulating a gradual worsening of cognitive and brain impairments from ALC to KS, is valid for emotional crossmodal processing.

Methods: Sixteen KS, 17 ALC and 19 matched healthy controls (CP) had to detect the emotion (anger or happiness) displayed by auditory, visual or crossmodal auditory-visual stimuli. Crossmodal stimuli were either emotionally congruent (leading to a facilitation effect, i.e. enhanced performance for crossmodal condition compared to unimodal ones) or incongruent (leading to an interference effect, i.e. decreased performance for crossmodal condition due to discordant information across modalities). Reaction times and accuracy were recorded.

Results: Crossmodal integration for congruent information was dampened only in ALC, while both ALC and KS demonstrated, compared to CP, decreased performance for decoding emotional facial expressions in the incongruent condition.

Conclusions: The crossmodal integration appears impaired in ALC but preserved in KS. Both alcohol-related disorders present an increased interference effect. These results show the interest of more ecological designs, using crossmodal stimuli, to explore emotional decoding in alcohol-related disorders. They also suggest that the continuum hypothesis cannot be generalised to emotional decoding abilities.

ARTICLE HISTORY

Received 7 March 2017
Accepted 25 August 2017

KEYWORDS

Crossmodal integration; emotion; alcohol-dependence; Korsakoff syndrome

Introduction

Numerous studies (e.g., Marinkovic et al., 2009; Oscar-Berman et al., 2014; Maurage et al., 2009; Uekermann, Daum, Schlebusch, & Trenckmann, 2005) have explored emotional

processing in alcohol dependence, repeatedly showing that affective deficits are a central feature in the development and maintenance of this disorder (Thoma, Friedmann, & Suchan, 2013). Indeed, alcohol-dependent individuals (ALC) present emotional decoding impairments, leading to erroneous interpretations and impaired interpersonal interactions which, in turn, can encourage alcohol consumption as a dysfunctional way to escape social stress and interpersonal conflicts (Oscar-Berman et al., 2014). These experimental studies exploring emotional decoding abilities among ALC were mainly focused on unimodal stimuli (i.e., involving stimulations from a single sensorial modality) such as emotional facial expressions (EFE) (e.g., D'Hondt, de Timary, Bruneau, & Maurage, 2015; Fein, Key, & Szymanski, 2010; Kornreich et al., 2002; Maurage, Campanella, Philippot, Martin, & De Timary, 2008), emotional prosody (Monnot, Nixon, Lovallo, & Ross, 2001) and body postures (Maurage et al., 2009). All these studies showed lower accuracies and/or longer reaction times (RTs) in ALC compared to matched control participants (CP), even when sensorimotor slowing or potentially biasing variables (e.g., depression and anxiety) were controlled for. Emotional decoding thus constitutes an important feature of the more global impairment for social cognition observed in this population, encompassing a large range of social disabilities, such as altered empathy and Theory of Mind (e.g., Amenta, Noël, Verbanck, & Campanella, 2013; Maurage et al., 2016; Thoma et al., 2013; Uekermann & Daum, 2008).

In everyday life, however, we most frequently integrate emotional signals from multiple sensory sources to form a unified and coherent representation of the environment (Campanella & Belin, 2007; Collignon et al., 2010; Müller, Cieslik, Turetsky, & Eickhoff, 2012). Understanding emotional information simultaneously expressed through different channels (i.e. prosody, facial expression, or body posture) is thus a crucial skill for efficient social interactions and communication. Unfortunately, only few studies have investigated the crossmodal processing of emotional stimuli in alcohol-dependence (Maurage et al., 2013; Maurage, Campanella, Philippot, Pham, & Joassin, 2007; Maurage, Philippot, et al., 2008). These studies showed that the facilitation effect (namely increased performance in crossmodal conditions compared to unimodal ones) classically found in CP is impaired in ALC, probably due to reduced activity of the cerebral network involved in crossmodal integration (inferior occipital, middle frontal, and superior parietal areas) and reduced connectivity between this network and brain regions sustaining unimodal processing (Maurage et al., 2013).

Studies investigating emotional decoding abilities (whether in unimodal or crossmodal conditions) are even scarcer in Korsakoff syndrome patients (KS), a neurological condition that constitutes the most frequent complication of alcohol-dependence. Korsakoff Syndrome most often arises following long-lasting and excessive alcohol consumption and results from a combination of alcohol neurotoxicity and thiamine deficiency (Oscar-Berman, 2012). KS patients are characterised by varying intensity of retrograde amnesia (following a temporal gradient with the oldest memory being generally spared) and severe anterograde amnesia (Butters & Cermak, 1980; Kopelman, 2015 for review, Talland, 1965), as well as large-scale cognitive deficits encompassing other memory systems and executive functions (e.g., Maharasingam, Macniven, & Mason, 2013; Van Oort & Kessels, 2009).

The continuity hypothesis (Ryback, 1971) postulates a linear worsening of cognitive and cerebral deficits between uncomplicated ALC and KS, the latter presenting more severe behavioural and brain impairments. In line with this hypothesis, the intensification of the deficits between ALC and KS would be progressive, these two disorders reflecting

successive stages of a single pathology (Bowden, 1990). The idea of a continuity between ALC and KS has gained a heuristic value, but its validity should be further examined within each cognitive function (Butters & Brandt, 1985). Indeed, this hypothesis has been up to now empirically tested for episodic memory (where KS showed disproportionate impairments compared to ALC) and for other cognitive functions such as working memory and executive functions (where KS did not strongly differ from ALC) (Pitel et al., 2008), but its validity has never been tested for emotional processing (Brion, D'Hondt, Davidoff, & Maurage, 2016).

Very few studies have up to now investigated emotional abilities in KS. It has been shown that KS have preserved ability to acquire affective responses following musical emotional induction (Johnson, Kim, & Risse, 1985), but that they have reduced emotion-based judgement and preferences towards fictional characters. Later, it has been suggested that KS patients might present EFE decoding deficits, particularly for fear, anger and surprise (Montagne, Kessels, Wester, & de Haan, 2006), as well as disrupted complex emotional prosody decoding, while the basic discrimination of affective prosody would be preserved (Snitz, Hellinger, & Daum, 2002). Finally, KS patients are impaired for categorising stimuli (e.g., words and pictures) according to their emotional valence, this deficit being centrally related to an overestimation of the emotional content of neutral stimuli (Clark, Shagrin, Pencina, & Oscar-Berman, 2007; Labudda, Todorovski, Markowitsch, & Brand, 2008). At the cerebral level, neuroimaging studies suggest that structural and functional deficits in the limbic system and in frontocerebellar circuit evidenced in ALC would be even more severe in KS (Pitel et al., 2012; Sullivan & Pfefferbaum, 2009). As a whole, those results suggest that KS patients might present lower emotional decoding abilities compared to ALC, in line with the continuity hypothesis (Labudda et al., 2008; Marinkovic et al., 2009).

Accordingly, the present study explored emotion decoding abilities in ALC and KS using an emotion-detection task (Maurage et al., 2007) comprising both unimodal (visual or auditory) and crossmodal (congruent or incongruent) conditions. This experimental design was chosen to: (1) offer the first measure of crossmodal emotional integration in KS; (2) explore the generalisation of the continuity hypothesis towards emotional identification in unimodal and crossmodal settings, by comparing KS patients with matched ALC and CP; and (3) provide the first insights regarding emotional incongruence and conflict resolution between two sensory channels in alcohol-use disorders. We hypothesised that ALC and KS patients would present, as compared to CP, reduced decoding abilities in the unimodal and congruent crossmodal situations as well as increased interference effect (i.e. decreased performance due to discordant information expressed by two modalities) in incongruent situations. In line with the continuity hypothesis, we predicted a worsening of crossmodal identification impairments from ALC to KS.

Materials and methods

Participants

Sixteen KS, 17 ALC and 19 CP took part in the study. They were matched for age and gender. Groups differed according to education level [$F(2,49) = 13.95$, $p < .001$], as assessed by the number of years of education completed since starting primary school. CP had higher education level than ALC and KS, the latter having a lower level of

education compared to ALC. Demographic data are provided in Table 1. KS were diagnosed with “Alcohol-Induced major neurocognitive Disorder (amnesic confabulatory type)” according to the DSM-V criteria, following a semi-structured interview conducted by trained psychiatrist and neurologist. They were recruited during their long-term stay at the Neuropsychiatric Hospitals of Saint-Martin and Beau-Vallon (Belgium). Wernicke’s encephalopathy had been diagnosed in one patient during early detoxification. For all other patients, KS had developed insidiously (Cutting, 1978). Crucially, all KS patients had a history of alcohol-dependence but were in a stabilised phase of the disease when the experiment was conducted. In order to confirm the diagnosis, information regarding cognitive functioning was collected from the neuropsychological assessment performed at the acute phase of the pathology (Brion, de Timary, Pitel, & Maurage, 2017), confirming that KS patients presented severe verbal episodic memory disorders [i.e., free recall and delayed recall scores being lower than 2 standard deviations from the mean on the French version of the Grober and Buschke 16-item free/cued word learning and recall test (Van Der Linden & Adam, 2004)]. Regarding executive functions, raw scores on the Stroop task and trail making test (TMT) were recorded among KS. While KS reaction times were within the norms for Stroop interference, the number of errors on the Stroop and performance on the TMT were two standard deviations below normative data from GREFEX (Godefroy, 2008), suggesting inhibition and set shifting impairments. The KS participant abstinence duration ranged from 76 to 812 days and they were given adapted nutrition and vitamin supplementation.

ALC participants were diagnosed with severe alcohol use disorder according to DSM-V criteria and recruited during their detoxification treatment. ALC abstinence duration ranged from 14 to 600 days. CP had non-hazardous alcohol consumption as defined by the most common thresholds, i.e. lower than 2 alcohol units per days for women and 3 alcohol units per days for men (Gache et al., 2005). They did not present any alcohol consumption during the three days preceding testing and were free of any past or present alcohol abuse or dependence. For CP, drinking habits were explored by the Alcohol-Use Disorders Identification Test (AUDIT) questionnaire [mean score: 4 (S.D.: 2.08)]. A general cognitive assessment was performed among all participants using the Montreal Cognitive Assessment (MoCA). Besides the sequelae caused by a history of alcohol abuse in ALC and KS groups, all participants were free of any major medical problem, psychiatric disorder,

Table 1. Demographic and psychopathological measures for control (CP), alcohol-dependent (ALC) and Korsakoff Syndrome (KS) participants: mean (S.D.).

	CP (n = 19)	ALC (n = 17)	KS (n = 16)	Post hoc comparisons p-value (t-values)		
				CS-ALC t(34)	CS-KS t(33)	ALC-KS t(31)
Demographic measures						
Age	51.84 (7.19)	50.71 (8.23)	51.44 (8.56)	.661 (0.42)	.881 (0.14)	.805 (0.26)
Gender ratio (F/M)	10/9	9/8	6/10	$\chi^2 = .596$		
Education Level (in years)	16.95 (4.31)	13.59 (2.71)	11.13 (2.21)	.003 (3.17)	<.001 (5.23)	.036 (2.36)
Alcohol consumption (units/day)	.91 (.80)	23.45 (11.24)	14.85 (12.40)	<.001 (7.17)	<.001 (4.36)	.045 (2.62)
Abstinence (in days)	3	99.12 (148.75)	264.85 (265.60)	/	/	.719
Psychopathological measures						
Beck Depression Inventory	2.89 (6.79)	11.30 (6.16)	6.18 (5.12)	<.001 (3.82)	.120 (1.58)	.030 (2.24)
State Anxiety Inventory	29.52 (7.77)	35.00 (23.28)	38.93 (9.16)	.280 (1.09)	.070 (1.84)	.455 (0.75)
Trait Anxiety Inventory	33.35 (8.48)	51.00 (12.40)	44.43 (10.51)	<.001 (4.52)	.003 (3.07)	.105 (1.65)
General cognitive assessment						
MOCA	28.55 (1.09)	26.92 (1.15)	22.43 (2.12)	<.001 (4.79)	<.001 (10.71)	<.001 (6.58)

neurological disease (e.g., stroke, multiple sclerosis, epilepsy, coma, head trauma), and past or present polysubstance abuse (except tobacco), as assessed by a clinical interview.

In addition, subclinical psychopathological factors that may affect cognitive functions were controlled for with self-reported questionnaires assessing anxiety [State and Trait Anxiety Inventory, forms A and B (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983)] and depression [Beck Depression Inventory (Beck, Steer, & Brown, 1996)]. Due to missing data for some participants in some questionnaires, the sample size finally included in the analyses slightly varied across variables. The study was approved by the Ethics Committee of the Medical School (Université catholique de Louvain, Belgium) and was conducted according to the principles of the Declaration of Helsinki. All participants provided written informed consent to take part in the study and were tested individually. The entire evaluation required 140 minutes and participants were given breaks between tasks.

Task and procedure

The task was adapted from the emotion-detection task used in a previous study (Maurage et al., 2007) in which participants had to categorise faces and voices according to their emotional content (anger or happiness). Participants were confronted with three conditions (unimodal, crossmodal congruent, crossmodal incongruent) which varied according to the stimuli presented: the auditory and visual unimodal conditions, respectively, consisted of the presentation of voices or faces alone. The crossmodal congruent condition consisted of faces and voices presented simultaneously and always depicting the same emotion. The crossmodal incongruent condition consisted of faces and voices presented simultaneously but always depicting conflicting emotions (e.g., happy voice with angry face).

It has been shown that visual processing is faster than auditory one (e.g., faces are identified more rapidly than voices) (Joassin, Maurage, Bruyer, Crommelinck, & Campanella, 2004) but a classical way to overcome this imbalance is to increase the perceptual complexity of faces by a morphing procedure (Hanley, Smith, & Hadfield, 1998). Therefore, to standardise reaction times for auditory and visual stimuli, faces were morphed at 40–60% level (i.e., 40% happiness–60% anger or conversely) (Maurage et al., 2007).

The study comprised 12 experimental conditions [2 emotions (anger, happiness) × 2 modalities (visual, auditory) × 3 conditions (unimodal, congruent, incongruent)] with a total of 600 trials: 100 trials for each unimodal condition (visual or auditory) and 200 trials for each crossmodal condition (congruent and incongruent) distributed in four blocks. In crossmodal conditions, participants had to focus on the face in 100 trials and on the voice in the other 100 trials. Each trial started with a fixation cross (500 ms) followed by the stimulus (face or voice in the unimodal conditions, both in the crossmodal conditions) for 700 ms. Participants had to categorise each stimulus according to its emotional content, as fast and accurately as possible by pressing the appropriate keyboard keys, and had a total of 2290 ms to answer.

Data analyses

Experimental measures

Signal-detection theory (Stanislaw & Todorov, 1999) holds that discrimination tasks involve the distribution of signal (i.e., item entitled as a target) and noise (i.e., item

entitled as a distractor). On this basis, *Discrimination* [d'] corresponds to the participant's sensitivity toward the task (i.e., the ability to distinguish target from distractors) while *Response bias* [β] corresponds to the strategy used by the participant (i.e., the degree of certainty needed to identify a target). When the task's instructions equally emphasise accuracy and processing speed, it is usual to combine experimental measures into a single performance index. Data analyses were thus performed following the procedure described by Collignon et al. (2010). First, task accuracy was estimated by indices d' (Sensitivity Index) and β (Bias Index) (Snodgrass & Corwin, 1988), and RTs. Second, d' and RTs were combined into a single score to obtain a general performance index that discounts possible criterion shift or speed/accuracy trade-off effects (Bruyer & Brysbaert, 2011; Townsend & Ashby, 1983). This general performance index, namely the speed-accuracy composite score (SACS; Collignon et al., 2010) was computed by first normalising ($M = 0$ and $SD = 1$) the d' and the RT indices obtained across all conditions in each group and then subtracting the normalised RTs from the normalised d' [$Z(d') - Z(RTs) = SACS$]. The normalisation procedure (Z-scores) allows to: (1) attribute the same weight to accuracy and RT performance across participants; (2) exclude the possibility that between-group differences were due to mean and variance differences across the three groups.

Statistical analysis

A preliminary analysis of variance (ANOVA) showed that the emotion type (anger-happiness) did not lead to any main effect or interaction in any experimental measure. Thus, both emotion types were merged. The SACS and β were submitted to a repeated measures ANOVA with modality (visual and auditory) and condition (unimodal, crossmodal congruent and crossmodal incongruent) as within-subjects factors, groups (CP, ALC and KS) as between-subjects factors, and education level as covariate (as education level correlated with SACS). Violations of sphericity were corrected by the Greenhouse-Geisser correction when necessary. *Post hoc* analyses were computed for significant main effects and interactions. Pearson's correlations were also used to explore the links between d' , β , RT, and SACS-dependent variables (4 variables \times 3 conditions \times 2 modalities) and potential biasing variables (e.g., anxiety, depression) using Bonferroni-adjusted alpha levels of .002 per test (.05/24).

Results

Psychopathological comorbidities

As described in Table 1, groups did not significantly differ for state anxiety [$F(2,49) = 1.74$, $p = .185$]. However, differences were observed for: (a) Depression [$F(2,45) = 7.30$, $p = .002$], ALC presenting higher depression scores than CP and KS, who did not differ; (b) Trait anxiety [$F(2,42) = 10.89$, $p < .001$], CP presenting lower scores than ALC and KS, who did not differ. There were no significant correlation neither between the BDI and d' , β , RT, and SACS scores (all $r < .292$, $p > .05$) nor between Trait anxiety and d' , β , TR, SACS scores (all $r < .361$, $p > .05$).

SACS analyses

These results are described in Table 2 and illustrated in Figure 1.

Visual modality

A significant effect was found for Group [$F(2,48) = 9.74, p < .001$] but not for the condition [$F(2,96) = .03, p = .729$]. A significant Group \times Condition interaction was found [$F(4,96) = 4.80, p = .001$]: In the unimodal condition, CP [$t(33) = 3.54, p = .001$] and ALC [$t(31) = 3.51, p = .001$] performed better than KS, but did not differ [$t(34) = 0.60, p = .548$]. In the crossmodal congruent condition, CP did not differ from KS [$t(33) = 0.51, p = .606$] but performed better than ALC [$t(34) = 2.27, p = .027$] who did not differ from KS [$t(31) = 1.67, p = .101$]. In the incongruent condition, CP performed better than KS [$t(33) = 2.43, p = .019$] and ALC [$t(33) = 4.2, p < .001$], who did not differ [$t(31) = 1.36, p = .178$].

Main findings: ALC displayed preserved unimodal but impaired congruent crossmodal processing compared to CP, while the reverse pattern was observed in KS (impaired unimodal but preserved congruent crossmodal processing). Both ALC and KS were impaired for incongruent crossmodal processing.

Auditory modality

No significant effect was found for Group [$F(2,48) = 2.03, p = .141$], Condition [$F(2,96) = 1.73, p = .182$], or Group \times Condition interaction [$F(4,96) = 2.14, p = .100$].

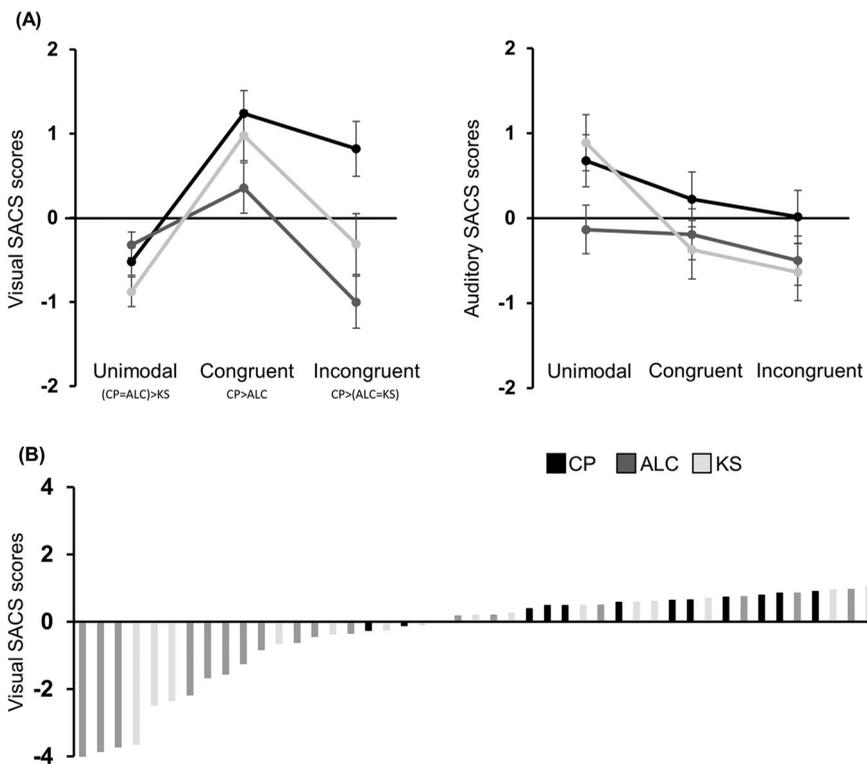


Figure 1. SACS performance. *Part A:* Speed-accuracy composite score (SACS) for each group [Control (CP), alcohol-dependent (ALC) and Korsakoff Syndrome (KS) participants] in visual and auditory modality. The presented scores are corrected for education level (evaluated at the following value in the model: 14.06). Error bars represent standard errors of the mean. *Part B:* Speed-accuracy composite score (SACS) for each participant in the incongruent condition for the visual modality.

Table 2. Unimodal and crossmodal scores in visual (A) and auditory (B) modalities for control (CP), alcohol-dependent (ALC) and Korsakoff Syndrome (KS) participants: mean (S.D.).

	(A) Visual modality					
	CP (n = 19)	ALC (n = 17)	KS (n = 16)	Post hoc comparisons p-value		
				CP-ALC	CP-KS	ALC-KS
d'						
Unimodal _[u]	1.42 (.41)	1.09 (.56)	.97 (.63)		<i>No interaction effect</i>	
Crossmodal congruent _[cc]	1.63 (.51)	.91 (1.48)	1.39 (.82)			
Crossmodal incongruent _[ci]	1.14 (.55)	-.39 (1.36)	-.22 (1.41)			
Conditions comparisons		<i>No interaction effect</i>				
RT						
Unimodal _[u]	949.79 (232.45)	806.54 (225.27)	942.22 (229.91)	.561	.074	.009
Crossmodal congruent _[cc]	475.34 (114.70)	558.35 (325.37)	492.62 (115.89)	.078	.227	.708
Crossmodal incongruent _[ci]	478.68 (103.40)	636.02 (352.29)	471.10 (102.98)	.003	.139	.164
Conditions comparisons	u > [cc = ci]	u > [cc = ci]	u > [cc = ci]			
SACS						
Unimodal _[u]	-.51 (.66)	-.32 (.56)	-.87 (.86)	.548	.001	.001
Crossmodal congruent _[cc]	1.23 (.64)	.35 (1.44)	.97 (.87)	.027	.606	.101
Crossmodal incongruent _[ci]	.82 (.52)	-.99 (1.63)	-.31 (1.35)	<.001	.019	.178
Conditions comparisons	u < [cc = ci]	ci < u < cc	u < ci < cc			
β						
Unimodal _[u]	1.44 (1.24)	1.15 (.47)	1.20 (.50)		<i>No interaction effect</i>	
Crossmodal congruent _[cc]	2.17 (3.06)	1.51 (.84)	1.76 (1.75)			
Crossmodal incongruent _[ci]	.75 (.23)	1.11 (.29)	1.76 (2.61)			
Conditions comparisons		<i>No interaction effect</i>				
(B) Auditory modality						
	CP (n = 19)	ALC (n = 17)	KS (n = 16)	Post hoc comparisons p-value		
				CP-ALC	CP-KS	ALC-KS
d'						
Unimodal _[u]	3.36 (.63)	2.91 (.58)	3.48 (.54)		<i>No interaction effect</i>	
Crossmodal congruent _[cc]	2.95 (.79)	2.07 (1.28)	2.11 (1.03)			
Crossmodal incongruent _[ci]	2.52 (.95)	1.63 (1.19)	1.38 (1.36)			
Conditions comparisons		<i>No interaction effect</i>				
RT						
Unimodal _[u]	535.98 (160.77)	632.71 (288.35)	512.08 (226.98)		<i>No interaction effect</i>	

(Continued)

Table 2. Continued.

	(A) Visual modality					
	CP (<i>n</i> = 19)	ALC (<i>n</i> = 17)	KS (<i>n</i> = 16)	Post hoc comparisons <i>p</i> -value		
				CP-ALC	CP-KS	ALC-KS
Crossmodal congruent _[cc]	564.60 (185.39)	504.74 (198.57)	548.88 (201.90)			
Crossmodal incongruent _[ci]	535.89 (234.48)	495.10 (208.83)	482.95 (124.42)			
Conditions comparisons		<i>No interaction effect</i>				
SACS						
Unimodal _[a]	.67 (.82)	-.13 (1.40)	.88 (1.26)		<i>No interaction effect</i>	
Crossmodal congruent _[b]	.22 (1.05)	-.19 (.97)	-.37 (1.58)			
Crossmodal incongruent _[c]	.015 (1.23)	-.49 (.92)	-.63 (1.39)			
Conditions comparisons		<i>No interaction effect</i>				
β						
Unimodal _[u]	3.01 (3.20)	3.14 (3.84)	5.97 (4.38)	.716	.026	.026
Crossmodal congruent _[cc]	2.62 (2.76)	2.34 (2.84)	1.87 (1.37)	.788	.518	.628
Crossmodal incongruent _[ci]	1.39 (1.70)	0.92 (.50)	1.01 (.44)	.181	.274	.944
Conditions comparisons	<i>u</i> = <i>cc</i> = <i>ci</i>	<i>u</i> > <i>ci</i>	<i>u</i> > [<i>cc</i> = <i>ci</i>]			

Main findings: In contrast with the visual modality, auditory processing did not show any significant group difference.

Response bias (β) analyses

Visual modality

No significant effect was found for Group [$F(2,48) = .50, p = .609$], Condition [$F(2,96) = 1.08, p = .333$] or Group \times Condition interaction [$F(4,96) = 1.46, p = .228$].

Auditory modality

No significant effect was found for Group [$F(2,48) = 1.32, p = .276$] or Condition [$F(2,96) = 0.12, p = .885$] but a significant Group \times Condition interaction [$F(4,96) = 2.78, p = .031$] was found. In the unimodal condition, KS were more conservative than CP [$t(33) = 2.29, p = .026$] and ALC [$t(31) = 2.29, p = .026$], who did not differ [$t(34) = 0.36, p = .716$]. No group difference was observed in the congruent, [CP-ALC: $t(34) = 0.26, p = .788$; CP-KS: $t(33) = 0.65, p = .518$; ALC-KS: $t(31) = 0.48, p = .628$] and incongruent [CP-ALC: $t(34) = 1.35, p = .181$; CP-KS: $t(33) = 1.11, p = .274$; ALC-KS: $t(31) = 0.07, p = .944$] conditions.

Regarding conditions, CP used a conservative strategy ($\beta > 1$) in every condition [U-C: $t(18) = 0.10, p = .918$; U-I : $t(18) = 1.17, p = .247$; C-I: $t(18) = 1.41, p = .164$]. For ALC, unimodal condition was significantly different from incongruent ones [U-I: $t(16) = 2.31, p = .025$], ALC using a more conservative strategy ($\beta > 1$) in the unimodal condition, other comparison being non-significant [U-C: $t(16) = 0.87, p = .386$; C-I: $t(16) = 1.92, p = .060$]. For KS, unimodal condition was significantly different from congruent [U-C: $t(15) = 3.93, p < .001$] and incongruent [U-I: $t(15) = 4.70, p < .001$] conditions, KS using a more conservative strategy ($\beta > 1$) in the unimodal condition, the last comparison being non-significant [C-I: $t(15) = 1.12, p = .265$].

Main findings: The β analysis suggests the use of a more conservative strategy (i.e., less frequent signal detection due to a lower degree of certainty) in the auditory modality, although this conservative strategy is not found in the visual modality.

Supplementary measures

Groups significantly differed for the MoCA [$F(2,45) = 69.53, p < .001$]: CP had higher scores than ALC and KS, ALC having higher scores than KS (see [Table 1](#)). Correlations across groups between MOCA score and d' , β , RT, and SACS scores were not significant (all $r < .31, p > .034$) after using Bonferroni-adjusted alpha levels of 0.002 per test (0.05/24).

Discussion

Multimodal integration is a crucial ability to understand others' affective states in everyday life (e.g., Collignon et al., 2008; de Gelder, Pourtois, Vroomen, & Bachoud-Lévi, 2000; Ethofer et al., 2006; Maurage et al., 2007). The present study proposed to explore cross-modal processing of emotional stimuli at different stages of alcohol-related disorders. EFE decoding deficits had been described in ALC, but we show here for the first time that: (1) KS present a deficit for unimodal visual processing; (2) ALC are impaired in

congruent crossmodal processing; (3) both ALC and KS are impaired when there is an interference between visual and auditory information (incongruent condition). This suggests a distinctive profile in emotional processing across alcohol-use disorders.

KS displayed substantial disruptions in unimodal EFE categorisation compared to ALC and CP. These findings are in line with earlier studies exploring emotional decoding in KS and stressing lower classification performance for emotional words, pictures and faces, with a tendency to misconceive neutral stimuli as being emotional (e.g., Clark et al., 2007; Labudda et al., 2008; Montagne et al., 2006; Oscar-Berman, Hancock, Mildworf, Hutner, & Weber, 1990). The present findings clearly showed that, even when the affective discrimination is simple (here, distinguishing happiness and anger), KS patients displayed strong decoding deficits. This might be explained by the extensive impairments in limbic structures (i.e., amygdala and mammillary bodies) described in this pathology (e.g., for review Oscar-Berman, 2012).

Conversely, KS were able to compensate their unimodal deficit when several sources of congruent information were available (in the congruent crossmodal condition). Earlier findings (Johnson et al., 1985) also supported the idea that KS have the ability to develop affective reactions under some conditions (e.g., developing preferences for melodies). This improvement in crossmodal decoding could be due to their longer abstinence period and could either index a brain reorganisation following abstinence or be associated with a form of post-amnesia behavioural adaptation. This could be due to the fact that KS, unlike non-amnesic ALC, were involved in cognitive rehabilitation programmes. Usually focusing on the increase of attentional abilities towards multiple external cues (Wilson, 2000), rehabilitation might have improved their ability to simultaneously perceive several sensorial signals. Many rehabilitation strategies are used to improve alcohol-related memory deficits (e.g., for review Svanberg & Evans, 2013). Among them, a context-based approach consisting of adapting the environment and encouraging KS patients to rely on external cues has been effective in compensating memory deficits (Wilson et al., 2012). Hence, a recent study (Altgassen, Ariese, Wester, & Kessels, 2015) assessing prospective memory showed that despite their substantial episodic and executive deficits, KS improved their performance when they could rely on highly salient external cues. This result centrally underlines that KS, while presenting significant unimodal difficulties, are still able to integrate and benefit from the various congruent information. This is not found among ALC, who present globally impaired congruent processing. It should however be underlined that the results obtained using the SACS only partially confirms earlier results (Maurage et al., 2007). Hence, while confirming the crossmodal deficit in ALC, a preservation of the facilitation effect was found as the difference between modalities (illustrated in Table 2) was observed within each group and showed greater performance for the crossmodal congruent condition compared with incongruent and unimodal ones.

Another central finding is the significant deficit found for both ALC and KS regarding the incongruent condition. This condition involves inhibitory control as it requires to suppress conflicting information from a second modality (Müller et al., 2011). The severe impairments in the incongruent condition found in ALC and KS might therefore be underpinned by inhibition deficits (Uekermann et al., 2005). The concomitant frontal lobe damage and executive dysfunction often present in KS has long been acknowledged (Joyce & Robbins, 1991; Kopelman, 1991). Alcohol neurotoxicity, predominantly affecting frontal lobes (Fujiwara, Brand, Borsutzky, Steingass, & Markowitsch, 2008), leads to impaired executive functions in the different stages of alcohol-use disorders (e.g., Le

Berre et al., 2014; Noël et al., 2012; Noël, Bechara, Dan, Hanak, & Verbanck, 2007; Oscar-Berman, 2012; Pitel et al., 2007, 2008).

As a whole, the present results encourage future studies to further explore the neural correlates of crossmodal integration during the processing of incongruent emotional information, its potential association with executive function impairments, as well as its influence on everyday life where the emotional signals received from others are often ambiguous or contradictory. These results should be replicated and extended on larger samples, with a better control of cognitive abilities (particularly in exploring the precise role of inhibition on emotional decoding), but also of abstinence duration. Indeed, although the minimum abstinence length was fourteen days to avoid any influence of alcohol withdrawal or acute effects of recent alcohol consumption, this study also included ALC with several months of abstinence, which constitutes a major limitation. Moreover, alcohol consumption was assessed only by self-report (leading to potential over- or under-estimation), and ALC and KS were not matched on this criterion.

Despite these limits, this first exploration of congruent and incongruent crossmodal processing in the successive stages of alcohol-use disorders already bears several fundamental and clinical implications. First, it offers confirmatory evidence to the visual dominance proposal (Collignon et al., 2008) as categorising prosody, even when matched with congruent EFE, was much more complicated than categorising visual stimuli. This is further reinforced by the β analysis, as β values were lower in the visual than auditory modality in all groups. Second, our results show that the unimodal exploration of emotional decoding is not sufficient to understand the complexity of the deficit in ALC and KS. The use of more ecological designs including crossmodal stimuli is therefore encouraged. Third, we offer the first exploration of the continuity hypothesis in emotional processing (Bowden, 1990; Ryback, 1971), and suggest, as only KS seem to benefit from crossmodal integration in the congruent condition, that this continuum does not apply to emotional decoding. Moreover, both groups presented impairments when the tasks involved interference from conflicting information in the incongruent condition, without worsening in KS. This suggests that some abilities might be preserved in KS and might serve as levers for rehabilitation, for example by promoting the use of congruent crossmodal stimulations to improve emotional decoding. Regarding clinical implications, by highlighting a distinct profile of the multimodal processing of emotion from ALC to KS, the present findings suggest that emotional decoding is a deficit of crucial importance in alcohol-related disorders. In view of the close relationship between emotional decoding and interpersonal abilities (Kornreich et al., 2002) and of the role of this deficit in relapse (Schmidt et al., 2016), this study claims for incorporating emotional processing assessment and rehabilitation (at a multimodal level) in neuropsychological therapeutic programmes.

Disclosure statement

No potential conflict of interest was reported by the authors.

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