Visual abilities in Severe Alcohol Use Disorder: Preserved spatial but impaired temporal resolution

Coralie Creupelandt [a,d], Fabien D'Hondt [b,c,d], Bruno Bocanegra [e], Sebastien Szaffarczyk [b,c], Philippe de Timary [f], Jory Deleuze [g], Carine Lambot [g], Pierre Maurage [a,*]

[a] *Louvain Experimental Psychopathology Research Group (UCLEP), Psychological Sciences Research Institute (IPSY), UCLouvain, B-1348, Louvain-la-Neuve, Belgium*
[b] *Univ. Lille, Inserm, CHU Lille, U1172 - LilNCog, Lille Neuroscience & Cognition, F-59000, Lille, France*
[c] *CHU Lille, Clinique de Psychiatrie, CURE, F-59000, Lille, France*
[d] *Centre National de Ressources et de Résilience Lille-Paris (CN2R), F-59000, Lille, France*
[e] *Department of Psychology, Educational, and Child Studies, Erasmus University Rotterdam, the Netherlands*
[f] *Department of Adult Psychiatry, Saint-Luc Academic Hospital, B-1200, Brussels, Belgium*
[g] *Le Beau Vallon, B-5002, Saint-Servais, Belgium*

ARTICLE INFO

ABSTRACT

Visuospatial impairments have long been reported in Severe Alcohol Use Disorder but remain poorly understood, notably regarding the involvement of magnocellular (MC) and parvocellular (PC) pathways. This empirical gap hampers the understanding of the implications of these visual changes, especially since the MC and PC pathways are thought to sustain central bottom-up and top-down processes during cognitive processing. They thus influence our ability to efficiently monitor our environment and make the most effective decisions. To overcome this limitation, we measured PC-inferred spatial and MC-inferred temporal resolution in 35 individuals with SAUD and 30 healthy controls. We used Landolt circles displaying small apertures outside the sensitivity range of MC cells or flickering at a temporal frequency exceeding PC sensitivity. We found evidence of preserved PC spatial resolution combined with impaired MC temporal resolution in SAUD. We also measured how spatial and temporal sensitivity is influenced by the prior presentation of fearful faces – as emotional content could favor MC processing over PC one – but found no evidence of emotional modulation in either group. This spatio-temporal dissociation implies that individuals with SAUD may process visual details efficiently but perceive rapidly updating visual information at a slower pace. This deficit has implications for the tracking of rapidly changing stimuli in experimental tasks, but also for the decoding of crucial everyday visual incentives such as faces, whose micro-expressions vary continuously. Future studies should further specify the visual profile of individuals with SAUD to incorporate disparate findings within a theoretically grounded model of vision.

1. Introduction

Severe Alcohol Use Disorder (SAUD) represents a major societal burden and is associated with several disabling individual consequences, including reduced attentional, memory, and executive abilities combined with abnormal processing of social and emotional information (Caneva et al., 2020; Oscar-Berman et al., 2014; Stavro et al., 2013). While cognitive and emotional impairments undoubtedly contribute to the disease (Czapla et al., 2016; Ottonello et al., 2019; Sliedrecht et al.,

2019), researchers and clinicians generally overlook the presence of concomitant sensory alterations, centrally neglecting the role that visual impairment might play in the onset or maintenance of SAUD. Yet, given the prominence of vision for everyday life functioning, one may wonder whether impaired decision-making and social cues decoding might at least partly result from poorer environment monitoring and visual analysis.

Modified "visuospatial processing" has long been described in SAUD, even after long-term abstinence (Creupelandt et al., 2021a,b). However,

most studies used unspecific tasks requiring not only efficient visual analysis but also memory or executive abilities, such as the Rey-Osterrieth Complex Figure or the WAIS Block Design subtest. As such, visuospatial impairments encompass a large variety of cognitive and cerebral processes, making it difficult to discern their exact nature. More compelling evidence of genuine visual-related impairments in SAUD suggest reduced luminance contrast sensitivity (Creupelandt et al., 2021a; Martins et al., 2019; Roquelaure et al., 1995), color vision deficiencies (de Oliveira Castro et al., 2009; Martins et al., 2019; Mergler et al., 1988), motion and speed processing deficits (Pillunat et al., 1985; Wegner et al., 2001), and abnormal visual evoked potentials (Cadaveira et al., 1991; Chan et al., 1986; Nazliel et al., 2007; Porjesz et al., 1980). Nevertheless, these studies failed to interpret their results in the light of the organization of the visual system, impeding a theory-grounded integration of the deficits. Consequently, little is known about the functional integrity of the two main human visual pathways, namely the magnocellular (MC) and parvocellular (PC) pathways, that originate at the level of the retinal ganglion cells, project onto specific layers of the lateral geniculate nucleus and primary visual cortex, and predominantly feed the dorsal and ventral extrastriate visual streams, respectively (Dacey, 2000; Merigan and Maunsell, 1993; Nassi and Callaway, 2009). Scarce reports of deficits for global rather than local visual configurations (Beatty et al., 1997; Daig et al., 2010; Kramer et al., 1989) combined with reduced motion perception (Chambers and Wilson, 1968; Wegner et al., 2001) and signs of overactivation of ventral rather than dorsal visual streams during spatial memory tasks (Pfefferbaum et al., 2001; Tapert et al., 2001) suggest that the MC pathway might be predominantly impaired in SAUD. Direct evidence is nonetheless lacking to confirm this hypothesis.

Exploring MC and PC pathways is also relevant regarding bidirectional influences between low-level vision and high-level cognition, including attentional, executive, and affective processes (Barrett and Bar, 2009; Newen and Vetter, 2017; O'Callaghan et al., 2017). Indeed, bidirectional visual feedback depends on their integrity and smooth interplay: The MC pathway promotes a rapid but coarse analysis of incoming visual information thanks to its high temporal but low spatial frequency sensitivity. In parallel, the PC pathway conducts a slower but more precise analysis of details owing to its high spatial but low temporal frequency sensitivity (Livingstone and Hubel, 1988). Based on their distinct properties, and especially the faster axonal conduction velocity of MC cells (Bullier et al., 1996; Schmolesky et al., 1998), coarse MC-related signals could be retro-injected into lower-order areas to guide PC finer processing (Bullier, 2001; Chen et al., 2007). Besides, the MC pathway shares close links with frontal structures, including the orbitofrontal cortex which receives inputs from affective and autonomic centers (Barrett and Bar, 2009; Cavada et al., 2000; Rolls and Grabenhorst, 2008). These interactions, supported by neuroimaging (Bar et al., 2006; Kveraga et al., 2007) and tDCS (Bognár et al., 2017) findings, could promote online predictions regarding the identity and affective/goal-relevant values of surrounding stimuli. In this view, the MC pathway could act as a pivotal structure allowing vision to be cognitively and emotionally driven (Bar, 2003; Barrett and Bar, 2009). Within this framework, low-level MC and/or PC-related visual impairment would thus dysregulate the whole continuum of cognitive processing, by impairing not only the quality of incoming visual information (bottom-up deficit) but also the monitoring of vision by top-down processes (Creupelandt et al., 2019; D'Hondt et al., 2014). The cognitive deficits largely described in SAUD should thus be reevaluated in light of their interactions with MC and PC impairments.

Accordingly, our main objective was to assess the integrity of MC and PC basic properties in SAUD. To do so, we exploited the spatiotemporal properties of (sub-)cortical MC and PC pathways and their afferent cortical circuits. Following Bocanegra and Zeelenberg (2011)'s methodology, participants performed judgments on Landolt Cs presenting small apertures or separated by a short time interval to investigate PC spatial and MC temporal resolution, respectively. Our second objective

was to assess the influence of higher-level mechanisms, and especially emotional content, on these judgments. Bocanegra and Zeelenberg (2011) showed that presenting fearful (compared with neutral) faces just before the Landolt Cs induced a spatiotemporal trade-off by improving fast temporal vision at the expense of fine-grained spatial vision. They interpreted their results as the sign that emotions facilitate rapid and coarse MC processing but also inhibit PC functioning to enhance the detection of threats in the environment. We intended to replicate this top-down phenomenon in healthy individuals and test whether a similar biasing of vision occurs in SAUD.

We compared the performance of patients with SAUD and healthy controls on a temporal resolution task (MC-biased) and a spatial resolution task (PC-biased), each declined in a purely perceptual (no facial cue, bottom-up) and an emotional (facial cue, top-down) version. Capitalizing on the aforementioned findings suggesting primary MC deficits, we expected patients to show reduced temporal resolution combined with preserved spatial resolution. We also hypothesized that they would show reduced emotional modulation of vision due to their combination of perceptual, cognitive, and emotional deficits.

2. Material and methods

2.1. Participants

Thirty-five inpatients with SAUD from two Belgian detoxification facilities (Beau Vallon, Saint-Servais; Saint-Luc University Hospital, Brussels) and 30 healthy controls (HC) participated in the study (Table 1). Inpatients fulfilled DSM-5 criteria for SAUD (American Psychiatric Association, 2013), scored a minimum of 20 at the Alcohol Use Disorders Identification Test (AUDIT, Babor et al., 2001), and were free of comorbid psychiatric diagnoses, except tobacco use disorder. To avoid measuring alcohol-withdrawal or pharmacologically induced short-term visual changes, testing took place at the end of the 3-week detoxification program, when participants had been abstinent for a minimum of 10 days and benzodiazepine medication had been stopped or strongly reduced. Five patients were still administered benzodiazepines at testing time, with a limited average daily dosage of 8.0 mg (SD = 4.47) of diazepam. HC were free of any history of psychiatric diagnosis (except tobacco use disorder) and drank a maximum of 100 g of pure ethanol per week, with an upper limit of 30 g/day. They scored

Table 1
Group characteristics for Individuals with Severe Alcohol Use Disorder (SAUD) and Healthy Controls (HC): Mean (SD).

	SAUD (N = 35)	HC (N = 30)
Demographic measures		
Gender ratio (M/F) [NS]	20/15	16/14
Age (in years) [NS]	46.97 (9.34)	49.13 (11.12)
Education (in years) [NS]	13.34 (2.73)	13.97 (3.55)
Alcohol and tobacco consumption		
DSM-5 criteria	8.60 (1.68)	NA
AUDIT score ***	29.31 (5.58)[a]	2.83 (2.36)
Alcohol units per day ***	19.92 (9.12)	0.40 (0.44)
Years of SAUD	11.73 (11.20)	NA
Duration of abstinence (days)	20.03 (5.54)	NA
No. of previous detoxifications	1.74 (2.37)	NA
No. of cigarettes per day ***	13.34 (13.09)	1.23 (5.58)
Psychopathological measures		
BDI-II ***	17.61 (12.60)[a]	5.47 (5.29)
STAI-A (state) ***	34.79 (9.92)[a]	27.85 (8.21)
STAI-B (trait) ***	52.71 (8.22)[b]	37.1 (10.32)
LSAS ***	46.70 (25.72)[b]	24.28 (18.97)[a]
FrACT examination		
Visual acuity (logMAR) [NS][c]	−0.11 (0.11)	−0.13 (0.11)

NA: not applicable; NS: non-significant; ***p < .001.
[a] One missing data.
[b] Two missing data.
[c] Negative values reflect better visual acuity.

lower than 8 at the AUDIT and refrained from drinking alcohol 72 h before testing. Exclusion criteria for both groups included ophthalmological or neurological diseases and severe head traumas. Participants had normal or corrected-to-normal vision and audition. Visual acuity was checked with the Freiburg Visual Acuity Test (FrACT 3.9.9a; Bach, 1996, 2007). We collected self-reported evaluations of depression, state and trait anxiety, and social anxiety via Beck's Depression Inventory (BDI-II; Beck et al., 1996), the State and Trait Inventory form A and B (Spielberger et al., 1983), and Liebowitz's social anxiety scale (LSAS; Liebowitz, 1987).

The study protocol was approved by the biomedical ethics committee of UCLouvain and carried out according to the standards of the latest Declaration of Helsinki. Participants gave their written informed consent before inclusion in the study and HC received a 20€ monetary compensation.

3. Apparatus and stimuli

We ran the experiments on Matlab (Mathworks Inc., version R2017a) using Psychtoolbox-3 (Kleiner et al., 2007). Stimuli were displayed on a 24.5-inch AORUS KD25F screen (240 Hz refresh rate; 1920 × 1080 pixels resolution) calibrated with a Minolta LS-100 photometer and controlled by an ASUS ROG ZEPHYRUS-S-GX535GV-ES021T laptop with an NVidia GeForce RTX2060 graphic card. During all tasks, a light-grey (25 cd/m^2) fixation point (0.2° × 0.2°) was displayed at the center of the screen on a uniform grey background (15 cd/m^2). Targets consisted of Landolt circles (0.8°, 75 cd/m^2) presented at 50% Michelson luminance contrast. Facial cues (5.2° × 8.2°) depicted prototypical neutral and fearful expressions. We selected four actors (2 men/2 women) from the Radboud Face database (Langner et al., 2010) based on the highest inter-rater consensus concerning emotional expression. The eight original pictures (4 actors x 2 emotions)[1] were cropped to remove non-facial attributes, converted into black and white, and equated in terms of luminance and contrast using Matlab's ShineToolbox (Willenbockel et al., 2010).

3.1. Tasks and procedure

Participants were seated 57 cm away from the screen in a dark room and had to maintain their attention towards the fixation point throughout the tasks. We randomized the order of the spatial and temporal resolution tasks across subjects but participants systematically performed the uncued followed by the face cued versions to get familiarized with the perceptual demands before the inclusion of faces. Uncued tasks lasted around 7 min; face cued versions around 15 min. Instructions emphasized accuracy over speed: participants had to respond as accurately as possible, at their own pace. We recorded responses via two keyboard keys ("w", "m"), counterbalanced across participants and tasks but kept constant between the uncued/face cued versions. Visual feedback was provided after each response [the fixation point changed to a plus (correct answers) or minus (incorrect answers) sign for 200 ms] and each task started with 20 training trials.

In both the spatial and temporal resolution tasks, the fixation point appeared on screen for 1000 ms, followed by a target Landolt circle (Fig. 1). In the spatial resolution task, the target Landolt circle appeared randomly at 4° eccentricity on the right or left of the fixation point for 100 ms and contained a small aperture at the top in 50% of trials, and no aperture in the remaining 50%. Following Bocanegra and Zeelenberg (2011), we used five aperture sizes that are outside the sensitivity range of MC cells (Leonova et al., 2003; McAnany and Alexander, 2008): 2, 4, 6, 8, or 10 arcmin. Participants had to indicate whether the Landolt circle contained a small spatial gap or not by pressing the corresponding key. In the temporal resolution task, two consecutive Landolt circles

appeared in 50% of the trials, while only one single Landolt circle appeared in the remaining trials. When two consecutive Landolt circles were presented, each was displayed during 40 ms. They were separated by five possible time intervals with only the fixation point visible: 8, 10, 12, 14, and 16 ms. This small-time gap in the "temporal gap" trials made the Landolt circle flicker on the screen, indicating the presence of a temporal discontinuity. Of note, we selected shorter time gaps than those of Bocanegra and Zeelenberg (2011), namely 10, 15, 20, 25, and 30 ms, based on pretests showing that the temporal resolution task was much easier than the spatial resolution one in its original form. Fast onset asynchronies ranged from 48 to 56 ms, which is outside the temporal sensitivity range of PC cells (De Valois et al., 2000). The duration of the unique Landolt circle ("no temporal gap" trials) ranged from 88 to 96 ms (88, 90, 92, 94, and 96 ms) to match the duration of the "temporal gap" trials. Participants had to indicate whether the Landolt circle was flickering or temporally continuous by pressing the corresponding key. The spatial and temporal resolution tasks both comprised 160 fully randomized trials following a 2 (gap presence/absence) x 5 (gap sizes) x 2 (left/right position) x 8 (repetitions) factorial design.

In the face cued spatial and temporal resolution tasks, faces were briefly (70 ms) displayed before the target Landolt circle, with a 30 ms interval. Two identical faces, either neutral or fearful, appeared simultaneously on the screen, one in each visual hemifield, at 10° eccentricity from the fixation point. All other parameters remained unchanged, including participants' instructions. Face cued tasks comprised twice the number of trials (N = 360), due to the additional 2-level facial cue (neutral/fearful) factor.

3.2. Data preparation and statistical analyses

We conducted the analyses in R (version ×64 3.6.0) and compared group characteristics using (i) Wilcoxon rank-sum tests and Welch's *t*-test for quantitative variables depending on their normality (measured by a Shapiro-Wilk test); (ii) Pearson chi-square tests for qualitative variables.

We pre-processed experimental data and discarded trials associated with reaction times lower than 250 ms (64 out of 62,400 total trials, 0.1%) to ensure proper processing of visual cues and remove anticipatory responses (Fabre-Thorpe, 2011). Following Bocanegra and Zeelenberg (2011), our main analyses focused on dprimes (d'), calculated as z (hits) – z (false alarms) through the "sensR" package (Christensen and Brockhoff, 2018).[2] Sensitivity indices based on the Signal Detection Theory (Macmillan et al., 2004) display the difference between the "Signal Present" (gap) and "Signal Absent" (no gap) distributions. By considering hits and false alarm rates simultaneously, d' acknowledge that individuals may reach high hit rates due to spurious strategies (e.g., always respond that the target is present) and therefore constitute an unbiased performance index. Near zero d' indicate chance performance while larger positive d' reflect a greater ability to discriminate targets (higher sensitivity). We followed a two-step procedure and examined d' from the uncued and facial cued tasks separately. To directly compare spatial and temporal resolution, we applied a single linear mixed model (LMM) to d' from the spatial and temporal resolution tasks through the "nlme" package (Pinheiro et al., 2020) with Group, Task, and Gap size as fixed effects, and participants as a random effect (random intercept). We then computed a second LMM including the additional fixed effect of Face cue. The random factor for participants considered the dependence between our observations due to repeated measures while adjusting the intercept for each participant. Diagnostics of linearity, homoscedasticity, and normality of residuals and random effects ensured that the central assumptions of the models were met. To assess the global effects of each predictor, we applied an analysis of variance using type III sum

---

[1] Face identities are available as Supplementary material.

[2] Raw proportions of hits and false alarms are available as Supplementary material.
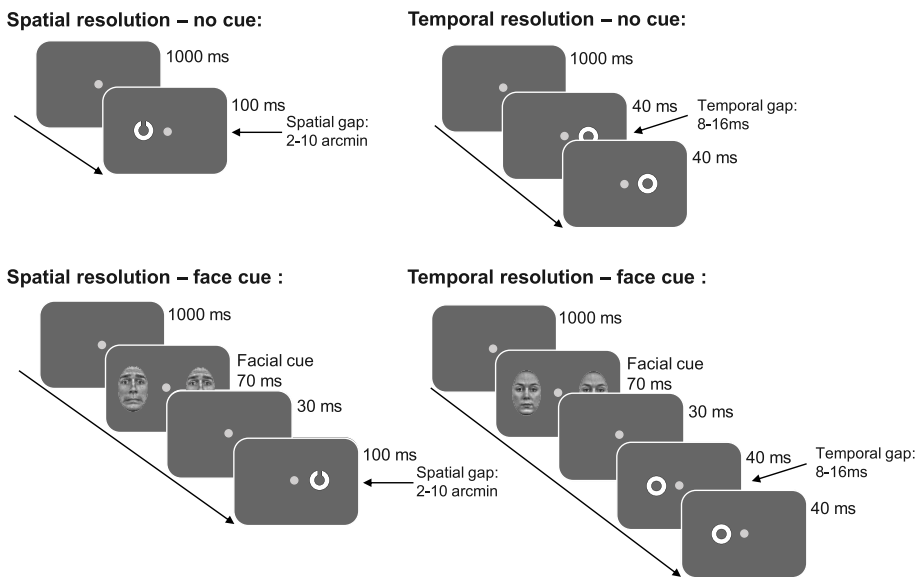
Fig. 1. Illustration of the spatial and temporal resolutions tasks based on a replication of Bocanegra and Zeelenberg (2011)'s design. Each task comprised a perceptual version without any cue (upper part of the Figure) and a facial cued version (lower part of the Figure). Targets appeared randomly on the left or right of the fixation point. Participants had to detect the presence of a spatial or temporal gap of varying size or duration. Facial cues consisted of black and white cropped faces (male/female) depicting either a neutral or fearful facial expression.

of squares (Kenward-Rogers degrees of freedom approximation method) to each LMM. When relevant, we performed Bonferroni-corrected post-hoc comparisons by computing t-ratios based on the estimated marginal means from the LMM through the "emmeans" package (Lenth et al., 2019). Marginal and conditional R^2 values from the "piece-wiseSEM" package (Lefcheck, 2016) measured the proportion of total variance explained by the fixed effects, and by both the fixed and random effects.

Finally, we computed Pearson's and Spearman's correlations (Bon-ferroni-corrected for multiple comparisons) between d' from individuals with SAUD and HC and descriptive variables associated with a significant group difference, as well as between d' from the SAUD group and alcohol-related characteristics.

4. Results

4.1. General group characteristics

Groups (Table 1) did not differ for age ($W = 446.5$, $p = .304$), sex ratio [$\chi^2(1) = 0.003$, $p = .954$], level of education ($W = 482.5$, $p = .573$), and visual acuity ($W = 575.5$, $p = .510$). Patients with SAUD reported higher AUDIT scores ($W = 1020$, $p < .001$) and daily alcohol consumption ($W = 1050$, $p < .001$) than HC. They also smoked more cigarettes per day ($W = 836.5$, $p < .001$) and scored higher on depression ($W = 856.5$, $p < .001$), state anxiety ($W = 731$, $p = .003$), trait anxiety [$t(55.4) = 6.596$, $p < .001$], and social anxiety ($W = 751.5$, $p < .001$) measures.

4.2. Spatial and temporal resolution tasks

We found a significant main effect of Task [$F(1,567) = 41.782$, $p < .001$], Gap size [$F(4,567) = 143.604$, $p < .001$] and Group [$F(1,63) = 8.675$, $p = .005$], as well as significant Task x Gap size [$F(4,567) = 14.738$, $p < .001$] and Task x Group [$F(4,567) = 16.119$, $p < .001$] interactions for the spatial and temporal resolution tasks that did not include facial cues. The Gap size x Group [$F(4,567) = 1.620$, $p = .168$] and Task x Gap size x Group [$F(4,567) = 0.104$, $p = .981$] interactions did not reach significance. Because we were primarily interested in the Group-related effects, we focused on significant main effects and interactions involving the group.[3] D-primes were higher in the spatial than

temporal resolution task in SAUD [$\beta = 0.626$, $t(567) = 7.712$, $p < .001$], whereas no difference across tasks emerged for HC [$\beta = 0.146$, $t(567) = 1.670$, $p = .191$]. As expected, performances overall increased with gap sizes, confirming that larger gaps were easier to detect (Fig. 2). Pairwise comparisons between successive gap sizes were all significant with $p < .032$, except between gap sizes 4 and 5 ($p = .143$), indicating that participants may have reached a plateau performance. More importantly, individuals with SAUD performed worse than HC in the temporal [$\beta = -0.705$, $t(82.2) = -4.177$, $p < .001$] but not spatial [$\beta = -0.225$, $t(82.2) = -1.332$, $p = .373$] resolution task. 95%CI for the significant group difference was [-1.090; -0.319] d'. Marginal and conditional R^2 values reached 0.42 and 0.64, respectively.

We replicated the same profile of results in the face cued spatial and temporal resolution tasks (Fig. 2), with a main effect of Task [$F(1,1197) = 378.893$, $p < .001$], Gap size [$F(4,1197) = 266.680$, $p < .001$] and Group [$F(1,63) = 4.948$, $p = .030$], and significant Task x Gap size [$F(4,1197) = 38.338$, $p < .001$] and Task x Group [$F(1,1197) = 29.304$, $p < .001$] interactions. Contrary to our expectation, there was no main effect nor interaction involving Face cue (all $ps > .287$). All other interactions were also non-significant (all $ps > .111$). D-primes increased with larger gap sizes (all $ps < .007$ for pairwise comparisons between successive gap sizes) and were higher for the spatial than temporal resolution task in both groups [SAUD: $\beta = 1.014$, $t(1197) = -18.310$, $p < .001$; HC: $\beta = 0.572$, $t(1197) = 9.575$, $p < .001$]. Individuals with SAUD exhibited lower d' than HC in the temporal task only [spatial: $\beta = -0.174$, $t(69.8) = -0.955$, $p = .686$; temporal: $\beta = -0.615$, $t(69.8) = -3.381$, $p = .002$]. 95%CI for this group difference was [-0.748; -0.040] d'. Marginal and conditional R^2 values reached 0.42 and 0.69, respectively.

4.3. Correlations

We found no significant correlation between d' in the spatial and temporal resolution tasks (either in the cued or uncued versions) and depression, state anxiety, trait anxiety, and social anxiety in either group (all $ps > .068$), arguing against the inclusion of these variables as

---

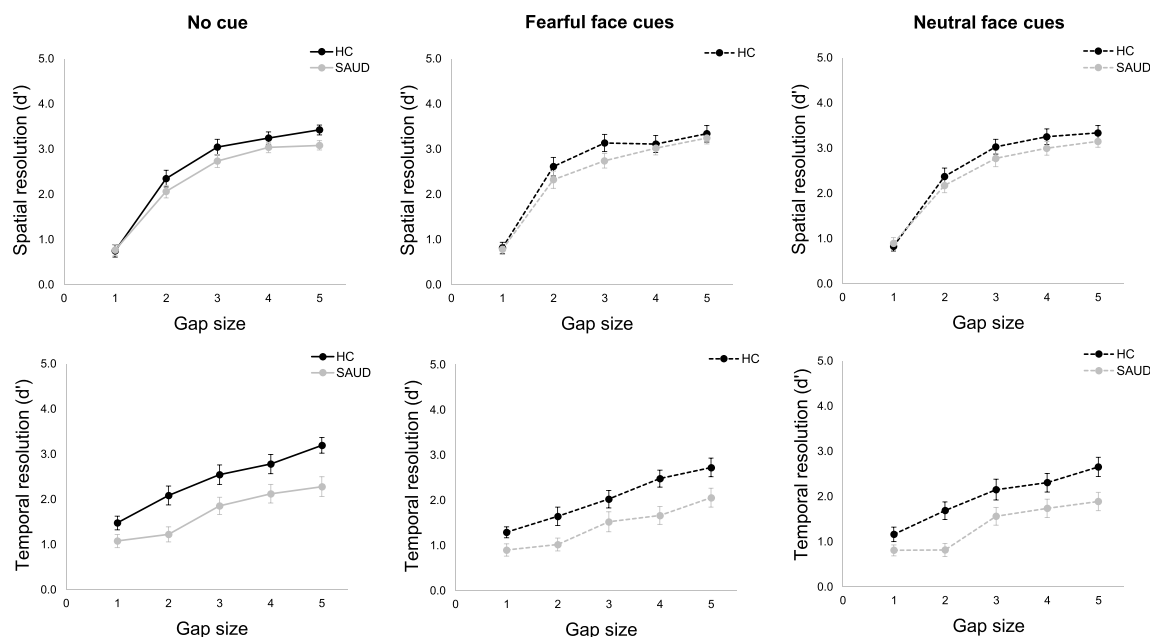[3] Details of the other interactions are available as Supplementary material.

Fig. 2. Results from the spatial and temporal resolution tasks. Spatial and temporal discrimination (d') as a function of gap size in the uncued, fearful face cue, and neutral face cue conditions in both groups of participants. Error bars show the standard error of the mean.

covariates in our LMMs.[4] No significant association emerged between patients' d' and daily alcohol consumption, AUDIT scores, years of SAUD, number of previous detoxification, number of cigarettes smoked per day, and benzodiazepine dosage[5] (all ps > .091). We only found a significant positive correlation between duration of abstinence and d' in the cued version of the temporal resolution task (r_s = 0.46, p = .035).[6]

5. Discussion

Our main objective was to propose a theoretically grounded measurement of bottom-up visual functioning in SAUD through tasks capitalizing on MC and PC's basic spatiotemporal properties. Consistent with our expectations, we found a dissociation between spatial and temporal visual resolution suggesting that MC temporal properties are more sensitive to the neurotoxicity of alcohol than PC spatial ones. Indeed, patients with SAUD performed worse than HC in the temporal but not spatial resolution task, and this group difference emerged at every temporal gap size considered (from 8 to 16 ms). When aggregating the percentages of correct responses across all gap sizes, individuals with SAUD discriminate less efficiently 8–10% of trials compared to HC. This outcome complies with previous studies showing impaired integration and detection of motion signals in SAUD (Chambers and Wilson, 1968; Wegner et al., 2001). It also matches records of lower flicker fusion thresholds (i.e., the frequency at which an intermittent flashing stimulus is seen as completely still; Pillunat et al., 1985; Williams, 1984), a parameter associated with MC neural efficiency (Brown et al., 2018). This implies that individuals with SAUD perceive visual changes at a slower pace and that their visual system recovers less rapidly from

stimulation before being able to respond again (Brown et al., 2018). Conversely, PC spatial resolution appears preserved in SAUD, suggesting that patients are still able to discriminate between two close spatial locations, and can thus process small visual details. This is consistent with their good visual acuity measured by the FrACT. Importantly, including participants with normal or corrected-to-normal acuity did not preclude the presence of group differences in the spatial resolution tasks, as standard visual acuity does not constitute a strong predictor of all other spatial vision measures (Haegerstrom-Portnoy et al., 2000), with different tasks show varying sensitivity to deficits (Enoch et al., 1984). In our study, we did not find any significant correlation between the FrACT and d' for spatial resolution in either group, reinforcing the idea that different visual processes might have been at play. Likewise, evidence of lower contrast sensitivity at high spatial frequencies has been reported in SAUD with normal visual acuity (Cruz et al., 2016; Roquelaure et al., 1995) even though sensitivity at high spatial frequencies and acuity tap the same physiological bottleneck (Bach, 2007). Of most interest, the absence of a deficit in the spatial resolutions tasks, despite their higher attentional and processing speed demands compared to the FrACT, argues against a major deleterious influence of impaired attention and cognitive speed on group differences. Besides, the latter persisted after controlling for depression and anxiety, further strengthening the robustness of the spatio-temporal dissociation.

Our second goal was to explore how performances are modulated by emotional facial cues to collect evidence regarding potential impaired top-down vision-emotion interactions in SAUD. We did not replicate the results obtained by Bocanegra and Zeelenberg (2011) as no difference emerged between neutral and fearful conditions in any task and group. A few dissimilarities in methodology (e.g., absence of prior training with faces in our study) and group characteristics (e.g., age, as Bocanegra and Zeelenberg tested university students) might explain this discrepancy. We recorded lower d', especially for the first gap sizes, suggesting that the tasks were more difficult for our participants. Nevertheless, emotions should not only affect supra-threshold vision but also vision at thresholds, so that we did not expect this lack of effect. For instance, Phelps et al. (2006) measured lower (i.e., better) contrast sensitivity thresholds for Gabor patches presented after a fearful versus neutral face. Alternatively, facial expressions may have been less thoroughly processed by our participants, who were unable to report the emotion

---

[4] We nevertheless performed similar LMMs including depression, state anxiety, trait anxiety, and social anxiety as covariates to ensure the robustness of our findings. We added them one at a time in the model and then all together. We systematically found the same Group × Task interaction characterized by a significant group difference for the temporal but not spatial resolution task.

[5] Adding benzodiazepines dosage as covariate in the LMMs did not change the results either. The proportions of patients still taking benzodiazepines was very low (N = 5).

[6] Details of correlations are available as Supplementary material.

displayed. While we were unable to generate emotional modulations of visual processing, face cued versions of the tasks allowed replicating the same dissociation between preserved spatial and impaired temporal resolution, further reinforcing the strength of our main result.

As a whole, our results stress the need to pay attention to temporal resolution in SAUD, as the speed at which the brain processes visual information has implications for the ability to attend and respond to surrounding stimuli (Brown et al., 2018). Patients may not optimally detect and discriminate very brief visual changes, and thus monitor rapidly evolving visual stimuli, with implications not only for short stimulations in attention or memory tasks but also for crucial stimuli such as faces, whose micro-expressions vary rapidly. Within our theoretical framework of vision, our findings suggest that the rapid but coarse MC analysis might not properly inform the slower but finer parallel PC analysis, overall hampering intra-visual feedback. Researchers and clinicians should thus bear in mind the presence of visual changes in SAUD to better appraise their impact on the subsequent steps of cerebral processing, and ultimately, decision making. Such an integrative approach appears consistent with work conducted in other psychiatric populations displaying visual disturbances, such as schizophrenia or autism spectrum disorders, in which MC/PC dissociations have also been observed, and changes in low-level sensory functioning are more systematically considered in the course of the pathology (e.g., Baum et al., 2015; Chieffi, 2019). While this strategy is much newer in the substance use disorder literature, some studies also suggest that cannabis users show visual changes starting at the level of the retina (Schwitzer et al., 2015) and that these deficits could be particularly marked for MC-biased stimuli (Remy et al., 2022). From a rehabilitation perspective, promising improvement of motion processing and flicker fusion threshold has been documented in healthy individuals after a few training sessions (Seitz et al., 2005, 2006; Watanabe et al., 2002). Interventional studies will help to address: (i) whether patients could benefit from similar training, and; (ii) how MC visual improvement may, in turn, help them recover other higher-level cognitive skills, such as emotional decoding or attentional control for alcohol-related visual cues, which both comprise an indisputable, yet often omitted, perceptual component (Creupelandt et al., 2019).

To conclude, our study demonstrates a dissociation between MC and PC visual functioning in SAUD, characterized by preserved PC-inferred spatial resolution but impaired MC-inferred temporal resolution. We did not observe any emotional modulation of these performances. This specific profile calls for multiple investigations of visual processing, as distinct properties might be differentially impacted. Performing simple visual acuity tests to ensure preserved visual cognition in SAUD might not be sufficient as subtle changes can occur despite normal-range visual acuity. Future work should extend our findings by focusing on other MC and PC-related properties, such as, for instance, low (MC-biased) and high (PC-biased) spatial frequencies. Together, visual changes thus constitute an additional marker of SAUD. Exploring their nature and consequences would help to better integrate the widespread brain dysfunctions reported in this clinical population.

Role of the funding sources

Declarations of interest

The authors report no conflict of interest.

Ethical statement

The study protocol met the requirements of the Helsinki Declaration in its latest form and was approved by the Ethics Committee of Saint-Luc University Hospital, Brussels (Belgium), and le Beau Vallon Hospital, Saint-Servais (Belgium).

Acknowledgements

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jpsychires.2022.02.040.

References

American Psychiatric Association, 2013. Diagnostic and Statistical Manual of Mental Disorders, fourth ed. https://doi.org/10.1176/appi.books.9780890425596 Authors, Washington, DC.

Babor, T.F., Higgins-Biddle, J.C., Saunders, J.B., Monteiro, M.G., 2001. AUDIT: the Alcohol Use Disorders Identification Test: Guidelines for Use in Primary Health Care, second ed. World Health Organization, Geneva.

Bach, M., 2007. The Freiburg visual acuity test-variability unchanged by post-hoc re-analysis. Graefes Arch. Clin. Exp. Ophthalmol. Albrecht Von Graefes Arch. Klin. Exp. Ophthalmol. 245, 965–971. https://doi.org/10.1007/s00417-006-0474-4.

Bach, M., 1996. The Freiburg Visual Acuity test–automatic measurement of visual acuity. Optom. Vis. Sci. Off. Publ. Am. Acad. Optom. 73, 49–53.

Bar, M., 2003. A cortical mechanism for triggering top-down facilitation in visual object recognition. J. Cognit. Neurosci. 15, 600–609. https://doi.org/10.1162/089892903321662976.

Bar, M., Kassam, K.S., Ghuman, A.S., Boshyan, J., Schmid, A.M., Dale, A.M., Hämäläinen, M.S., Marinkovic, K., Schacter, D.L., Rosen, B.R., Halgren, E., 2006. Top-down facilitation of visual recognition. Proc. Natl. Acad. Sci. U.S.A. 103, 449–454. https://doi.org/10.1073/pnas.0507062103.

Barrett, L.F., Bar, M., 2009. See it with feeling: affective predictions during object perception. Philos. Trans. R. Soc. B Biol. Sci. 364, 1325–1334. https://doi.org/10.1098/rstb.2008.0312.

Baum, S.H., Stevenson, R.A., Wallace, M.T., 2015. Behavioral, perceptual, and neural alterations in sensory and multisensory function in autism spectrum disorder. Prog. Neurobiol. 134, 140–160. https://doi.org/10.1016/j.pneurobio.2015.09.007.

Beatty, W.W., Blanco, C.R., Hames, K.A., Nixon, S.J., 1997. Spatial cognition in alcoholics: influence of concurrent abuse of other drugs. Drug Alcohol Depend. 44, 167–174. https://doi.org/10.1016/S0376-8716(97)01334-3.

Beck, A.T., Steer, R.A., Brown, G.K., 1996. BDI-II: Beck Depression Inventory Manual, second ed. Psychological Corporation, San Antonio, TX.

Bocanegra, B.R., Zeelenberg, R., 2011. Emotion-induced trade-offs in spatiotemporal vision. J. Exp. Psychol. Gen. 140, 272–282. https://doi.org/10.1037/a0023188.

Bognár, A., Csete, G., Németh, M., Csibri, P., Kincses, T.Z., Sáry, G., 2017. Transcranial stimulation of the orbitofrontal cortex affects decisions about magnocellular optimized stimuli. Front. Neurosci. 11, 234. https://doi.org/10.3389/fnins.2017.00234.

Brown, A., Corner, M., Crewther, D.P., Crewther, S.G., 2018. Human flicker fusion correlates with physiological measures of magnocellular neural efficiency. Front. Hum. Neurosci. 12, 176. https://doi.org/10.3389/fnhum.2018.00176.

Bullier, J., 2001. Integrated model of visual processing. Brain Res. Rev. 36, 96–107. https://doi.org/10.1016/S0165-0173(01)00085-6.

Bullier, J., Hupé, J.M., James, A., Girard, P., 1996. Functional interactions between areas V1 and V2 in the monkey. J. Physiol. Paris 90, 217–220. https://doi.org/10.1016/S0928-4257(97)81426-X.

Cadaveira, F., Grau, C., Roso, M., Sanchez-Turet, M., 1991. Multimodality exploration of event-related potentials in chronic alcoholics. Alcohol Clin. Exp. Res. 15, 607–611. https://doi.org/10.1111/j.1530-0277.1991.tb00568.x.

Caneva, S., Ottonello, M., Torselli, E., Pistarini, C., Spigno, P., Fiabane, E., 2020. Cognitive impairments in early-detoxified alcohol-dependent inpatients and their associations with socio-demographic, clinical and psychological factors: an exploratory study. Neuropsychiatric Dis. Treat. 16, 1705–1716. https://doi.org/10.2147/NDT.S254369.

Cavada, C., Company, T., Tejedor, J., Cruz-Rizzolo, R.J., Reinoso-Suarez, F., 2000. The anatomical connections of the macaque monkey orbitofrontal cortex. A review. Cereb. Cortex N. Y. N 1991 10, 220–242.

Chambers, J.L., Wilson, W.T., 1968. Perception of apparent motion and degree of mental pathology. Percept. Mot. Skills 26, 855–861. https://doi.org/10.2466/pms.1968.26.3.855.

Chan, Y.W., McLeod, J.G., Tuck, R.R., Walsh, J.C., Feary, P.A., 1986. Visual evoked responses in chronic alcoholics. J. Neurol. Neurosurg. Psychiatry 49, 945–950. https://doi.org/10.1136/jnnp.49.8.945.

Chen, C.-M., Lakatos, P., Shah, A.S., Mehta, A.D., Givre, S.J., Javitt, D.C., Schroeder, C.E., 2007. Functional anatomy and interaction of fast and slow visual pathways in macaque monkeys. Cereb. Cortex 17, 1561–1569. https://doi.org/10.1093/cercor/bhl067.

Chieffi, S., 2019. Dysfunction of magnocellular/dorsal processing stream in schizophrenia. Curr. Psychiatr. Res. Rev. 15, 26–36. https://doi.org/10.2174/1573400515666190119163522.

Christensen, R.H.B., Brockhoff, P.B., 2018. sensR: an R-package for sensory discrimination. R package version 1.5-1. http://www.cran.r-project.org/package=sensR. (Accessed July 2021). Retrieved July2021.

Creupelandt, C., D'Hondt, F., Maurage, P., 2019. Towards a dynamic exploration of vision, cognition and emotion in alcohol-use disorders. Curr. Neuropharmacol. 17, 492–506. https://doi.org/10.2174/1570159X16666180828100441.

Creupelandt, C., D'Hondt, F., Maurage, P., 2021a. Neural correlates of visuoperceptive changes in severe alcohol use disorder: a critical review of neuroimaging and electrophysiological findings. J. Neurosci. Res 99, 1253–1275. https://doi.org/10.1002/jnr.24799.

Creupelandt, C., Maurage, P., D'Hondt, F., 2021b. Visuoperceptive impairments in severe alcohol use disorder: a critical review of behavioral studies. Neuropsychol. Rev. 31, 361–384. https://doi.org/10.1007/s11065-020-09469-x.

Cruz, É.D.N. da, de Andrade, M.J.O., Cavalcanti-Gaudino, M.K., Nogueira, R.M.T.B.L., Santos, N.A., 2016. Effects of chronic alcoholism in the sensitivity to luminance contrast in vertical sinusoidal gratings. Psicol. Reflexão Crítica 29. https://doi.org/10.1186/s41155-016-0023-y.

Czapla, M., Simon, J.J., Richter, B., Kluge, M., Friederich, H.-C., Herpertz, S., Mann, K., Herpertz, S.C., Loeber, S., 2016. The impact of cognitive impairment and impulsivity on relapse of alcohol-dependent patients: implications for psychotherapeutic treatment. Addiction Biol. 21, 873–884. https://doi.org/10.1111/adb.12229.

Dacey, D.M., 2000. Parallel pathways for spectral coding in primate retina. Annu. Rev. Neurosci. 23, 743–775. https://doi.org/10.1146/annurev.neuro.23.1.743.

Daig, I., Mahlberg, R., Schroeder, F., Gudlowski, Y., Wrase, J., Wertenauer, F., Bschor, T., Esser, G., Heinz, A., Kienast, T., 2010. Low effective organizational strategies in visual memory performance of unmedicated alcoholics during early abstinence. Psycho Soc. Med. 7, Doc07. https://doi.org/10.3205/psm000069.

de Oliveira Castro, A.J., Rodrigues, A.R., Côrtes, M.I.T., de Lima Silveira, L.C., 2009. Impairment of color spatial vision in chronic alcoholism measured by psychophysical methods. Psychol. Neurosci. 2, 179–187. https://doi.org/10.3922/j.psns.2009.2.009.

De Valois, R.L., Cottaris, N.P., Mahon, L.E., Elfar, S.D., Wilson, J.A., 2000. Spatial and temporal receptive fields of geniculate and cortical cells and directional selectivity. Vision Res. 40, 3685–3702. https://doi.org/10.1016/S0042-6989(00)00210-8.

D'Hondt, F., Lepore, F., Maurage, P., 2014. Are visual impairments responsible for emotion decoding deficits in alcohol-dependence? Front. Hum. Neurosci. 8, 128. https://doi.org/10.3389/fnhum.2014.00128.

Enoch, J.M., Essock, E.A., Williams, R.A., 1984. Relating vernier acuity and Snellen acuity in specific clinical populations. Doc. Ophthalmol. Adv. Ophthalmol. 58, 71–77. https://doi.org/10.1007/BF00140901.

Fabre-Thorpe, M., 2011. The characteristics and limits of rapid visual categorization. Front. Psychol. 2 https://doi.org/10.3389/fpsyg.2011.00243.

Haegerstrom-Portnoy, G., Schneck, M.E., Lott, L.A., Brabyn, J.A., 2000. The relation between visual acuity and other spatial vision measures. Optom. Vis. Sci. Off. Publ. Am. Acad. Optom. 77, 653–662. https://doi.org/10.1097/00006324-200012000-00012.

Kleiner, M., Brainard, D., Pelli, D., Ingling, A., Murray, R., Broussard, C., 2007. What's new in psychtoolbox-3. Perception 36, 1–16.

Kramer, J.H., Blusewicz, M.J., Robertson, L.C., Preston, K., 1989. Effects of chronic alcoholism on perception of hierarchical visual stimuli. Alcohol Clin. Exp. Res. 13, 240–245. https://doi.org/10.1111/j.1530-0277.1989.tb00320.x.

Kveraga, K., Boshyan, J., Bar, M., 2007. Magnocellular projections as the trigger of top-down facilitation in recognition. J. Neurosci. 27, 13232–13240. https://doi.org/10.1523/jneurosci.3481-07.2007.

Langner, O., Dotsch, R., Bijlstra, G., Wigboldus, D.H.J., Hawk, S.T., van Knippenberg, A., 2010. Presentation and validation of the Radboud faces database. Cognit. Emot. 24, 1377–1388. https://doi.org/10.1080/02699930903485076.

Lefcheck, J.S., 2016. piecewiseSEM: piecewise structural equation modeling in R for ecology, evolution, and systematics. Methods Ecol. Evol. 7, 573–579. https://doi.org/10.1111/2041-210X.12512.

Lenth, R., 2019. Emmeans: Estimated Marginal Means, Aka Least-Squares Means. R package version 1.3.4. https://CRAN.R-project.org/package=emmeans. Retrieved July 2021.

Leonova, A., Pokorny, J., Smith, V.C., 2003. Spatial frequency processing in inferred PC- and MC-pathways. Vision Res. 43, 2133–2139. https://doi.org/10.1016/S0042-6989(03)00333-X.

Liebowitz, M.R., 1987. Social phobia. Mod. Probl. Pharmacopsychiatr. 22, 141–173. https://doi.org/10.1159/000414022.

Livingstone, M., Hubel, D., 1988. Segregation of form, color, movement, and depth: anatomy, physiology, and perception. Science 240, 740–749. https://doi.org/10.1126/science.3283936.

Macmillan, N.A., Creelman, C.D., Creelman, C.D., 2004. Detection Theory : A User's Guide. Psychology Press. https://doi.org/10.4324/9781410611147.

da Martins, I.C.V.S., da Souza, G.S., Brasil, A., Herculano, A.M., Lacerda, E.M., da, C.B., Rodrigues, A.R., Rosa, A.A.M., Ventura, D.F., Castro, A.J. de O., Silveira, L.C. de L., 2019. Psychophysical evaluation of visual functions of ex-alcoholic subjects after prolonged abstinence. Front. Neurosci. 13, 179. https://doi.org/10.3389/fnins.2019.00179.

McAnany, J.J., Alexander, K.R., 2008. Spatial frequencies used in Landolt C orientation judgments: relation to inferred magnocellular and parvocellular pathways. Vision Res., Special Issue: Receptors, Retina, and Color 48, 2615–2624. https://doi.org/10.1016/j.visres.2008.02.012.

Mergler, D., Blain, L., Lemaire, J., Lalande, F., 1988. Colour vision impairment and alcohol consumption. Neurotoxicol. Teratol. 10, 255–260. https://doi.org/10.1016/0892-0362(88)90025-6.

Merigan, W.H., Maunsell, J.H., 1993. How parallel are the primate visual pathways? Annu. Rev. Neurosci. 16, 369–402. https://doi.org/10.1146/annurev.ne.16.030193.002101.

Nassi, J.J., Callaway, E.M., 2009. Parallel processing strategies of the primate visual system. Nat. Rev. Neurosci. 10, 360–372. https://doi.org/10.1038/nrn2619.

Nazliel, B., Arikan, Z., İrkec, C., 2007. Visual evoked potentials in chronic alcoholism. Addict. Behav. 32, 1470–1473. https://doi.org/10.1016/j.addbeh.2006.09.006.

Newen, A., Vetter, P., 2017. Why cognitive penetration of our perceptual experience is still the most plausible account. Conscious. Cognit. 47, 26–37. https://doi.org/10.1016/j.concog.2016.09.005.

O'Callaghan, C., Kveraga, K., Shine, J.M., Adams, R.B., Bar, M., 2017. Predictions penetrate perception: converging insights from brain, behaviour and disorder. Conscious. Cogn 47, 63–74. https://doi.org/10.1016/j.concog.2016.05.003.

Oscar-Berman, M., Valmas, M.M., Sawyer, K.S., Ruiz, S.M., Luhar, R.B., Gravitz, Z.R., 2014. Profiles of impaired, spared, and recovered neuropsychological processes in. Alcoholism. Handb. Clin. Neurol. 125, 183–210. https://doi.org/10.1016/B978-0-444-62619-6.00012-4.

Ottonello, M., Fiabane, E., Pistarini, C., Spigno, P., Torselli, E., 2019. Difficulties in emotion regulation during rehabilitation for alcohol addiction: correlations with metacognitive beliefs about alcohol use and relapse risk. Neuropsychiatric Dis. Treat. 15, 2917–2925. https://doi.org/10.2147/NDT.S214268.

Pfefferbaum, A., Desmond, J.E., Galloway, C., Menon, V., Glover, G.H., Sullivan, E.V., 2001. Reorganization of frontal systems used by alcoholics for spatial working memory: an fMRI study. Neuroimage 14, 7–20. https://doi.org/10.1006/nimg.2001.0785.

Phelps, E.A., Ling, S., Carrasco, M., 2006. Emotion facilitates perception and potentiates the perceptual benefits of attention. Psychol. Sci. 17, 292–299. https://doi.org/10.1111/j.1467-9280.2006.01701.x.

Pillunat, L.E., Christ, T., Luderer, H.J., Stodtmeister, R., 1985. Flicker fusion frequency and organic syndrome in alcoholics. Percept. Mot. Skills 60, 487–494. https://doi.org/10.2466/pms.1985.60.2.487.

Pinheiro, J., Bates, D., DebRoy, S., Sarkar, D., R Core Team, 2020. Nlme: Linear and NonlinearMixed EffectsModels [R Package]. Version 3.1-145. https://CRAN.R-project.org/package=nlme. (Accessed July 2021).

Porjesz, B., Begleiter, H., Garozzo, R., 1980. Visual evoked potential correlates of information processing deficits in chronic alcoholics. Adv. Exp. Med. Biol. 126, 603–623. https://doi.org/10.1007/978-1-4684-3632-7_46.

Remy, I., Schwitzer, T., Albuisson, É., Schwan, R., Krieg, J., Bernardin, F., Ligier, F., Lalanne, L., Maillard, L., Laprevote, V., 2022. Impaired P100 among regular cannabis users in response to magnocellular biased visual stimuli. Prog. Neuro-Psychopharmacol. Biol. Psychiatry 113, 110437. https://doi.org/10.1016/j.pnpbp.2021.110437.

Rolls, E.T., Grabenhorst, F., 2008. The orbitofrontal cortex and beyond: from affect to decision-making. Prog. Neurobiol. 86, 216–244. https://doi.org/10.1016/j.pneurobio.2008.09.001.

Roquelaure, Y., Le Gargasson, J.F., Kupper, S., Girre, C., Hispard, E., Dally, S., 1995. Alcohol consumption and visual contrast sensitivity. Alcohol Alcohol. Oxf. Oxfs 30, 681–685. https://doi.org/10.1093/oxfordjournals.alcalc.a045781.

Schmolesky, M.T., Wang, Y., Hanes, D.P., Thompson, K.G., Leutgeb, S., Schall, J.D., Leventhal, A.G., 1998. Signal timing across the macaque visual system. J. Neurophysiol. 79, 3272–3278.

Schwitzer, T., Schwan, R., Angioi-Duprez, K., Ingster-Moati, I., Lalanne, L., Giersch, A., Laprevote, V., 2015. The cannabinoid system and visual processing: a review on experimental findings and clinical presumptions. Eur. Neuropsychopharmacol 25, 100–112. https://doi.org/10.1016/j.euroneuro.2014.11.002.

Seitz, A.R., Nanez, J.E., Holloway, S.R., Watanabe, T., 2006. Perceptual learning of motion leads to faster flicker perception. PLoS One 1, e28. https://doi.org/10.1371/journal.pone.0000028.

Seitz, A.R., Nanez, J.E., Holloway, S.R., Watanabe, T., 2005. Visual experience can substantially alter critical flicker fusion thresholds. Hum. Psychopharmacol. Clin. Exp. 20, 55–60. https://doi.org/10.1002/hup.661.

Sliedrecht, W., de Waart, R., Witkiewitz, K., Roozen, H.G., 2019. Alcohol use disorder relapse factors: a systematic review. Psychiatr. Res. 278, 97–115. https://doi.org/10.1016/j.psychres.2019.05.038.

Spielberger, C.D., Gorsuch, R.L., Lusthene, R., Vagg, P.R., Jacobs, G.A., 1983. Manual for the State-Trait Anxiety Inventory. Consulting Psychology Press, Palo Alto, CA.

Stavro, K., Pelletier, J., Potvin, S., 2013. Widespread and sustained cognitive deficits in alcoholism: a meta-analysis. Addiction Biol. 18, 203–213. https://doi.org/10.1111/j.1369-1600.2011.00418.x.

Tapert, S.F., Brown, G.G., Kindermann, S.S., Cheung, E.H., Frank, L.R., Brown, S.A., 2001. fMRI measurement of brain dysfunction in alcohol-dependent young women. Alcohol Clin. Exp. Res. 25, 236–245. https://doi.org/10.1111/j.1530-0277.2001.tb02204.x.

Watanabe, T., Náñez, J.E., Koyama, S., Mukai, I., Liederman, J., Sasaki, Y., 2002. Greater plasticity in lower-level than higher-level visual motion processing in a passive perceptual learning task. Nat. Neurosci. 5, 1003–1009. https://doi.org/10.1038/nn915.

Wegner, A.J., Gunthner, A., Fahle, M., 2001. Visual performance and recovery in recently detoxified alcoholics. Alcohol Alcohol 36, 171–179. https://doi.org/10.1093/alcalc/36.2.171.

Willenbockel, V., Sadr, J., Fiset, D., Horne, G.O., Gosselin, F., Tanaka, J.W., 2010. Controlling low-level image properties: the SHINE toolbox. Behav. Res. Methods 42, 671–684. https://doi.org/10.3758/BRM.42.3.671.

Williams, D.E., 1984. Visual electrophysiology and psychophysics in chronic alcoholics and in patients on tuberculostatic chemotherapy. Am. J. Optom. Physiol. Opt. 61, 576–585. https://doi.org/10.1097/00006324-198409000-00007.