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Time perception and alcohol use: A systematic review

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ABSTRACT

Attentional, executive, and memory processes play a pivotal role in time perception. As acute or chronic alcohol consumption influences these processes, it should also modify time perception. We systematically reviewed and critically assessed all existing studies on time perception among alcohol drinkers, following the PICOS procedure and PRISMA guidelines. We selected 31 articles, distributed across four populations (i.e., alcohol intoxication, binge/heavy drinking, severe alcohol use disorder [SAUD], and Korsakoff syndrome). Several studies suggested the overestimation or underestimation of time during alcohol intoxication. No direct effect of binge/heavy drinking was observed on time perception, while studies on SAUD reported conflicting results. Participants with Korsakoff syndrome exhibited globally impaired time perception and marked deficits in associated cognitive abilities. This systematic review suggests that alcohol consumption affects time perception only when specific cognitive processes are depleted. However, due to the methodological limitations related to existing studies, no firm conclusion can be drawn. Guidelines and perspectives to advance the field are proposed.

1. Introduction

The ability to correctly perceive time is a crucial component of everyday life, both for very short durations (i.e., from milliseconds to one second), which are the backbone of key processes (e.g., motor planning, Wiener et al., 2019), and for longer durations (i.e., from a few seconds to several days), which affect day-to-day activities (e.g., time management). Influential models of time perception[1] (e.g., Block and Gruber, 2014; Levin and Zakay, 1989) separate this ability into explicit (i.e., prospective time perception; PTP) and implicit (i.e., retrospective time perception; RTP) components. PTP constitutes a conscious and ad hoc process in which the individual knows beforehand that there will be a time interval to be estimated. This process is accounted for by models such as the attentional gate model (Zakay and Block, 1995), which postulates that an internal mechanism (i.e., the pacemaker) produces a regular pulse during the entire target interval. This pulse is thought to be recorded by the accumulator, and then confronted by the comparator with durations previously stored in memory. This comparison provides an estimation of the target interval. Furthermore, this model also proposes that time estimation is modulated by two attentional processes, namely: (1) the switch, operating in an on-off design (i.e., letting pulses go through only when one is focusing on time), and (2) the attentional gate, working incrementally: The more someone focuses on time, the more the gate opens, therefore allowing more pulses to enter and leading to an elongated estimation, the opposite taking place when one is not fully focused on time estimation. Conversely, RTP is an unconscious and post hoc process, taking place when individuals are requested to estimate a duration a posteriori. RTP is currently better accounted for by cognitive models based on episodic and working memory (e.g., Roseboom et al., 2019). Its most prominent model is the contextual change model (Block and Reed, 1978), based on the number of observable events (i.e., contextual changes) happening in a given interval. The higher the number of events or contextual changes occurring during a time interval, the longer it will be estimated.

Previous studies have proposed a large range of tasks measuring temporal abilities, which can be summarized as six main paradigms (Table 1) split into two categories according to the duration used (i.e., seconds or minutes). Similarities exist across tasks in accordance with

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[1] Although the studies included in the current systematic review measure time estimation rather than perception, the common nomenclature “time perception” is used for the sake of clarity.

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Table 1
Summary of the main time-related tasks available.

Task	Design	Target duration
Estimation task	Participants have to provide the accurate estimation of an experienced duration (e.g., "how long was this video?", "how long have you been doing this task?").	
Reproduction task	Participants have to first experience a duration (similarly to the estimation task), and then perform an action (e.g., pressing a button, performing a task) for the same duration.	Seconds to minutes
Production task	Participants are given a specific duration and have to perform an action (similar to the reproduction task) for this duration.	
Comparison task	Participants are presented with two stimuli and have to decide whether they lasted the same duration, or which stimulus had the longer duration.	
Generalization task	Participants have to first familiarize with a specific duration (i.e., during a training block). They are then presented with various durations and have to decide whether these durations are shorter, longer, or of identical length than the one presented initially.	Milliseconds to seconds
Bisection task	Participants have to first familiarize with two durations (called anchors) during a training block. They are then presented with random durations falling between these two anchors and have to decide to which anchor each duration is closer.	

the key processes at stake. For example, both estimation and comparison tasks highlight the experienced duration factor of time perception, whereas reproduction and production tasks measure the effectiveness of the reference system (i.e., the core notion of what a unit of time is – e.g., a second). However, the underlying mechanisms at stake in these tasks remain poorly understood, as multiple factors (e.g., exact duration, stimuli used) and, centrally, other cognitive abilities influence them. Droit-Volet et al. (2015a) proposed a comprehensive model of time perception for both adults and children that included multiple temporal measures (i.e., bisection, generalization, and reproduction tasks), using various duration units (0.4−0.8 s and 8−16 s) and cognitive tasks (e.g., Corsi Block-Tapping test, forward and backward digit span). These authors showed that although inhibition capacities predicted the bisection accuracy score and its variability, attentional resources predicted the accuracy of both the generalization and the reproduction tasks. Furthermore, inhibition capacities also predicted the variability of the generalization score for the long duration, whereas selective attention predicted this variability for shorter durations. Attentional, executive, and memory processes are thus crucial cognitive abilities for efficient time perception, as underlined in the most influential models (e.g., attentional gate model; Zakay and Block, 1995). This is particularly true for working memory, which plays a pivotal role in both PTP and RTP. Regarding PTP, the role of working memory has been supported by research showing that PTP performance is predicted by the visuospatial sketchpad component of working memory (Baudouin et al., 2006; Bi et al., 2013). Furthermore, the lower accuracy of older individuals in time perception tasks has been linked to impaired working memory (Baudouin et al., 2006). Regarding RTP, the contextual change model (and other recent models of RTP) postulates that the estimation of a given time interval is a direct function of the processed events taking place during this interval (Block and Reed, 1978; Roseboom et al., 2019). Having a limited ability to process an elevated number of events may thus result in time underestimation.

The brain correlates of time perception have also been largely documented through studies using functional magnetic resonance imaging and transcranial stimulation (i.e., both electrical and magnetic). Time perception may rely on either a supramodal timer located in specific brain areas or on modality-specific areas (e.g., auditory cortex for auditory stimuli; see Coull et al., 2011; Mioni et al., 2020 for systematic reviews). On the one hand, most of the literature supports that short durations rely on the neural firing of striatal neurons activated when they receive cortical input, which then involves the basal ganglia and frontal cortex (i.e., striatal-beat frequency models; Matell and Meck, 2004). On the other hand, the supramodal hypothesis better fits with the longest durations and postulates the existence of different brain areas that represent the different stages of the timing models of time perception (Mioni et al., 2020). Studies have shown that the involved areas are primarily the cerebellum, basal ganglia, supplementary motor area, and frontal/prefrontal cortex.

Time perception can be biased by numerous internal (e.g., emotional interference, Droit-Volet, 2013; or cognitive disabilities, Wittmann, 2009) or external (e.g., ongoing activities, Campbell and Bryant, 2007; drug consumption, Williamson et al., 2008) factors, but it is also more stably disrupted in several psychopathological disorders such as mood disorders (e.g., Kent et al., 2019; Yoo and Lee, 2015), schizophrenia (e.g., Gómez et al., 2014; Thoenes and Oberfeld, 2017), and substance use disorders (e.g., Williamson et al., 2008), leading to deleterious consequences. Time perception is susceptible to the effects of acute or chronic excessive alcohol consumption, but the available evidence has to date not been subjected to a systematic and critical review, thus hampering a comprehensive consideration of the associations between alcohol consumption and time perception.

The impact of alcohol on time perception has been explored in four subgroups of alcohol drinkers: (1) acute alcohol intoxication (i.e., an isolated episode of intense alcohol consumption), (2) binge/heavy drinking (i.e., a consumption pattern characterized by intense but episodic alcohol consumption episodes), (3) severe alcohol use disorder (SAUD; i.e., a pathological regular consumption of alcohol leading to negative consequences; American Psychiatric Association, 2013), and (4) Korsakoff syndrome (KS; i.e., a neurological syndrome frequently resulting from a thiamine deficiency associated with excessive and prolonged alcohol consumption; World Health Organization, 2018). A global overview of the field thus needs to include both acute intoxication and the various patterns of chronic alcohol use. Understanding the links between time perception disturbances and alcohol consumption is of high interest for several reasons. First, alcohol consumption influences the structure and functioning of the three above-mentioned structures known to act as supramodal timers, namely, the frontal cortex, cerebellum, and basal ganglia (for reviews, see Bjork and Gilman, 2014; Bühler and Mann, 2011; Lannoy et al., 2019; Zahr and Pfefferbaum, 2017), which reinforces the proposal that alcohol consumption might be related to time perception deficits. Second, excessive, acute, or chronic alcohol consumption is characterized by impairments in key cognitive abilities involved in time perception, such as attentional or executive functions (for reviews, see Arts et al., 2017; Carbia et al., 2018; Stavro et al., 2013; Zoethout et al., 2011), and notably leads to impaired working memory (e.g., Boissoneault et al., 2014; Carbia et al., 2017; Nowakowska-Domagała et al., 2017; Pitel et al., 2008), which was identified as the cornerstone cognitive process in time perception. Finally, impulsivity, a central construct in substance use and addictive disorders (e.g., Stephan et al., 2017), has been thoroughly associated with time perception (Paasche et al., 2018). Impulsive individuals tend to overestimate time, potentially due to an increased tempo of their pacemaker (i.e., leading to more pulses recorded within the same interval; Wittman et al., 2007). This proposal is further supported by studies showing that populations marked by heightened impulsivity (e.g., individuals with attention deficit/hyperactivity disorder, borderline personality disorder, or addictive disorder) tend to overestimate time duration (Stanford and Barratt, 1996). It has moreover been suggested (Paasche et al., 2018) that such time overestimation is directly related to impulsivity and to the development of substance use and addictive disorders, as this would increase the tendency to choose immediate instead of delayed gratifications. In other words, time overestimation would increase the perceived temporal distance to an expected reward (i.e., increased delay discounting), which would favor impulsivity and the seeking of immediate rewards (notably through alcohol consumption).

Neuropsychological and neuroscience data thus converge to suggest that excessive alcohol consumption affects the cognitive functions and brain areas involved in time perception. However, no systematic review is currently available to gather the sparse and limited results on this topic. The aim of this paper is therefore to systematically review and critically assess studies that have explored time perception in excessive alcohol consumption. Such work is needed to better account for the potential interaction between excessive alcohol consumption and compromised time perception, and it may ultimately result in theoretical knowledge (e.g., relevant for a process-based model of excessive alcohol consumption) or translate into specific clinical applications (e.g., incorporating time perception measures in the assessment of excessive alcohol consumption).

2. Methods

2.1. Research question, article identification, and selection procedure

We followed the Population, Intervention, Comparator, Outcome, Setting (PICOS) procedure for observational studies (Liberati et al., 2009) to identify the main characteristics of the retained studies (Table 2). Regarding Population, we included all studies that focused on excessive alcohol consumption (i.e., acute alcohol intoxication, binge/heavy drinking, SAUD, KS). Regarding the Intervention, the inclusion criteria varied with the population studied and the method used. For studies exploring alcohol intoxication, we included those in which alcohol was administered to a group of participants and reliably compared with a control group who was administered a placebo. For the studies exploring chronic alcohol use, there was no intervention per se, although they had to include a reliable comparison between a population with excessive alcohol consumption and a matched control group. Regarding the Comparator, we considered the studies that included an experimental design in which two reliable groups (e.g., alcohol consumption with placebo, SAUD with matched controls) were compared. Concerning the Outcome, we included studies that proposed a reliable estimation of a predetermined temporal interval. Therefore, studies that focused solely on a measure of time perspective (i.e., how individuals project themselves in the past, present, or future; Zimbardo and Boyd, 1999) or time experience (i.e., a self-reported assessment on how "fast" time passed without actual estimation) were not included. For Settings, studies were included if their design involved a comparison between groups or experimental conditions (i.e., in this case, alcohol exposure). Therefore, single case studies and papers without experimental data (e.g., reviews) were excluded. To reduce the risk of bias toward published studies in this review, we also included the papers that presented null findings.

The methodology used in this systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and the related 27-item checklist (Moher et al., 2009). Two authors (FN and PM) independently searched three databases (i.e., ScienceDirect, PubMed, and PsycINFO) for papers published before January 31, 2021 (without a lower limit for the publication year), by using keywords related to time perception (i.e., "time perception" OR "interval timing" OR "temporal cognition" OR "time estimation" OR "temporal estimation" OR "temporal perception" OR "duration estimation" OR "duration evaluation") and alcohol consumption (i.e., "intoxication" OR "binge drink*" OR "heavy drink*" OR "social drink*" OR "episodic drink*" OR "college drink*" OR "alcohol*" OR "Korsakoff"). The terms included in the different databases did not differ.

We included only the papers that fulfilled the following inclusion criteria: (1) inclusion of a (quasi-) experimental setting (i.e., exclusion of online survey, reviews, and meta-analyses), (2) published in English or French (i.e., languages spoken by the authors), (3) peer-reviewed (i.e., excluding gray literature such as conference proceedings, unpublished PhD theses), and (4) inclusion of a human sample. The initial search led to 128 papers (20 in ScienceDirect, 55 in PubMed, and 53 in PsycINFO).

We selected the papers through a three-step process (Fig. 1). First, the duplicates between the different databases were removed, leading to a total of 86 papers. Second, the title and abstract of the remaining papers were screened, leading to the rejection of 53 papers not fitting the PICOS inclusion criteria: 13 focused on a topic unrelated to alcohol (e.g., cancer treatment, engineering), six did not present peer-reviewed empirical data (e.g., reviews, conference proceedings), 14 did not include a population presenting excessive alcohol consumption (i.e., mainly studies on populations with schizophrenia), 19 did not offer a reliable measure of time perception in humans (e.g., studies on time perspective rather than time perception, animal studies), and one was not published in English/French. The full texts of the 33 remaining papers were screened, which led to the exclusion of two papers that did not measure time perception.

Our systematic review thus included 31 papers belonging to one of the following categories: (i) alcohol intoxication (17 studies), (ii) binge/heavy drinking (four studies); (iii) SAUD (seven studies), and (iv) KS (three studies). The two independent literature searches performed by both authors (FN and PM) ended in the selection of the same 31 articles, thus reinforcing the reliability of the literature search conducted.

2.2. Quality assessment

We evaluated each paper with an adapted version of the "quality assessment tool for observational cohort and cross-sectional studies" (National Heart, Lung, Blood Institute, 2014) adapted by Maurage et al. (2020). The present version of the scale includes 20 items with dichotomic scoring (i.e., yes/no) evaluating the methodological strength of each included study. These 20 items can therefore result in a total score of 20, which is then divided by the total number of items (i.e., 20), leading to a percentage that serves as the quality rating (i.e., poor score below 50 %, fair score between 50 and 69 %, good score between 70 and 79 %, and strong above 80 %, Black et al., 2017). To increase the reliability of the procedure adopted, two independent judges (FN and PM) performed the quality assessment. Total agreement score between them was 93.9 % (601/640 evaluation criteria), which can be considered very high. Assessment discrepancies were then discussed between the two judges to obtain a consensus. A synthesis of the quality assessment is presented in Table 3.

2.3. Data extraction and synthesis

We provide the critical information that pertains to the PICOS procedure for each paper in Table 2. These critical elements fall into four categories: (1) population (sample size, age, gender ratio, exclusion criteria, and control group), (2) exposures (diagnosis/characteristics, alcohol measure, and comorbidities), (3) design (non-temporal and temporal measures included), and (4) outcomes (main results, reported limitations, and key conclusions). Furthermore, the procedure followed by each study regarding alcohol administration is reported in Table 4 under the following categories: (1) parameters for alcohol dose computation, (2) alcohol dose administered, (3) alcohol level measure, (4) alcohol level measurement time, and (5) level of blood alcohol concentration measured (i.e., mean, SD, and range).

3. Results

3.1. Quality check

The quality score of the papers included in this systematic review varied between 15 % and 70 %. Most of the papers achieved a fair quality rating (N = 16), followed by studies achieving a poor score

Table 2
Description and main results of the reviewed papers.

Authors (year)	Population					Exposures			Design			Outcomes		
	Sample (N)	Age [M (SD)]	Gender ratio (% males)	Exclusion criteria	Control group	Diagnosis / Characteristics	Alcohol measure	Comorbidities	Non-temporal processes measured	Time perception measure (duration)	Time range measured	Main results	Reported limitations	Key conclusions
Bauer and Ceballos (2014)	97	Age range: 18-20	0%	Past-year pregnancy Psychosis Major medical disorders affecting general health or EEG response	42 frequent bingers 55 non-frequent bingers	Frequent bingers = Binging monthly or weekly Non-frequent bingers = Never binging or less than monthly	Alcohol Use Disorders Identification Test	Drug use (Drug Abuse Screening Test)	EEG activity during production task BIS-11 Toronto Alexithymia Scale Sensation Seeking Scale DNA analysis on saliva sample	Production task (50 x 1.5s)	Seconds	Slow cortical potential in right parietal cortex while performing the production task in frequent bingers, indicating an unimpaired timing ability	Only a pinpoint exploration, unsure of implications over time Participants used only the left index finger to answer (implication of right hemisphere)	The slow cortical potential tends to support a preserved time perception among frequent binge drinkers
Bech et al. (1973)	8	Age range: 21-29	100%	Alcohol or marijuana abuse	Marijuana Placebo Alcohol	None (within-subjects design)	BAC	Marijuana and alcohol use	Test battery from Rafaelsen et al. (1973)	Estimation task and time experience (3min at 40km/h, 3min at 70km/h) in a driving simulator	Minutes	Participants time experience increased more than the actual estimation after consuming alcohol, but only at 70km/h	Participants may not have known in which condition they were Small sample size	Alcohol seems to influence the time experience of participants more than their temporal estimation abilities
Caneto et al. (2018)	51	22.98 (3.36)	NR	Drinking less than 56 g (women) or 70 g (men) of alcohol over the last month Psychiatric, neurological, or cardiac condition Alcohol-related disorder Psychopharmacological medication Serious medical condition	23 FH+ 28 FH- Alcohol vs. placebo	FH+ = Biological relative with current or past alcohol-related disorder FH- = No such history	BAC	NR	Balloon Analogue Risk-taking Task Heart rate Brief Biphasic Alcohol Effects Scale Impulsive Behavior Scale (UPPS-P)	Production task (5 x 60s)	Seconds	Family history did not impact the BrAC, nor the production of the participants. Furthermore, alcohol, or its interaction with family history, did not impact the participants production.	NR	Potential influence of FH+ on motor impulsivity but not on time-related impulsivity
Cangemi et al. (2010)	120	Abstinent AD: 46.28 (10.21) HC: 46.45 (10.19)	47.50%	Borderline disorder Cognitive deficits	60 Abstinent AD 60 HC	Abstinent AD = No alcohol consumption over the past 20 days (on	Inpatients Interview for HC	Other substances (NR)	BIS-11 Beck Depression	Production task (NR) [a]	NR[1]	No group difference in the production score	The production task used in this experiment does not prevent subvocal	Alcohol does not affect time perception even though it affects the participants'

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Table 2 (*continued*)

Authors (year)	Population					Exposures			Design			Outcomes		
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				Alcohol abuse (for HC)		average), hospitalized for their addiction. Poly-abusing was controlled (exact nature NR)			inventory 2nd version Beck Anxiety Inventory TCIP				counting by participants, explaining the lack of results	delay discounting
Cappon and Tyndel (1967)	30	NR	NR	NR	15 AD 15 HC	AD = hospitalized for their addiction (randomly selected) HC = matched to AD in term of age and education	Drinking questionnaire Cornell Medical Index	NR	Future orientation questionnaire General temporal orientation questionnaire	Estimation task (1.5s, 17.5s, 15min, and 35min) Production and reproduction tasks (1.5 and 17.5s)	Seconds and minutes	No group difference on temporal tasks	SAUD participants were not split between euphoric and depressed No exploration of the SAUD participants differences between the peak of their disorder and after recovery	SAUD does not affect temporal skills
Duka et al. (1998)	25	23.9 (6.4)	52%	Drug abuse Abnormal weight	Alcohol Placebo	NA	Alcohol consumption BrAC	Nicotine dependence	Discrimination task (alcohol vs. placebo) Subjective effect of alcohol (visual analog task) Heart rate, salivation, galvanic skin response Logical reasoning task Visual vigilance task	Production task (1 x 27s)	Seconds	No direct effect of alcohol consumption on any of the temporal tasks Positive correlation between ethanol-appropriate responding (i.e., subjective effect of alcohol on the participants) with time estimation	NR	Alcohol does not seem to be related to time perception at such a dose, although the perceived intoxication is related to it
El Haj et al. (2017)	38	HC: 55.40 (5.19) KS: 56.78 (5.65)	44.73%	Other neurological or psychiatric disorders (KS)	20 HC 18 KS	KS: Korsakoff syndrome participants with anterograde amnesia. Confirmed through a DSM-IV-based psychiatric interview HC: Matched to KS on	NA	None	Mini-Mental State Examination Grober and Buschke task	Estimation task (15, 30, 45, and 60s) – RTP while performing easy tasks (reading aloud, filling connected squares, or word categorization), but done in two sessions	Seconds	Underestimation of time among KS participants. Both KS and HC participants underestimated time compared with real duration Correlations between episodic	While first timing is definitively RTP, as the participants would not know about time perception, the timings that followed may switch to PTP because of their consciousness of	Decline in episodic memory could have complicated the retrieval of information necessary to produce a retrospective time estimation in KS

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Table 2 (*continued*)

Authors (year)	Population					Exposures			Design			Outcomes		
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Plus-minus task Stroop task				Being under treatment or using psychotropic drugs (KS) Previous substance addiction (HC)		education level and gender distribution			Forward and backward span tests Any neurological or psychiatric history (HC)	separated by a week		memory/ executive functions (only inhibition through a multiple linear regression) and absolute timing error in HC and KS	time rising. This effect may have been reduced by the week separation between the two testing sessions	
Ehrensing et al. (1970)	30	Age range: 18-38	53%	Bad physical condition	15 alcohol 15 placebo	Participants abstained from drinking alcohol the day before the testing and from smoking and eating the day of the test	BAC	Smoking	NA	Categorization task (0.15, 0.45, 0.75, 1.05, 1.35, 1.65, 1.95s x 10). Participants had to classify these from very much less than 1s (1) to very much more than 1s (9). This task was performed with visual and auditory stimuli	Milliseconds, seconds	Intravenous alcohol administration influenced the estimation of duration more than the saline solution (i.e., time underestimation) for durations of 1.05s and above. Furthermore, this effect was greater for durations of 1.35s and above	NA	Alcohol would slow down the timer's clock, therefore reducing the amount of pulses produced over a specific duration, resulting in an underestimation of time
Goldfarb et al. (1974)	71	"Mid-thirties to forties"	100%	NR	30 AD 24 general psychiatric patients 17 HC	AD: NR General psychiatric inpatients: NR Healthy control: general medical inpatients and volunteers	NA	NR	Manual dexterity task Abstract reasoning task	Estimation task of empty intervals (7, 21, 42, 84, and 163s) Estimation task of filled interval (i.e., time taken to read a 14-page text) Bisection task (0.5 and 1s)	Milliseconds, seconds, minutes	Participants overestimated the duration of the empty intervals, no results being significant for the filled interval and the bisection task	NR	SAUD participants show specific impairment in temporal abilities, which may result from specific depleted cognitive skills
Goldstone et al. (1977)	70	AUD: 47	AUD: 58.54%	Other addictions	Social drinkers: 29	AD: Abstinent for two weeks, hospitalized in	NR	Other addictions	WAIS	[2]task[b]	Milliseconds, seconds	In a first experiment including nine	No control of drinking history, duration of	AD participants, if impaired cognitively, will

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Table 2 (*continued*)

Authors (year)	Population					Exposures			Design			Outcomes		
	Sample (N)	Age [M (SD)]	Gender ratio (% males)	Exclusion criteria	Control group	Diagnosis / Characteristics	Alcohol measure	Comorbidities	Non-temporal processes measured	Time perception measure (duration)	Time range measured	Main results	Reported limitations	Key conclusions
						an alcoholism treatment program						participants of each group, the impaired participants performed worse than the other two groups in the five-duration version of both tasks	abstinence, and age	perform worse in a temporal task than both unimpaired AD and social drinkers
		HC (XP1): 43 HC (XP2): 26	HC: NR	Medication	Impaired AD: 25	Impairment: based on a four-point system resulting from the WAIS and the Bender Gestalt Test			Bender Gestalt Test	[2]task[c]		In a second experiment comparing 20 impaired AD to 20 controls, the impaired AD performed worse on all the temporal tasks, regardless of the conditions		
					Psychological or neurological conditions	Unimpaired AD: 16			Social drinkers: NR					
SAUD (for HC)														
		AD: 47.2 (8.3)		Alcohol abuse (except AD)	48 AD	AD: Diagnosed as alcohol dependent based on the DSM-IV-TR (American Psychiatric Association, 2000); abstinent for 3 to 12 months	DSM-IV-TR	Attention Deficit Hyperactivity Disorder	Stop signal task				Study included mostly males	
Goudriaan et al. (2006)	193		74.61%			PG: Diagnosed as a pathological gambler based on the DSM-IV-TR and the Diagnostic Interview Schedule (i.e., >5 symptoms; Robins et al., 1998)				Estimation and reproduction tasks (2, 4, 8, 12, 12, and 20s)	Seconds	AD group had higher score discrepancy than HC on the estimation task, especially for longer durations		Deficit in terms of inhibition, cognitive flexibility, motor planning, and time perception among the AD group
		HC: 35.6 (11.4)		Other substance abuse	50 HC		Urine screen (for recent consumption)	Nicotine dependence	Circle Tracing Task				Not enough comorbidities detected to analyze them	
		PG: 37.3 (9.5)		Other psychiatric disorder	49 PG	TS: Diagnosed with Tourette syndrome by a	South Oaks Gambling Screen	Trait anxiety	Stroop Task				Bias in TS, HC, and AD selection	

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Table 2 (*continued*)

Authors (year)	Population					Exposures			Design			Outcomes		
	Sample (N)	Age [M (SD)]	Gender ratio (% males)	Exclusion criteria	Control group	Diagnosis / Characteristics	Alcohol measure	Comorbidities	Non-temporal processes measured	Time perception measure (duration)	Time range measured	Main results	Reported limitations	Key conclusions
		TS: 36.8 (12.1)		Being over 60 or under 18 Severe cognitive impairment (AD) Following a treatment for mental disorder Condition affecting motor performance or cognition Use of psychotropic medication Positive urine screen for alcohol, marijuana, or benzodiazepines	46 TS	psychiatrist or neurologist AD, HC, and TS matched to PG first recruited		Depression Antisocial personality disorder	Wisconsin Card Sorting Test Controlled Oral Word Association Test Self-Ordered Pointing Task, Abstract Designs Digit span test Tower of London Benton Visual Retention Test WAIS block design and vocabulary Sorting Task				(i.e., to match PG) Cross-sectional approach (i.e., no causality)	
Heishman et al. (1997)	5	22 (3.8)	100%	History of or current treatment for substance or alcohol abuse	Alcohol Marijuana Placebo	Participants drank 4 to 15 alcoholic drinks per week (8.2 on average) and smoked between one and six marijuana cigarettes per week (4.4 on average)	Frequency of drinking BrAC	NR	Reproduction task (5, 20, and Expired air carbon monoxide, Heart rate, and plasma concentration of THC Subjective analog scale on the effect of drugs and alcohol RT task Digit Symbol Substitution Test Number recognition Word recall	Seconds	No effect of alcohol on the temporal task	NR	This study shows that alcohol does not affect time perception	80s) – repeated measures over the span of seven sessions
Jones and Stone (1970)	10	25	100%	" Obvious psychiatric disorder" “Extreme eccentricity”	Alcohol Marijuana Placebo	Heavy marijuana users (within-subjects design)	BrAC	NR	Digit Symbol Substitution Test Rod and Frame Subjective effect of drugs Pulse rate	Estimation and production tasks (15s)	Seconds	After consuming alcohol, participants underestimated time in the estimation task. No effect being	NR	Alcohol would only affect specific underlying mechanisms of time perception

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Table 2 (*continued*)

Authors (year)	Population					Exposures			Design			Outcomes		
	Sample (N)	Age [M (SD)]	Gender ratio (% males)	Exclusion criteria	Control group	Diagnosis / Characteristics	Alcohol measure	Comorbidities	Non-temporal processes measured	Time perception measure (duration)	Time range measured	Main results	Reported limitations	Key conclusions
									EEG			observed for the production task		
Klahr et al. (2011)	8	Age range: 21-32	100%	Psychiatric medication History of alcoholism Neurological disorders	Alcohol Placebo	Right-handed	BAC	NR	fMRI Counting task	Bisection task (4 and 6s)	Seconds	No effect of alcohol on the counting and timing tasks When administered alcohol, the RT for the timing task was longer than for the counting task Increased BOLD signal in the supplementary motor area and the left ventrolateral nucleus of the thalamus during the timing task compared with that in the counting task when administered alcohol	Low number of participants Complexity of their measurement Forced to ask the participants to exit the scanner to consume drinks Pre- and post-drink conditions not counterbalanced (due to technical impossibility) Use of a commercial breathalyzer	The amygdala would be more activated in the counting task, as the timing task was more cognitively demanding. Similar discussion for the right superior parietal lobe required in important visual processing
Lapp et al. (1994)	42	26.57 (4.04)	100%	Medical, legal, or personal reasons not to consume alcohol Score higher than 0 on the Short Michigan Alcohol Screening Test	Alcohol Placebo	Participants were drinking moderately (i.e., 15.89 ± 8.83 drinks per week)	Short Michigan Alcohol Screening Test BAC	NR	RT task Subjective analog scale on the effect of alcohol	Production task (1, 5, 10, and 30s); pre-drink, 35min after drink, 95min after drink Subjective passage of time	Seconds	Higher presence of extreme score for high dose of alcohol 35min post-consumption Participants overestimated time 35min after alcohol consumption for low dose of alcohol and at 95min for the high dose The subjective flow of time positively mediated the link between both the	NR	Participants seemed to compensate for the alcohol they thought they were administered in their time perception The actual estimation of time could only be related to a brief duration, as it would be a very immediate experience

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Table 2 (*continued*)

Authors (year)	Population					Exposures			Design			Outcomes		
	Sample (N)	Age [M (SD)]	Gender ratio (% males)	Exclusion criteria	Control group	Diagnosis / Characteristics	Alcohol measure	Comorbidities	Non-temporal processes measured	Time perception measure (duration)	Time range measured	Main results	Reported limitations	Key conclusions
												received and expected dose of alcohol received, and the actual time production		
Laties and Weiss (1962)	XP1: 14 XP2: 13 XP3: 36 XP4: 4	NR	XP1: 78.57% XP2: 76.92% XP3: NR XP4: 75%	NR	XP1,2,4: NA XP3: 12 alcohol, 12 placebo, 12 prochlorperazine	XP 1-3: Participants were not allowed to eat up to two hours before the experiment XP4: Participants were instructed not to eat since the evening before the experiment (morning testing)	NR	NR	XP2: Arithmetic task XP3: Monitoring task	XP1-4: production task (24s – as many times as possible over 5min)	Seconds	XP1-3: No effect of alcohol on time perception XP4: Three participants got sick from the increased alcohol dose; no effect of alcohol consumption was observed on time perception	NR	Alcohol intoxication does not impact the ability to produce regular interval
Mimura et al. (2000)	32	FP: 53.6 (NR) KS: 53.2 (NR) AD and HC: Matched to FP and KS (NR)	100%	Depression, psychosis, dementia	8 AD 8 FP 8 HC	FP and KS: Outpatients and inpatients referred by their current (neuro) psychologist FP: Frontal lesion resulting from different causes (e.g., head injury, tumor) KS: Stable condition with severe anterograde amnesia and a different degree of	Diagnosis for AD and KS NR for HC and FP	NR	WAIS-R Wisconsin Card Sorting Test Wechsler Memory Scale – Revised	Estimation task in PTP (4 x 10, 30, 60, 90, and 120s) Production task (4 x 10, 30, 60, 90, and 120s) “tempo” task (i.e., counting every 1s for 10, 30, 60, 90, and 120s)	Seconds, minutes	KS had a lower estimation accuracy (stronger effect for longer duration) compared to AD; results replicated for the two longest durations in the production task For KS participants, overestimation of short durations on the estimation and production tasks were related to the scores on the Wisconsin Card Sorting Test KS underestimated the long duration compared with AD	NR	The overestimation of short duration in KS and FP participants would result from working memory depletion KS participants impaired in time perception above 30s despite their unaffected tempo, indicating an effect of episodic memory

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Table 2 (*continued*)

Authors (year)	Population					Exposures			Design			Outcomes		
	Sample (N)	Age [M (SD)]	Gender ratio (% males)	Exclusion criteria	Control group	Diagnosis / Characteristics	Alcohol measure	Comorbidities	Non-temporal processes measured	Time perception measure (duration)	Time range measured	Main results	Reported limitations	Key conclusions
					8 KS	retrograde amnesia AD: Matched in age and education to KS HC: Matched in age and education to FP								
		Female: 22.74 (3.96)		Initial BrAC higher than 0	Placebo		BrAC			Generalization task (400 and 800ms)		In the time experience task, participants reported time to be going faster when administered a high dose of alcohol and to be going slower when administered a low dose		Alcohol does not seem to affect RTP, although participants reported past time passing more quickly
Ogden et al. (2011)	58	Male: 22.28 (3.25)	51.72%	Drank at least 10 units in the previous week	Low alcohol dose	NA	Substance Use History Questionnaire	NR	Word categorization (while performing RTP)	Estimation task in RTP (255s)	Milliseconds, seconds	In the prospective estimation task, participants overestimated time when administered a high dose of alcohol. When administered a low dose, they also overestimated one of the durations (1183ms) compared to the placebo. There was no effect on the retrospective timing	Only one task used for the RTP	A high dose of alcohol disrupted PTP estimation but “improved” generalization abilities. This could indicate a more conservative decision strategy, especially since participants’ answers were less variable in the estimation task when administered a high dose
				Weighing at least 50 kg (female) or 60 kg (male)	High alcohol dose		Addiction Research Centre Inventory			Time experience task Estimation task in PTP (77, 358, 582, 767, 958, and 1183ms)		The performances were increased in the high alcohol dose for the short generalization task		The different effects of alcohol between durations could be explained by the different processes involved in durations below and above 1s (i.

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Table 2 (*continued*)

Authors (year)	Population					Exposures			Design			Outcomes		
	Sample (N)	Age [M (SD)]	Gender ratio (% males)	Exclusion criteria	Control group	Diagnosis / Characteristics	Alcohol measure	Comorbidities	Non-temporal processes measured	Time perception measure (duration)	Time range measured	Main results	Reported limitations	Key conclusions
														e., sensory timing vs. cognitive timing)
Parsons et al. (1972)	96	AD: 47.00 HC: 47.30	AD: 100% HC: NR	History of psychosis Brain damage history SAUD (HC)	AD: 48 HC: 48	AD: NR HC: Matched in term of age with AD. However, education was significantly different between the two groups	NR	NR	Knob-turning test Hand dynamometer Hand control test Slow drawing test	Estimation task of filled interval (tasks duration) Estimation task of empty interval (1min – at the beginning and end of the experiment)	Minutes	AD participants overestimated the one-minute empty interval, but only at the end of the experiment. All other temporal tasks were not significant. Their estimation was technically closer to the actual duration, although the HC estimation was congruent to previous research	NR	The study partially shows that SAUD participants would present an impaired time perception
Rammsayer (1995)	60	24.4 (3.6)	100%	Tobacco use Chronic drug intake Allergy Current psychiatric treatment or history Endocrine or cardiovascular disease	15 extroverts - alcohol 15 extroverts - placebo 15 introverts - alcohol 15 introverts - placebo	Extroverts: High extraversion score demonstrated by a score above 14 on the Extraversion scale (Eysenck Personality Questionnaire; M = 17.4 - Eysenck & Eysenck, 1975) Introverts: Low extraversion score demonstrated by a score below 12 on the Extraversion scale (M = 9.7) Both groups were matched in terms of anxiety, age, and drinking habits	Questionnaire on Alcohol Consumption Saliva screening	NR	Choice Reaction Time Critical Flicker Fusion Self-report on the alcohol effect	Comparison task (98ms adapting based on accuracy) Production task (30 × 1s)	Milliseconds, seconds	Alcohol impaired the ability of the participants to discriminate the short durations in the comparison task, without any interaction with extraversion Alcohol led introverts to overestimate time in the production task compared with both introverts in the placebo condition and extroverts in the alcohol condition	NR	Alcohol consumption would increase the pacemaker rate (i.e., timer model of time perception). Therefore, it would lead to overestimation in both populations The different effects of alcohol between extroverts and introverts indicates that the underlying mechanisms of time perception may vary depending on personality factors

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Table 2 (*continued*)

Authors (year)	Population					Exposures			Design			Outcomes		
	Sample (N)	Age [M (SD)]	Gender ratio (% males)	Exclusion criteria	Control group	Diagnosis / Characteristics	Alcohol measure	Comorbidities	Non-temporal processes measured	Time perception measure (duration)	Time range measured	Main results	Reported limitations	Key conclusions
				Acute infection or gastrointestinal disease More than 45 g/week of alcohol intake										
Rose & Grunsell (2008)	20	21.5 (0.4)	50%	<10 units/week Drug dependence Psychiatric disorder Any current medication incompatible with alcohol consumption	10 bingers 10 non-bingers Alcohol vs. placebo	Bingers: Score of at least 24 on the Alcohol Use Questionnaire (Mehrabian & Russell, 1978) Non-bingers: Maximum score 16 on the Alcohol Use Questionnaire	Alcohol Use Questionnaire Alcohol Urge Questionnaire	NR	Nuffield Medical Questionnaire BIS-11 Temptation and Restraint Inventory Alcohol Visual Analogue Scale TCIP	Production task (5 × 60s)	Seconds	No effect on time perception of binging, alcohol consumption, or their interaction Impulsive participants underestimated time compared with non-impulsive in the placebo group, but the opposite result was shown in the alcohol group	Impulsivity analysis was based on median split, rather than recruiting low and high impulsivity participants and an a priori cut-off score Small sample size Non-ecologically valid rewards in the TCIP (i.e., points) No control of alcohol expectation	Alcohol may disinhibit only highly impulsive individuals, as reflected by the more accurate time perception following alcohol consumption by impulsive participants
Rutschmann and Rubinstein (1966)	5	NR	100%	NR	NA	^2^)[d], (2) the durations used (i.e., 1s or 2s), (3) the drug administered (i.e., d-amphetamine sulfate, secobarbital, alcohol, and placebo), and (4) the dose (i.e., low or high). Participants were not allowed to eat up to four hours before the experiment	NR	NR	NA	Production task (1s for 90s or 10s for 15min)	Seconds	The low dose of alcohol decreased the temporal production variability of 1s in the knowledge condition while the high dose increased this variability regardless of the condition and duration	NR	Alcohol intoxication produces variable effect depending on the dose, the duration, and the knowledge of accuracy
Sanchez-Roige et al. (2014)	44	21.18 (1.89)	50%	>0 on baseline breathalyzer	22 bingers	Bingers: Score of at least 32 on the Alcohol Use Questionnaire (Mehrabian & Russell, 1978)	BrAC	NR	BIS-11	Production task (1 x 27s)	Seconds	Bingers selected less delayed options in the TCIP than did non-bingers	No information on drinking pattern	Binge drinking is not related to time perception deficits despite the differences on the TCIP

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Table 2 (*continued*)

Authors (year)	Population					Exposures			Design			Outcomes		
	Sample (N)	Age [M (SD)]	Gender ratio (% males)	Exclusion criteria	Control group	Diagnosis / Characteristics	Alcohol measure	Comorbidities	Non-temporal processes measured	Time perception measure (duration)	Time range measured	Main results	Reported limitations	Key conclusions
				Mental/neurological illness Alcohol/substance abuse Medication BrAC score above 1mg/dl	22 non-bingers	Non-bingers: Maximum score of 16 on the Alcohol Use Questionnaire	Alcohol Use Questionnaire Alcohol Use Disorders Identification Test		National Adult Reading Task Sx-5CSRTT Stop signal task Delay Discounting Questionnaire TCIP			No group difference on the production task	No correction applied on correlations Small sample size No causality assessment	
				Alcohol/substance abuse	24 FH+	FH+: Participants reporting one or more family history of alcohol abuse on the Family Tree Questionnaire	BAC	Tobacco use	BIS-11				FH was self-reported, allowing retrospective biases	
Sanchez-Roige et al. (2016)	64	21.98 (3.22)	46.88%	Heavy smokers (>10 cigarettes per day)	40 FH-	FH-: No such family history	Alcohol Use Questionnaire	Drug use	Drug Use Questionnaire Beck Depression inventory 2nd version	Production task (1 x 27s)	Seconds	No significant effect on time perception	Mother history of SAUD was not excluded, allowing potential fetal alcohol exposure	A family history of SAUD or its interaction with alcohol consumption does not affect time perception
					Alcohol vs. placebo			Marijuana use	Rey Auditory Verbal Learning Test Alcohol Visual Analogue Scale Sx-5CSRTT Stop signal task Delay Discounting Questionnaire TCIP				Higher BIS scores in the placebo group	
Shaw and Aggleton (1994)	30	AD: 50.6 (43-68)	90%	NR	9 AD	AD: Alcohol dependent	NR	NR	National Adult Reading Test	Filled (i.e., reading a text for the whole duration) and empty intervals estimation task (2 × 3, 6, 12, 24, 48, and 96s)	Seconds, minutes	KS participants made more errors than AD participants	NR	Although KS participants exhibited impaired time perception throughout the tasks and durations, the EA group did not
		EA: 41 (22-62)			3 EA	EA: Amnesiacs with symptoms			Wisconsin Card Sorting Test			KS participants over- and		KS impairment seems related to

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Table 2 (*continued*)

Authors (year)	Population					Exposures			Design			Outcomes		
	Sample (N)	Age [M (SD)]	Gender ratio (% males)	Exclusion criteria	Control group	Diagnosis / Characteristics	Alcohol measure	Comorbidities	Non-temporal processes measured	Time perception measure (duration)	Time range measured	Main results	Reported limitations	Key conclusions
						resulting from encephalitis				Reproduction task (same durations)		underestimated short durations (depending on trial/duration) but only underestimated longer durations (especially in the empty interval and RT). KS participants also underestimated time in the fixed interval task		their impaired frontal functions
		HC: 46.6 (20-59)			11 HC	KS: Korsakoff syndrome patients			WAIS-R	Automated fixed		KS participants' error correlated with the cognitive estimations error, which was partially reproduced in AD. On the other hand, the working memory score of KS correlated negatively with the error, whereas it correlated positively for the AD		Memory functions are not associated with prospective timing
									Verbal fluency					KS group did not show a similar trend of time perception as the HM patient did, which can be due to the way analyses were run (i.e., average estimation vs. error rate)
		KS: 57.7 (50-64)			7 KS				Design fluency	[2]nterval procedure (15 and 30s [e]		Negative correlation between memory in KS and their time perception performance		
									Picture arrangement Wechsler Memory Scale Warrington Word and Face Recognition Test					

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Table 2 (*continued*)

Authors (year)	Population					Exposures			Design			Outcomes		
	Sample (N)	Age [M (SD)]	Gender ratio (% males)	Exclusion criteria	Control group	Diagnosis / Characteristics	Alcohol measure	Comorbidities	Non-temporal processes measured	Time perception measure (duration)	Time range measured	Main results	Reported limitations	Key conclusions
Stam et al. (2020)	85	20.66 (4.32)	28.2%	NR	59 Light drinkers 26 Heavy drinkers	Light drinkers: Participants classified in the “none” or “light” drinker categories according to the Quantity-Frequency-Variability index (Lemmens et al., 1992) Heavy drinkers: Participants classified in the “medium” or “excessive” drinker categories according to the Quantity-Frequency-Variability index	Quantity-Frequency-Variability index	Tobacco use	Delay Discounting Questionnaire Eysenck I7 Behavioral inhibition/ activation system scale	Reproduction task (30 x 3, 6, & 9s)	Seconds	The reproduction task autocorrelations (i.e., correlations between trials) were positively associated with the Quantity-Frequency-Variability index score, indicating a difficulty for heavy drinkers to adapt their estimations based on previous ones	Use of a convenience sample of undergraduate students The participants’ estimation of time may not be stable over time	Heavy drinkers are less efficient to correct their own temporal estimation over repeated measurement
Stoltenberg et al. (2011)	439	22.49 (6.12)	35.30%	Non-Caucasian	NA	Participants were split based on the Michigan Alcohol Screening Test (Score higher than 5 being considered problematic; Selzer, 1971)	Michigan Alcohol Screening Test	Tobacco use Drug use	BIS-11 Boredom Proneness Scale Drug Abuse Screening Test Blood sampling (DNA)	Production task (5 × 60s)	Seconds	No association between the Michigan Alcohol Screening Test score and the production task	Missing facets of impulsivity (e.g., delay discounting) Missing alcohol consumption variables (e.g., age of onset) Small sample size	SAUD, as measured by the Michigan Alcohol Screening Test, is not associated with time perception
Terry et al. (2009)	36	24.3 (0.9)	22.22%	Medication Smoking more than 10 cigarettes per day	Alcohol vs. placebo Caffeine vs. placebo	NA	BrAC	Cigarettes Caffeine	Tapping and grip force RT and semantic verification task	Generalization task (300 or 500ms adapting based on accuracy)	Milliseconds	Participants’ tapping rhythm was more variable following consumption of alcohol Low dose of alcohol led to a lower discrimination threshold in the generalization	NR	Alcohol affected the timing abilities in the tapping task without impacting its motor aspect, indicating a potential effect of alcohol on the timer. However, a low dose of alcohol

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Table 2 (*continued*)

Authors (year)	Population					Exposures			Design			Outcomes		
	Sample (N)	Age [M (SD)]	Gender ratio (% males)	Exclusion criteria	Control group	Diagnosis / Characteristics	Alcohol measure	Comorbidities	Non-temporal processes measured	Time perception measure (duration)	Time range measured	Main results	Reported limitations	Key conclusions
				Drinking less than 125 mg caffeine daily (caffeine condition) Drinking less than 5 or more than 35 units of alcohol per month								task, meaning that their performance increased after consuming a low dose of alcohol (no effect of the high dose)		improved the participants time perception. This indicates that although motor timing may be impaired, longer interval may not, implying different underlying mechanisms
Tinklenberg et al. (1972)	15	"In their twenties"	100%	Consuming marijuana maximum twice a week	Marijuana Alcohol Placebo	No use of marijuana during the whole testing period and no alcohol up to 24h before each test day. Within design (participants included in all the conditions)	BAC	NR	Goal-Directed Serial Alternation Running Memory Span EEG and EOG	Production task (i.e., stating when 30, 60, and 120s had elapsed within a same 120s segment – performed twice)	Seconds	No effect of alcohol on time perception	NR	Alcohol intoxication does not affect temporal abilities
Tinklenberg et al. (1976)	12	23.8	100%	Consuming marijuana maximum twice a week	Marijuana Alcohol Placebo	No use of marijuana or other psychoactive drugs during the whole testing period and no alcohol up to 48h before each test day. Within design (participants included in all the conditions)	NR	NR	Heart rate Intoxication subjective measure	Production task (i.e., stating when 30, 60, and 120s had elapsed within a same 120s segment – performed twice)	Seconds	The alcohol administration led to an increase of the overall production of the participants compared to the placebo condition	NR	Alcohol intoxication leads to time underestimation
Vinader-Caerols and Monleón (2014)	46	Female: 19.5 (0.48) Male: 19.36 (0.21)	47.85%	Medication Mental disorder history	23 Abstinent (placebo) 23 Social drinkers (alcohol)	Abstinent: Abstinent participants (i.e., not consuming alcohol) Social drinkers who consumed at least 3 drink units for	Alcohol Use Disorders Identification Test BrAC	NR	Heart rate, blood pressure State-Trait Anxiety Inventory	Production task (10 × 10s)	Seconds	There was no effect of alcohol on the participants' time perception	NR	Alcohol does not affect time perception

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Table 2 (*continued*)

Authors (year)	Population					Exposures			Design			Outcomes		
	Sample (N)	Age [M (SD)]	Gender ratio (% males)	Exclusion criteria	Control group	Diagnosis / Characteristics	Alcohol measure	Comorbidities	Non-temporal processes measured	Time perception measure (duration)	Time range measured	Main results	Reported limitations	Key conclusions
						women and 4 for men over a short period in the last year								
				Irregular sleep pattern					Stroop task					
				History of substance abuse (including caffeine and tobacco)		Abstinent were included in the placebo group and Social drinkers in the alcohol group								
				Being younger than 18 years					Purdue Pegboard Test					
				body mass index not within normal range (18 – 28)										

Note. AD = alcohol dependent; SAUD = severe alcohol use disorder; BAC = blood alcohol concentration; BIS-11 = Barratt Impulsivity Scale, Version 11; BrAC = breath alcohol concentration; DSM-IV = *Diagnostic and Statistical Manual of Mental Disorders,* 4th ed.; DSM-IV-TR = *Diagnostic and Statistical Manual of Mental Disorders,* 4th ed., text revision; HC = healthy control; KS = Korsakoff syndrome; NA = non-applicable; NR = non-reported; PTP = prospective time perception; RTP = retrospective time perception; TCIP = Two Choice Impulsivity Paradigm; THC = tetrahydrocannabinol; TS = Tourette syndrome; WAIS-R = The Wechsler Adult Intelligence Scale – Revised.

[a] The authors used the "Time Paradigm" by Dougherty et al. (2003), which originally included durations of 60s. If non-modified, this study should use the same duration.

[b] Participants first had to categorize three different durations (0.10, 1.00, and 1.90s) which were presented three times (i.e., 9 stimuli to categorize) as "shortest", "middle", or "longest". The second condition was to categorize five durations (0.10, 0.55, 1.00, 1.45, and 1. 90s) which were presented five times (i.e., 25 durations) similarly, to the exception of intermediate values between these three categories (no further detail provided).

[c] Participants were presented two durations and had to decide which one was the longest. One of these was systematically 1s, the second varying upon three conditions: (I) Three non-dense durations (0.70, 1.00, and 1.30s), (II) three dense durations (0.85, 1.00, and 1.15s), or (III) five durations (0.70, 0.85, 1.00, 1.15, and 1.30s – encompassing both previous conditions).

[d] In the knowledge condition, participants were provided a feedback after each temporal production. If the participants were within the accepted range (i.e., 65-100ms for 1s and 320-600ms for 10s), their feedbacks were positive, if not, they were negative.

[e] For this task, one KS participant was not available, one extra participant was included in the AD group, and one participant was missing from the HC group

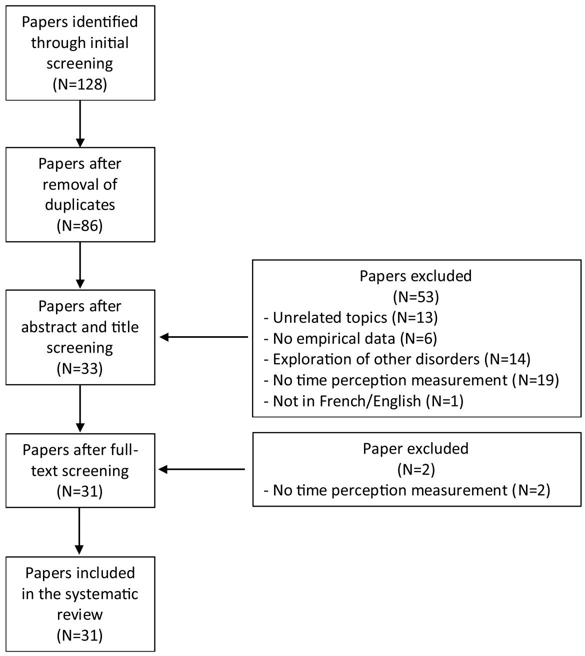

Fig. 1. PRISMA flow diagram depicting the article selection process.

(N = 12) and studies achieving a good score (N = 3). Among these studies, eight included at least 20 participants per group, 15 included between 10 and 20 participants per group (four of these failed to reach 20 participants for a single condition), and eight included fewer than 10 participants per group (among which two studies were about KS and one study only failing to recruit 10 participants per group for one experiment). The small sample size across the studies was associated with a lack of power description (no study provided a power analysis) and sample size justification. Furthermore, most studies (N = 25, 80.66 %) did not report effect size. Similarly, most authors did not consider potential confounding factors or discuss the limitations of their studies (N = 22, 70.97 %, and N = 20, 64.52 %, respectively). Concerning the studies on alcohol intoxication, most measured the blood alcohol concentration before intoxicating the participants (N = 25, 80.65 %), clearly defined the participants' exposure (e.g., alcohol concentration, placebo use, design; N = 21, 67.74 %), and implemented that exposure consistently across all participants (N = 20, 64.52 %). Notably, six studies (19.35 %) did not allow enough time for the alcohol to affect the participants' time perception.

3.2. Alcohol intoxication

The first study that measured the influence of alcohol intoxication on time perception (Laties and Weiss, 1962) explored the effect of different alcohol doses on a production task through four experiments. In the first experiment, 14 participants received a low alcohol dose, which did not influence their temporal production. In the second experiment, these results were replicated with 13 participants who performed an arithmetic task simultaneously with the production task. These results for the low dose of alcohol were further replicated in the third experiment, except that the arithmetic task was replaced by a monitoring task. Finally, in the fourth experiment, the authors doubled the alcohol dosage, which still failed to influence time perception.

Rutschmann and Rubinstein (1966) built upon the results of Laties and Weiss (1962), proposing that this lack of effect could be due to the feedback received by participants (i.e., correct or incorrect production). The authors thus explored the differential effect of alcohol, d-amphetamine sulfate, secobarbital, and placebo on time perception among five participants who performed a production task with or without feedback. These participants completed the production tasks before receiving any dose of any of the drugs (or a placebo) and after receiving a low/high dose of the drug (with dosage order randomized across participants). Results were inconclusive, although a low dose of alcohol could lead to lower score variability when participants received feedback; this variability would increase with higher alcohol doses.

Terry et al. (2009) studied the effect on time perception of different alcohol doses against the administration of caffeine and placebo. For this purpose, 36 participants performed a generalization task and a rhythmic tapping task. The authors observed two main results following alcohol administration: (1) increased variability in tapping rhythm and (2) improvement on the generalization task following the low alcohol dose.

Rammsayer (1995) explored how alcohol intoxication affects time perception differently among 60 participants with a high or low extraversion level. Participants were administered either a high dose of alcohol or a placebo before performing comparison and production tasks. Although alcohol intoxication affected the participants' score on the comparison task without interacting with the extraversion levels, only the introverted participants overestimated time in the production task following alcohol consumption.

Ehrensing et al. (1970) studied the effect of alcohol consumption on a categorization task in which participants had to classify different durations in nine categories varying from "very much less than 1 s" (1) to "very much more than 1 s" (9). In contrast to the studies presented earlier, in this study, alcohol was diluted in a saline solution and administered through an intravenous catheter instead of by oral ingestion. This study showed that participants underestimated time after consuming alcohol, this effect strengthening with longer durations.

This result was further replicated by Ogden et al. (2011), who explored how alcohol consumption affects different tasks and various timing paradigms (i.e., retrospective and prospective). Fifty-eight participants performed a generalization task, estimation tasks (prospectively and retrospectively), and a time experience task. Although neither of the alcohol doses impaired retrospective estimations, the low and high doses of alcohol affected both the experience of time and the prospective estimations, the generalization task being affected only by the high dose.

In an experiment by Lapp et al. (1994), 42 participants performed a production task before drinking (a low/high dose of alcohol or placebo), 35 min after drinking, and 95 min after drinking. They also performed a time experience task. When consuming alcohol, they presented a more extreme score 35 min after drinking and overestimated time 95 min after drinking. The participants also overestimated time 35 min after drinking the low alcohol dose. Interestingly, the subjective time flow (i.e., time experience) positively mediated the link between the dose of alcohol administered and actual time production.

Five studies compared the respective effects of alcohol and marijuana on time perception. In the first study, Jones and Stone (1970) recruited 10 heavy marijuana users who performed both an estimation and a production task after consuming a single dose of either alcohol or marijuana. The results showed an underestimation of time after alcohol consumption with the estimation task, results that were not replicated for the production task. Tinklenberg et al. (1972, 1976) evaluated time perception through an altered production task after participants consumed a single dose of these drugs. However, although the production was measured at three different times in the first study (i.e., 0 – baseline, 90 – first test post-consumption, and 210 min), it was measured at eight different times (i.e., 0 – baseline, 30 – first test post-consumption, 60, 90, 120, 150, 210, and 270 min) in the second. In the first study, the authors failed to find any significant effect of alcohol on time perception, whereas the second study showed that alcohol consumption led to overproduction (i.e., underestimation of time). Heishman et al. (1997) compared the effect of different doses of marijuana and alcohol to a placebo on human time perception. The participants had to perform a reproduction task after consuming the aforementioned drugs. None of the doses of alcohol or marijuana

Table 3
Quality assessment for the reviewed papers.

Authors (year)	Score for each Item																				% score	Methodological quality
	1	2	3	4a	4b	5a	5b	5c	5d	6	7	8	9a	9b	10	11a	11b	12	13a	13b		
Bauer and Ceballos (2014) [1]	Y	Y	N	Y	Y	Y	N	N	N	Y	Y	Y	N	N	N	Y	N	N	N	Y	50	FAIR
Bech et al. (1973)	N	N	N	Y	N	N	N	N	N	Y	Y	N	Y	Y	N	Y	Y	Y	N	N	40	POOR
Caneto et al. (2018)	Y	Y	N	Y	Y	N	N	N	Y	Y	Y	N	Y	Y	Y	Y	Y	N	N	N	60	FAIR
Cangemi et al. (2010)[1]	Y	Y	N	Y	Y	Y	N	N	Y	Y	N	N	N	N	N	Y	Y	N	N	N	45	POOR
Cappon and Tyndel (1967)[1]	Y	N	N	Y	N	N	N	N	N	Y	N	N	N	N	N	Y	Y	N	N	Y	30	POOR
Duka et al. (1998)	N	Y	N	Y	Y	N	N	N	N	Y	N	Y	Y	Y	N	Y	Y	Y	N	N	50	FAIR
El Haj et al. (2017)[1]	Y	Y	N	Y	Y	N	N	N	Y	Y	Y	N	Y	Y	N	Y	Y	N	Y	Y	65	FAIR
Ehrensing et al. (1970)	Y	N	N	N	Y	N	N	N	N	N	Y	N	Y	Y	N	Y	Y	N	N	N	35	POOR
Goldfarb et al. (1974)[1]	N	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	Y	Y	N	N	N	15	POOR
Goldstone et al. (1977)[1]	Y	Y	N	Y	Y	N	N	N	N	Y	Y	N	N	Y	N	Y	Y	N	N	Y	50	FAIR
Goudriaan et al. (2006)[1]	Y	Y	N	Y	Y	Y	N	N	Y	Y	Y	N	Y	Y	N	Y	Y	N	Y	Y	70	GOOD
Heishman et al. (1997)	Y	N	N	Y	Y	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	60	FAIR
Jones and Stone (1970)	N	N	N	N	N	N	N	N	N	N	N	N	Y	N	N	Y	Y	N	N	N	15	POOR
Klahr et al. (2011)	Y	N	N	Y	Y	N	N	N	N	Y	Y	N	Y	Y	Y	Y	Y	N	N	Y	55	FAIR
Lapp et al. (1994)	Y	Y	N	Y	Y	N	N	N	N	Y	Y	Y	Y	Y	N	Y	Y	Y	N	N	60	FAIR
Laties and Weiss (1962)	Y	N	N	N	N	N	N	N	N	N	N	Y	Y	N	N	Y	Y	N	N	N	25	POOR
Mimura et al. (2000)[1]	Y	Y	N	Y	Y	N	N	N	N	Y	Y	N	N	Y	N	Y	Y	N	Y	N	50	FAIR
Ogden et al. (2011)	Y	Y	N	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	50	FAIR
Parsons et al. (1972)[1]	Y	Y	N	Y	Y	Y	N	N	N	Y	Y	N	N	N	N	Y	Y	N	N	N	45	POOR
Rammsayer (1995)	Y	Y	N	Y	Y	N	N	N	N	Y	Y	N	Y	Y	N	Y	Y	Y	N	N	55	FAIR
Rose and Grunsell (2008)	Y	Y	N	Y	Y	N	N	N	Y	N	Y	N	Y	Y	N	Y	Y	N	Y	Y	60	FAIR
Rutschmann and Rubinstein (1966)	Y	N	N	N	N	N	N	N	N	N	Y	Y	N	N	N	Y	Y	N	N	N	25	POOR
Sanchez-Roige et al. (2014)[1]	N	Y	N	Y	Y	Y	N	N	N	Y	Y	N	Y	Y	N	Y	Y	N	Y	Y	60	FAIR
Sanchez-Roige et al. (2016)	Y	Y	N	Y	Y	N	N	N	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	N	Y	70	GOOD
Shaw and Aggleton (1994)[1]	Y	Y	N	Y	N	N	N	N	N	Y	Y	N	N	N	N	Y	Y	N	Y	N	40	POOR
Stam et al. (2020)	Y	Y	N	Y	N	Y	N	N	N	Y	Y	N	Y	Y	N	Y	Y	N	Y	Y	60	FAIR
Stoltenberg et al. (2011)[1]	Y	Y	N	Y	Y	Y	N	N	N	Y	Y	Y	Y	Y	N	Y	Y	N	Y	Y	70	GOOD
Terry et al. (2009)	Y	Y	N	N	Y	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	65	FAIR
Tinklenberg et al. (1972)	N	N	N	Y	Y	N	N	N	N	Y	Y	N	Y	Y	N	Y	Y	Y	N	N	45	POOR
Tinklenberg et al. (1976)	N	N	N	Y	Y	N	N	N	N	N	Y	N	N	N	N	Y	Y	Y	N	N	30	POOR
Vinader-Caerols and Monleón (2014)	Y	Y	N	Y	Y	Y	N	N	N	Y	Y	N	Y	N	N	Y	Y	N	N	N	50	FAIR

Legend: N, No; Y, Yes.
[1]These studies did not measure alcohol intoxication and questions 6–10 and 12 have been altered accordingly;
Note: Question related to each item:
(1) Was the research question or objective in this paper clearly stated?
(2) Was the study population clearly specified and defined (i.e. demographics, location, time period)?
(3) Was the participation rate of eligible persons at least 50 %?
(4a) Were all the subjects selected or recruited from the same or similar populations (including the same time period)?
(4b) Were inclusion and exclusion criteria for being in the study pre-specified and applied uniformly to all participants?
(5a) Was the sample size sufficiently large (higher than 20 participants per group)?
(5b) Was a sample size justification provided?
(5c) Was a power description provided?
(5d) Was a variance and effect estimates provided?
(6) *Studies on alcohol intoxication*: For the analyses in this paper, were the exposure(s) of interest (i.e. acute alcohol intoxication evaluation) measured prior to the outcome(s) being measured (causal relationship)? / *Studies on binge drinking (BD), severe alcohol-use disorders (SAUD) or Korsakoff Syndrome (KS)*: For the analyses in this paper, were the disorders of interest defined prior the outcome(s) being measured (causal relationship)?
(7) *Studies on alcohol intoxication*: Was the timeframe between alcohol administration and outcome measure sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed? / *Studies on BD, SAUD or KS*:
Was the timeframe since the disorder onset sufficient so that one could reasonably establish such a disorder?
(8) *Studies on alcohol intoxication*: For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure, or exposure measured as continuous variable) / *Studies on BD, SAUD or KS*:
did the study examine different levels of the exposure as related to the outcome (e.g., different stages of abstinence, intensity of disorder)?

(9a) *Studies on alcohol intoxication:* Were the exposure measures (independent variables) clearly defined? / *Studies on BD, SAUD or KS:* Were the disorders clearly diagnosed?
(9b) *Studies on alcohol intoxication:* Were the exposure measures (independent variables) valid, reliable, and implemented consistently across all study participants? / *Studies on BD, SAUD or KS:* Was the disorder's diagnosis valid, reliable, and implemented consistently across all study participants?
(10) *Studies on alcohol intoxication:* Was the exposure(s) assessed more than once over time? / *Studies on BD, SAUD or KS:* Was the disorder assessed more than once over time?
(11a) Were the outcome measures (dependent variables) clearly defined?
(11b) Were the outcome measures (dependent variables) valid, reliable, and implemented consistently across all study participants?
(12) *Studies on alcohol intoxication:* Were the outcome assessors blinded to the exposure status of participants? / *Studies on BD, SAUD or KS:* Was the outcome assessors blinded to the presence, or not, of the disorder among participants?
(13a) Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?
(13b) Were key potential confounding variables identified and discussed in the limitation section of the discussion?

affected the performance on the reproduction task for any of the durations tested. Finally, Bech et al. (1973) tested the effect of these drugs on the estimation of distance and duration in a driving simulator at two different speeds (i.e., 40 and 70 km/h). This study showed that the subjective time estimation (i.e., time experience) increased more than the objective one did (i.e., time estimation) following alcohol consumption.

Duka et al. (1998) used a low dose of alcohol and examined how one is able to discriminate the presence or absence (i.e., placebo condition) of such a low dose. Of the 25 participants recruited for the discrimination task, 17 also performed a production task after consuming alcohol. Although there was no direct effect of alcohol on temporal production performance, the subjective effect of alcohol was positively correlated with this performance.

Klahr et al. (2011) recruited eight participants who consumed either alcohol or a placebo before performing a bisection task during functional magnetic resonance imaging recording. Although no main effect of alcohol was observed on temporal perception, two indirect effects occurred. First, participants' reaction times during the bisection task became significantly longer after consuming alcohol. Second, an increased BOLD signal was observed in the supplementary motor area and left ventrolateral nucleus of the thalamus while participants performed the task after alcohol consumption.

Vinader-Caerols and Monleón (2014) recruited 33 abstinent participants and 33 social drinkers. The authors had the social drinkers consume alcohol, regardless of gender, before performing a production task (while the abstinent group did not consume alcohol). Alcohol did not affect temporal production.

Caneto et al. (2018) studied how a family history of SAUD affects the potential impact of alcohol on time perception. For this purpose, 23 participants with a family history of SAUD (i.e., either current or past) were compared with 28 participants without such a history; they were administered either a high alcohol dose or a placebo, and performed a production task. Alcohol consumption did not affect participants' ability to produce time intervals. Sanchez-Roige et al. (2016) replicated these results in a production task by administering a higher alcohol dose (regardless of gender) to 24 participants with a family history of SAUD and 40 participants without this history.

3.3. Binge/heavy drinking

Rose and Grunsell (2008) compared 10 binge drinkers with 10 non-binge drinkers on a production task. Furthermore, the authors had their participants consume alcohol or a placebo prior to testing. Although this specific interaction was non-significant, the authors found interesting results when they split the participants based on their impulsivity scores (9 participants with high impulsivity vs. 10 with low impulsivity). This analysis showed that impulsive participants, when consuming alcohol, overestimated time compared with low impulsive participants. Sanchez-Roige et al. (2014) also compared binge drinkers with non-binge drinkers on a production task. These authors replicated the finding that binge drinkers did not exhibit any time perception deficit.

Bauer and Cellabos (2014) explored the brain activations (i.e., electroencephalographic activity) observed among frequent binge drinkers compared with non-frequent binge drinkers when producing time intervals. The authors showed a slow cortical potential activation in the right parietal cortex during time production, which could be related to preserved time estimation. However, the authors did not report the actual productions of participants, and nothing can be concluded about the participants' temporal abilities.

Stam et al. (2020) included 85 healthy undergraduate students and categorized them as light or heavy drinkers. These participants performed a reproduction task. The autocorrelations (i.e., correlations between the repeated trials of the same duration) related to this task were analyzed regarding the intensity of their alcohol consumption (i.e.,

Table 4
Alcohol administration procedure and alcohol concentration in the reviewed papers.

Authors (year)	Parameters for alcohol dose computation	Alcohol dose administered	Alcohol level measure	Alcohol level measurement time	Actual BAC level measured (mg/dl)		
					Mean	SD	Range
Bauer and Ceballos (2014)	No alcohol administered						
Bech et al. (1973)	None	70g	BAC	60 min post-consumption	95	NR	67–129
Caneto et al. (2018)	Body weight and gender	0.6 g/kg (female) 0.7 g/kg (male)	BrAC	0min – 25 min – 55 min post-consumption	80[a]	10[a]	NR
Cangemi et al. (2010)							
Cappon and Tyndel (1967)	No alcohol administered						
Duka et al. (1998)	Body weight	0.2 g/kg during training 0.025, 0.05, 0.1, or 0.2 g/kg for testing	BrAC	End of session	Below detection limit (i.e., 1)		
El Haj et al. (2017)	No alcohol administered						
Ehrensing (1970)	Body weight[b]	0.59 g/kg	BAC	30 min post-consumption	Auditory: 79 Visual: 76	NR	Auditory: 59–103 Visual: 49–102
Goudriaan et al. (2006)							
Goldfarb et al. (1974)	No alcohol administered						
Goldstone et al. (1977)							
Heishman et al. (1997)	Body weight	0, 0.25, 0.5, 1.0 g/kg	BrAC	0min – 30 min – 60 min – 120 min post-consumption	30 min low: 10 30 min mid: 30 30 min high: 90 120 min low: 0 120 min mid: 20 120 min high: 70	NR	NR
Jones and Stone (1970)	Body weight	0.79 g/kg	BAC	60 min post-consumption	NR	NR	60–110
Klahr et al. (2011)	Body weight	0.25 g/kg	BrAC	5 min – 32 min post-consumption	5 min: 70[a,c] 32 min: 50[a,b]	40[a,b] 30[a,b]	NR
Lapp et al. (1994)	Body weight	0, 0.44, 0.88 g/kg	BrAC	0min – 35 min – 95 min post-consumption	Low: 37[c] High: 78[c]	8[c] 14[c]	NR
Laties and Weiss (1962)	Body weight	XP 1-3: 0.50 g/kg XP4: 1 g/kg	NR	NR	NR	NR	NR
Mimura et al. (2000)	No alcohol administered						
Ogden et al. (2011)	Body weight	0, 0.4, 0.6 g/kg	BrAC	0min – 10 min post-consumption – post-testing	10min (low): 52.5[d] Post (low): 46.2[d] 10min (high): 58.8[d] Post (high): 54.6[d]	25.2[d] 21[d] 21[d] 14.7[d]	NR
Parsons et al. (1972)	No alcohol administered						
Rammsayer (1995)	Body weight	0.65 g/kg	Saliva screening	70 min post-consumption	Extroverts: 78.1 Introverts: 73.3	NR	NR
Rose and Grunsell (2008)	Body weight and Gender	0.6 g/kg (male) 0.5 g/kg (female)	BrAC	Baseline to post-completion	Bingers: 60.9[e] Non-bingers: 69.3[e]	2.1[e] 6.3[e]	48.3-73.5[e] 50.4-107.1[e]
Rutschmann and Rubinstein (1966)	Per m^2	15.8 g/m^2 31.6 g/m^2	NR	NR	NR	NR	NR
Sanchez-Roige et al. (2014)	No alcohol administered						
Sanchez-Roige et al. (2016)	Body weight	0, 0.8 g/kg	BrAC	10 min – 90 min post-consumption	10 min FH-: 1.04 %[f] 90 min FH-: 0.91 %[f] 10 min FH+: 0.95 %[f] 90 min FH+: 0.83 %[f]	0.20%[f] 0.14%[f] 0.40%[f] 0.19%[f]	NR
Shaw and Aggleton (1994)							
Stam et al. (2020)	No alcohol administered						
Stoltenberg et al. (2011)							
Terry et al. (2009)	Body weight and Gender	0.12 or 0.37 g/kg (female) 0.14 or 0.42 g/kg (male)	BrAC	0min – 20 min post-consumption	20min low: 18.06[d] Post low:	5.67[d] 2.73[d]	NR

(continued on next page)

Table 4 (*continued*)

Authors (year)	Parameters for alcohol dose computation	Alcohol dose administered	Alcohol level measure	Alcohol level measurement time	Actual BAC level measured (mg/dl)		
					Mean	SD	Range
					8.61[d] 20min high: 48.93[d] Post high: 38.43[d]	10.71[d] 9.87[d]	
Tinklenberg et al. (1972)	Body weight	0.55 g/kg	BAC	60 min post-consumption	66 (median)	NR	48–76
Tinklenberg et al. (1976)	Body weight	0.79 g/kg	NR	NR	NR	NR	NR
Vinader-Caerols and Monleón (2014)	None	38.4 g (0.55 g/kg for male and 0.66 g/kg for female on average)	BrAC	Pre- and post-consumption	Men: 46.2[d] Women: 67.2[d]	3.36[d] 4.41[d]	NR

Note. BAC = blood alcohol concentration; BrAC = breath alcohol concentration; FH = family history; NR = non-reported; T1 = first measurement; T2 = second measurement.

[a] Where a BAC percentage is reported, it has been converted to mg/dl through a multiplication by 1000.

[b] In this specific study, the alcohol mixed with a saline solution was administered through an intravenous drip. The control group were administered a saline solution through the same procedure.

[c] No measurement provided; it was run with the "Digital Alcohol Breath Analyzer AlcoScan CA2000", whose output is usually the % of BAC.

[d] Where a BrAC was reported in mg/dl, mg/l, μg/ml or μg/dl, it has been converted to a BAC (mg/dl) through a multiplication by 2100, 210, 210 or 2.1, respectively.

[e] The authors did not report which measurement was used. However, they referred to the BrAC-related "mg/l" in their discussion, which could indicate that this measurement was used in their experiment as well.

[f] The authors did not give sufficient methodological details to allow a conversion from BrAC percentage to BAC mg/dl.

Quantity-Frequency-Variability Index score; Lemmens et al., 1992). Alcohol consumption was positively associated with the reproduction task's autocorrelations among heavy drinkers, indicating that they have difficulties correcting their own duration estimation over repeated trials.

3.4. SAUD

Parsons et al. (1972) explored variables underlying the faster knob turning observed in SAUD participants, one of these being impaired timing ability. For this purpose, 48 SAUD participants and 48 control participants had to estimate empty intervals at the beginning and end of the experiment, as well as to estimate the duration of the other tasks (i.e., filled interval). The SAUD participants, compared with the controls, overestimated the empty time interval at the end of the experiment, no effect being observed for the filled time intervals. Another study by Goldfarb et al. (1974) partially replicated these results. In their study, 30 SAUD participants, 24 general psychiatric patients, and 17 healthy controls performed both the estimation of empty intervals and a bisection task. Although no effect was reported for the bisection task, the SAUD participants overestimated time in the estimation task compared with controls.

These indications of impaired time perception in SAUD are further supported by the work of Goldstone et al. (1977), who compared control participants (i.e., social drinkers) to SAUD participants in two independent experiments. SAUD participants were further split into cognitively impaired and non-impaired SAUD (based on neuropsychological and intelligence measures). In both experiments, the participants had to perform "single-stimulus ranking" and "pair comparison" tasks, which are comparable to categorization (i.e., in which the durations are short, medium, or long) and comparison tasks. The difference between the two experiments lays within the modality of the stimuli to be estimated, as the participants had to perform these tasks with auditory stimuli, visual stimuli, or both. In the first experiment (nine participants for each group), the order of these modalities was randomized, whereas in the second experiment (20 impaired SAUD and 20 social drinkers), it was not, as no order effect was observed. Although these results did not indicate whether the SAUD participants over- or underestimated time, the authors indicated that, in both experiments and with both tasks, the impaired SAUD participants exhibited impaired time perception compared with the other groups.

Conversely, Cappon and Tyndel (1967) did not replicate such impaired time perception among 15 SAUD participants in comparison with 15 healthy controls. The experimenters used verbal estimation, production, and reproduction tasks, exploring durations of up to 35 min. The authors reported a slightly higher error rate among SAUD participants, which failed to reach significance regardless of the temporal task. Goudriaan et al. (2006) recruited pathological gamblers, abstinent SAUD participants, participants with Tourette syndrome, and healthy controls. The participants had to perform estimation and reproduction tasks alongside different cognitive tasks. The only result regarding alcohol and time perception was observed in the estimation task, where the participants with SAUD exhibited a higher discrepancy score than controls, especially for longer durations. A third study (Cangemi et al., 2010) explored how 60 abstinent participants with SAUD, including 12 poly-abusers, differed from 60 healthy controls regarding their ability to produce a time interval. This study did not show any significant difference between participants with SAUD, poly-abusers, and controls in the production task.

Although the study by Stoltenberg et al. (2011) did not recruit participants with SAUD, they are included in this section because the 439 participants were separated according to their scores on the Michigan Alcohol Screening Test (i.e., a score over five being considered problematic; Selzer, 1971). The problematic users were then split on the basis of gender (i.e., 155 males) and their screening test score used in a regression model to predict their production performances. However, neither men nor women showed any interaction between the Michigan Alcohol Screening Test scores and production scores.

3.5. Korsakoff syndrome

In their study, Shaw and Aggleton (1994) compared seven KS and nine SAUD participants, who completed three temporal tasks (i.e., a reproduction task and the estimation of empty or filled intervals), together with the Wisconsin Card Sorting Test (Grant and Berg, 1948) and the block design subtest of the Wechsler Adult Intelligence Scale – Revised (Wechsler, 1981). Results showed that the KS participants had significantly higher error rates than SAUD participants in all tasks, this difference being more important as the duration increased. Furthermore, the scores on the memory tasks were negatively related to the KS participants' scores on the temporal tasks.

Mimura et al. (2000) led a similar study that included eight KS participants and eight participants with SAUD who all had to perform an estimation task, a production task, and a "tempo task" (i.e., counting every 1-s interval). Participants also completed the Wisconsin Card Sorting Test (Grant and Berg, 1948), the Wechsler Adult Intelligence Scale – Revised (Wechsler, 1981), and the Wechsler Memory Scale (Wechsler, 1987). These authors replicated the higher error rates among KS participants compared patients with SAUD, as well as the growing difference with longer durations in both the production and estimation tasks, the scores of the latter correlating with results of the Wisconsin Card Sorting Test. Furthermore, they showed that KS participants could count the seconds (i.e., counting from 1 to the previously mentioned durations in 1-s increments) as accurately as patients with SAUD.

El Haj et al. (2017) tested the RTP of 18 KS participants compared with 20 healthy controls. Participants performed a task with a low cognitive load (i.e., reading aloud, filling connected squares, or word categorization), which duration had to be estimated a posteriori. Furthermore, participants had to perform the Selective Reminding Task (Bayard et al., 2011), the French Stroop Task (Grober and Buschke, 1987), a forward and backward span test, and a plus-minus task. Results showed a clear underestimation in KS participants compared with healthy controls. Furthermore, time estimation errors in the whole group were linked to episodic memory and executive functions. However, the authors showed, in a comprehensive regression model, that inhibitory control is the only significant predictor of time underestimation. Notably, there was more than one assessment of RTP and, as the authors pointed out, while the first measurement of RTP was indeed retrospective, the measurements that followed were probably prospective.

4. Discussion

4.1. Summary of the results

4.1.1. Alcohol intoxication

The alcohol intoxication studies showed mixed results: Three studies showed time overestimation under intoxication (Lapp et al., 1994; Rammsayer, 1995; Terry et al., 2009), and three showed underestimation (Ehrensing et al., 1970; Jones and Stone, 1970; Ogden et al., 2011; Tinklenberg et al., 1976). However, in most studies, the authors found no direct impact of alcohol on time perception (Bech et al., 1973; Caneto et al., 2018; Duka et al., 1998; Heishman et al., 1997; Klahr et al., 2011; Laties and Weiss, 1962; Rutschmann and Rubinstein, 1966; Sanchez-Roige et al., 2016; Tinklenberg et al., 1972; Vinader-Caerols and Monleón, 2014), and in two studies, they even observed improved performance on a generalization task after alcohol consumption (Ogden et al., 2011; Terry et al., 2009).

4.1.2. Binge/heavy drinking

No binge/heavy drinking study reported a direct time perception impairment (Bauer and Ceballos, 2014; Rose and Grunsell, 2008; Sanchez-Roige et al., 2014). As a matter of fact, Bauer and Ceballos (2014) reported slow cortical potential activation in the right parietal cortex during a production task among binge drinkers, which could indicate a preserved timing ability. However, Rose and Grunsell (2008) found that the binge drinkers with a higher impulsivity score had a longer time interval after consuming alcohol, and Stam et al. (2020) observed that the autocorrelations between several temporal reproductions were associated with the Quantity-Frequency-Variability index score among heavy drinkers.

4.1.3. SAUD

Two studies showed partial support of an overestimating effect in SAUD. First, Parsons et al. (1972) observed an overestimation when estimating empty intervals, an effect that was not present when estimating filled intervals. Second, Goldfarb et al. (1974) showed a similar overestimation in an estimation task. The possibility of an impaired temporal skill in SAUD is further supported by the increased variability observed among regular SAUD participants (Goudriaan et al., 2006) and cognitively impaired SAUD participants (Goldstone et al., 1977). However, most studies that explored time perception abilities in SAUD did not yield any significant result (Cangemi et al., 2010; Cappon and Tyndel, 1967; Goudriaan et al., 2006; Stoltenberg et al., 2011).

4.1.4. Korsakoff syndrome

KS clearly has an impact on time perception globally, as Shaw and Aggleton (1994) showed a higher error rate in both reproduction and estimation tasks, this error rate increasing with higher durations. Furthermore, the authors found a negative correlation between memory and time perception performances. Mimura et al. (2000) replicated this impairment with the production and estimation tasks, with a higher error rate associated with longer durations, although their participants exhibited a preserved ability to produce a regular rhythm. Furthermore, they found a positive correlation between temporal performance on the estimation task and working memory. El Haj et al. (2017) also showed an underestimation of time in a retrospective estimation task among participants with KS, which was associated with inhibitory abilities.

4.2. Implications of the reviewed studies

The overestimation of time partially observed in alcohol intoxication (Lapp et al., 1994; Rammsayer, 1995; Terry et al., 2009) could indicate an acceleration of the pacemaker, resulting in a higher accumulation of pulses (i.e., attentional gate model; Zakay and Block, 1995). Conversely, the underestimation of time observed in three other studies (Jones and Stone, 1970; Ogden et al., 2011; Tinklenberg et al., 1976) could indicate two potential processes. First, similar to overestimation, the pacemaker itself could be slowed down, leading to lower pulse accumulation (Zakay and Block, 1995). Second, an attentional effect could be at stake here, in which intoxicated participants would not remain focused on the temporal task, therefore "closing the attentional gate" and preventing further pulses from reaching the accumulator (Zakay and Block, 1995).

However, two studies (Ogden et al., 2011; Terry et al., 2009) observed improved time estimation by using a generalization task rather than the usual production and estimation tasks. As the generalization task includes an important decision-making aspect, it allows participants to control their response and potentially compensate for the effect of alcohol intoxication on time perception. This assumption is supported by the fact that (1) Ogden et al. (2011) observed a less variable temporal production (even though there was an overestimation), and (2) Lapp et al. (1994) showed that the subjective time flow mediated the relationship between the dose received or expected and the time interval produced. These observations further indicate that the conscious impact of alcohol on one's feeling of time affects time perception.

No impact of binge/heavy drinking was observed on time perception, despite the numerous cognitive impairments reported in these populations (e.g., Carbia et al., 2018). Interestingly, the indirect effect observed by Stam et al. (2020) indicates that even though the actual perception of time would be preserved, heavy drinkers would exhibit a reduced ability to adapt their own temporal estimation over several trials. Concerning SAUD participants, three main types of results have been reported. First, similar to the results on the binge/heavy drinking, three studies failed to find any significant relationship between SAUD and time perception (Cangemi et al., 2010; Goudriaan et al., 2006; Stoltenberg et al., 2011). Conversely, two studies (Goldfarb et al., 1974; Parsons et al., 1972) showed that SAUD participants overestimated durations, indicating acceleration of the pacemaker mechanism in accordance with the Attentional Gate Model (Zakay and Block, 1995). These results are partially supported by the studies of Goudriaan et al. (2006) and Goldstone et al. (1977), who observed increased variability in their SAUD participants' estimations. Interestingly, the results of Goldstone et al. (1977) may shed light on the two trends presented in the results of the SAUD literature. In their study, increased variability was observed only in cognitively impaired SAUD participants, indicating that only this subpopulation would be afflicted by an impaired time perception. The systematically impaired prospective and retrospective time perception observed in KS participants, a population associated with more intense cognitive impairments than SAUD (in particular for memory; Akhouri et al., 2020), would support this claim.

This possibility is supported by the studies that link temporal impairment with cognitive deficits. First, Shaw and Aggleton (1994) surprisingly linked this impairment in prospective timing to better short-term memory. However, prospective timing does not rely on short-term memory, but on a timer operating through attention and working memory (Droit-Volet et al., 2015a). Mimura et al. (2000) showed that reduced working memory was linked to time perception impairment. Second, episodic memory plays a central role in RTP (Block and Reed, 1978). El Haj et al. (2017) showed that KS participants underestimated time retrospectively, which was correlated with episodic memory. The results support the idea that PTP is directly affected by the frontal dysfunctions in KS, whereas RTP is biased following amnesia.

4.3. Limitations of the reviewed studies

4.3.1. Populations included

Although binge/heavy drinking did not influence time perception per se, several often uncontrolled factors influence this ability. Extraversion (Rammsayer, 1995) and impulsivity (Rose and Grunsell, 2008) are susceptible to impact time perception and should thus be controlled for when exploring time perception in excessive alcohol consumption. The subjective effect of alcohol reported by participants correlated with production task performance (Duka et al., 1998), suggesting that beyond the objective cognitive impact of alcohol intoxication, individuals' subjective opinion on alcohol's effects also has an impact on time perception.

The selection criteria used in SAUD studies also calls for caution when interpreting the results. First, most of the related studies recruited inpatients from a hospital without providing any validated diagnosis to confirm this alcohol abuse or to assess its severity (Cappon and Tyndel, 1967; Goldfarb et al., 1974; Goldstone et al., 1977; Parsons et al., 1972). Second, only two studies (Goldstone et al., 1977; Goudriaan et al., 2006) mentioned having recruited individuals who were diagnosed with SAUD without comorbidities, whereas three studies did not address this possibility (Cappon and Tyndel, 1967; Goldfarb et al., 1974; Parsons et al., 1972) and one study focused on polysubstance abusers (Cangemi et al., 2010). Finally, Stoltenberg et al. (2011) recruited undiagnosed excessive drinkers instead of actual SAUD participants. Future studies should thus propose a more standardized selection process in order to focus on a clearly identified clinical population.

4.3.2. Methodological issues

In the field of alcohol intoxication, it is crucial to control for the alcohol level obtained by adapting the administered dose for gender and body weight with the Widmark formula (e.g., Seidl et al., 2000). However, several investigators did not consider participants' gender (Ehrensing et al., 1970; Laties and Weiss, 1962; Sanchez-Roige et al., 2016), weight (Bech et al., 1973), or both (Vinader-Caerols and Monleón, 2014) when administering alcohol. This led, for example, to different blood alcohol concentrations between the different groups in Vinader-Caerols and Monleón (2014) study, and a large spread in concentrations in the study by Bech et al.(1973).

The time perception task should also be carefully selected. Various tasks have been used (e.g., production, reproduction, estimation), each involving specific psychological processes. For example, all the studies reporting a significant overestimation of time in the SAUD population used an estimation task (Goldfarb et al., 1974; Parsons et al., 1972), Goudriaan et al. (2006) showing an increased variability in their estimation task as well. In fact, only Cappon and Tyndel (1967) failed to observe such impaired timing with an estimation task. Conversely, no study that used a production task found such results (Cangemi et al., 2010; Cappon and Tyndel, 1967; Stoltenberg et al., 2011). This systematic lack of results for the production task suggests a preserved reference system (i.e., core knowledge of time units) among the SAUD population, these results being replicated in the KS population (Mimura et al., 2000). The results for the estimation tasks indicate an impaired experienced system (i.e., actual perception of time). This assumption is to be taken with caution, however, as Goudriaan et al. (2006) failed to find any significant result when using a reproduction task. Although this task relies on the reference system (i.e., regarding the production part), the results should still be impaired because of the importance of the experienced system (i.e., the perception part of this task).

4.4. Perspectives and conclusion

Beyond clarifying the aforementioned limitations, future studies should focus on a few central topics. First, the subjective evaluation of alcohol's influence when performing time perception tasks may affect performance: The lower variation of temporal estimation (Ogden et al., 2011) and the importance of the expected alcohol dose administered (Duka et al., 1998) indicate that the perceived intoxication influences timing performance. Such a conscious control of time has been explored previously for the impact of emotional stimuli on time perception (Droit-Volet et al., 2015b), and such explorations could be adapted to alcohol intoxication.

Second, a standardized time perception battery should be established to ensure a comprehensive measure of time perception and its associated cognitive functions. A joint exploration of prospective and retrospective timing should be performed. Retrospective timing should be limited to one task per participant and should be placed first in the experimental design. Indeed, although a first retrospective task tests retrospective timing, it raises participant's consciousness on the temporal aspect of the task, which thus switches from retrospective to prospective timing. Therefore, a comprehensive battery should include all of the following: (1) Both a retrospective and prospective absolute judgment task, for example, requiring the participant to cross a line representing a given duration (e.g., the whole line would represent 5 min). This task prevents the participants from rounding up their estimations to existing thresholds; (2) A prospective bisection task (i.e., allowing the measurement of the experienced system multiple times); (3) A production task (i.e., allowing the isolated evaluation of the reference system).

These tasks would allow an in-depth exploration of time perception. Furthermore, different durations should be explored in the case of alcohol intoxication studies. As highlighted earlier, the underestimation observed when administering alcohol could be due to either an attentional or an arousal (i.e., slowing down of pacemaker) effect. When two ranges of duration are used, an attention effect should not lead to a different rate of underestimation (i.e., additive effect) whereas arousal would lead to an increased rate of underestimation (i.e., multiplicative effect). This effect has been partially observed in Ehrensing et al.'s study (1970), in which participants' underestimation increased with longer durations after consuming alcohol. Therefore, further replication of this observation by using different duration ranges would confirm which of these hypotheses stands true for underestimation.

PTP and RTP have been associated with different cognitive abilities that should be measured in these experiments as well. RTP is mainly related to short-term memory, as the remembrance of particular changes in the environment during a given time interval is what determines the estimation according to the contextual change model (Block and Reed, 1978). Prospective timing is related to attention and working memory (Zakay and Block, 1995), which affect how one can focus on a time interval and compare its duration to previously stored durations. Not only are these functions associated with time perception, but they are also impaired by alcohol consumption (for reviews, see Arts et al., 2017;

Carbia et al., 2018; Stavro et al., 2013; Zoethout et al., 2011). Therefore, any study exploring how alcohol affects time perception should also include a measure of working memory such as the Corsi Block Test (Lezak, 1983) and a measure of attention such as the Attention Network Test – Revised (Fan et al., 2002).

In conclusion, existing evidence suggests that time perception is impaired only when the excessive or regular consumption of alcohol leads to a permanent deficit in the cognitive abilities associated with time perception (e.g., KS). Concerning alcohol intoxication, no definitive conclusion can be reached because of the multiple methodological limitations discussed. It should be noted that the present systematic review included only peer-reviewed papers and therefore did not include the gray literature (e.g., conference proceedings, unpublished Ph.D. dissertations), which could constitute a bias. However, the inclusion of the literature that presented null findings aimed to reduce this bias risk. Furthermore, as there is currently a lack of systematic studies to overcome the above-mentioned methodological issues, reliable conclusions cannot be fully drawn. However, this systematic review is a necessary step in summarizing the existing evidence comprehensively, in order to pave the way for further research. Most importantly, future research should evaluate time estimation and its related cognitive variables more systematically and by capitalizing on more powered experiments in order to fully grasp how alcohol use impairs time perception.

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