Journal Pre-proof

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PII: S0149-7634(21)00190-1

DOI: https://doi.org/10.1016/j.neubiorev.2021.04.027

Reference: NBR 4164

To appear in: *Neuroscience and Biobehavioral Reviews*

Received Date: 27 October 2020

Revised Date: 21 April 2021

Accepted Date: 24 April 2021

Please cite this article as: Nuyens FM, Billieux J, Maurage P, Time perception and alcohol use: A systematic review, *Neuroscience and Biobehavioral Reviews* (2021), doi: https://doi.org/10.1016/j.neubiorev.2021.04.027

Time perception and alcohol use: A systematic review

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Highlights

- We review studies that explore time perception in alcohol related disorders
- Alcohol intoxication may lead to time under or overestimation depending on the task
- Cognitively impaired patients with alcohol dependence present altered time perception
- Korsakoff syndrome is related to severe time perception impairments
- We present perspectives to improve the exploration of time perception in psychiatry

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, because of to the methodological limitations of existing studies, no firm conclusion can be drawn. Guidelines and perspectives to advance the field are proposed.

Keywords: time perception; severe alcohol use disorder; binge drinking; alcohol intoxication; Korsakoff syndrome; cognitive abilities.

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 & Gruber, 2014; Levin & 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 & 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 & 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 for measuring temporal abilities, which can be summarized as six main paradigms (Table 1) split into two categories according

[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.

to the duration used (i.e., seconds or minutes). Similarities exist across tasks in accordance with 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, Wearden, and colleagues (2015) 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 (0.4-0.8s and 8-16s) 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 & 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 (Baudoin 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 & Reed, 1978; Roseboom et al., 2019). Having a limited ability to process an elevated number of events may thus result in a direct time underestimation.

The brain correlates of time perception have also been largely documented through studies by 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 & Meck, 2004). On the other hand, the supramodal hypothesis better fits 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 & 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 & Lee, 2015), schizophrenia (e.g., Gómez et al., 2014; Thoenes & 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 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 & Gilman, 2014; Bühler & Mann, 2011; Lannoy et al., 2019; Zahr & 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., 2019). 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, and substance use and addictive disorder) tend to overestimate time duration (Stanford & Barratt, 1996). It has moreover been suggested (Paasche et al., 2019) 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 gratification. 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 systematic 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 the 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 drank 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 & 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 those 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 and colleagues (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 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 review varied between 15% and 70%. Most of the papers achieved a fair quality rating (N=16), followed by studies achieving a poor score (N=12) and studies achieving a good score (N=3). Of 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 of the studies (N=25, 80.66%) did not report effect size. Similarly, most of the 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 & 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 a higher alcohol dose.

Terry and colleagues (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 and colleagues (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 1s" (1) to "very much more than 1s" (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 and colleagues (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 dose of alcohol affected both the experience of time and the prospective estimations, the generalization task being affected only by the high dose.

In Lapp and colleagues' (1994) experiment, 42 participants performed a production task before drinking (a low/high dose of alcohol or placebo), 35 minutes after drinking, and 95 minutes after drinking. They also performed a time experience task. When consuming alcohol, they presented a more extreme score 35 minutes after drinking and overestimated time 95 minutes after drinking. The participants also overestimated time 35 minutes 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 had to perform 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 and colleagues (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 and colleagues (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, whether alcohol or marijuana, affected the performance on the reproduction task for any of the durations tested. Finally, Bech and colleagues (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 and colleagues (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 and colleagues (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 and colleagues (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 and colleagues (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 on the basis of 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 and colleagues (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 and colleagues (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., Quantity-Frequency-Variability Index score; Lemmens et al., 1992). Alcohol consumption was positively associated with the reproduction task autocorrelations among heavy drinkers, indicating that they have difficulties correcting their own duration estimation over repeated trials.

3.4. SAUD

Parsons and colleagues (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 and colleagues (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 and colleagues (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 duration is 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 and colleagues (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 and colleagues (2011) did not recruit participants with SAUD, they are included in this section because the 439 participants were separated by their scores on the Michigan Alcohol Screening Test (i.e., a score over 5 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 & 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 did 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 and colleagues (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 & 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 with 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 the patients with SAUD.

El Haj and colleagues (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 they had to estimate a posteriori. Furthermore, participants had to perform the Selective Reminding Task (Bayard et al., 2011), the French Stroop Task (Grober & 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 & 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 & Weiss, 1962; Rutschmann & Rubinstein, 1966; Sanchez-Roige et al., 2016; Tinklenberg et al., 1972; Vinader-Caerols & 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 & Ceballos, 2014; Rose & 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 and colleagues (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 and colleagues (1972) observed an overestimation when estimating empty intervals, an effect that was not present when estimating filled intervals. Second, Goldfarb and colleagues (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 results (Cangemi et al., 2010; Cappon & 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 and colleagues (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 and colleagues (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 & Block, 1995). Conversely, the underestimation of time observed in three other studies (Jones & 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 & 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 & Block, 1995).

However, two studies (Ogden et al., 2011; Terry et al., 2008) 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 and colleagues (2011) observed a less variable temporal production (even though there was an overestimation), and (2) Lapp and colleagues (1995) 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 and colleagues (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 & Block, 1995). These results are partially supported by the studies of Goudriaan and colleagues (2006) and Goldstone and colleagues (1977), who observed increased variability in their SAUD participants' estimations. Interestingly, the results of Goldstone and colleagues (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, surprisingly, Shaw and Aggleton (1994) 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, Wearden, et al., 2015). Mimura and colleagues (2000) showed that reduced working memory was linked to time perception impairment. Second, episodic memory plays a central role in RTP (Block & Reed, 1978). El Haj and colleagues (2017) showed that KS participants underestimated time retrospectively, which was correlated to 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) modify 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 & 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 & Tyndel, 1967; Goldfarb et al., 1974; Parsons et al., 1972) and one study focused on polysubstance abusers (Cangemi et al., 2010). Finally, Stoltenberg and colleagues (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 & Weiss, 1962; Sanchez-Roige et al., 2016), weight (Bech et al., 1973), or both (Vinader-Caerols & 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 Bech and colleagues' (1973) study.

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 and colleagues (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 & 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 for 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 and colleagues (2006) failed to find any significant results 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 to 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, Lamotte, et al., 2015), and such explorations could be adapted to alcohol intoxication.

Second, a standardized time perception battery should be established to ensure a comprehensive representation 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 minutes). 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 and colleagues'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 & Reed, 1978). Prospective timing is related to attention and working memory (Zakay & 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 have also been shown to be 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 risk of bias. 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 important, 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.

Funding

Pierre Maurage (Senior Research Associate) is funded by the Belgian Fund for Scientific Research (F.R.S.-FNRS, Brussels, Belgium). This funding source did not exert any influence or censorship on the present work.

Conflict of interest

The authors declare no conflict of interest.

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Figure Caption

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

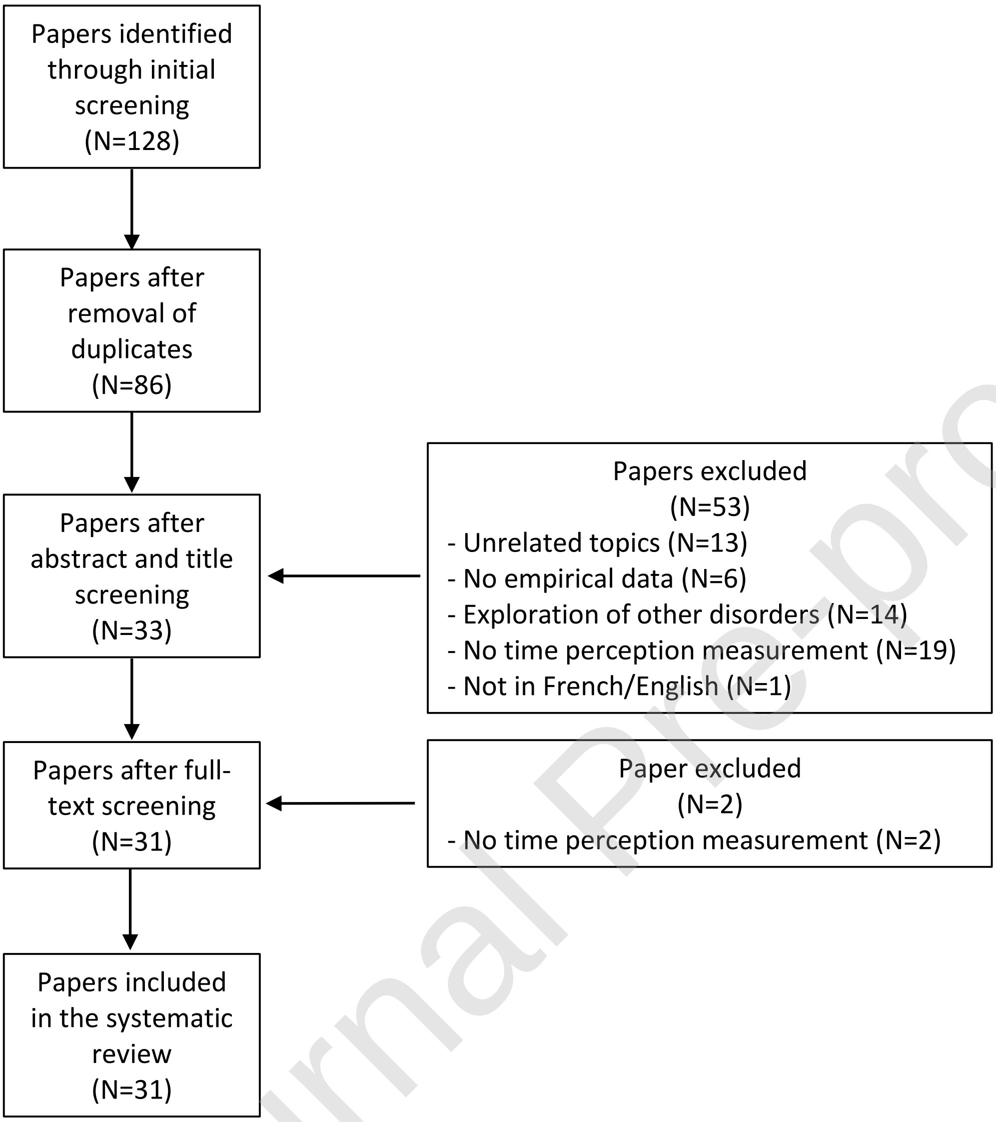

Table 1. Summary of the main time-related tasks available.

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?").	Seconds to minutes
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.	
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.	Milliseconds to seconds
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.	
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.	

Table 2. Description and main results of the reviewed papers

Authors (year)	**Population**					**Exposures**
	Sample (N)	*Age [M (SD)]*	*Gender ratio (% males)*	*Exclusion criteria*	*Control group*	*Diagnosis / Characteristics*
Bauer & 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
Bech et al., (1973)	8	Age range: 21-19	100%	Alcohol or marijuana abuse	Marijuana Placebo	None (within-subjects design)

					Alcohol	
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
Cangemi et al. (2010)	120	Abstinent AD: 46.28 (10.21) HC: 46.45 (10.19)	47.50%	Borderline disorder Cognitive deficits Alcohol abuse (for HC)	60 Abstinent AD 60 HC	Abstinent AD = No alcohol consumption over the pas 20 days (on average), hospitalized for their addiction Poly-abusing was controlled (exact nature NR)
Cappon & 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
Duka et al. (1998)	25	23.9 (6.4)	52%	Drug abuse Abnormal weight	Alcohol Placebo	NA
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 anterograd amnesia. Confirmed through a DSM-IV-based psychiatric interview

[2] 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.

				Being under treatment or using psychotropic drugs (KS) Previous substance addiction (HC) Any neurological or psychiatric history (HC)		
Ehrensing (1970)	30	Age range: 18-38	46.67%	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
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
Goldstone et al. (1977)	70	AUD: 47 HC (XP1): 43 HC (XP2): 26	AUD: 58.54% HC: NR	Other addictions Medication Psychological or neurological conditions SAUD (for HC)	Social drinkers: 29 Impaired AD: 16 Unimpaired AD: 25	AD: Abstinent for two weeks, hospitalized in an alcoholism treatment program Impairment: based on a four-point system resulting from the WAIS and the Bender Gestalt Test Social drinkers: NR
Goudriaan et al. (2006)	193	AD: 47.2 (8.3) HC: 35.6 (11.4) PG: 37.3 (9.5) TS: 36.8 (12.1)	74.61%	Alcohol abuse (except AD) Other substance abuse Other psychiatric disorder Being over 60 or under 18 Severe cognitive impairment (AD)	48 AD 50 HC 49 PG 46 TS	AD: Diagnosed as alcohol dependent based on the DSM-IV-TR (American Psychiatric Association, 2000 abstinent for 3 to 12 months PG: Diagnosed as a pathological gambler based on the DSM-IV-TR and the Diagnostic Interview Schedul (i.e., >5 symptoms; Robins et al., 1998) TS: Diagnosed with Tourette syndrome by a psychiatrist or neurologist

[3]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)

[4]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)

				Following a treatment for mental disorder Condition affecting motor performance or cognition Use of psychotropic medication Positive urine screen for alcohol, marijuana, or benzodiazepines		AD, HC, and TS matched to PG first recruited
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)
Jones & Stone (1970)	10	25	100%	Psychiatric disorder “Extreme eccentricity”	Alcohol Marijuana Placebo	Heavy marijuana users (within-subjects design)

Klahr et al. (2011)	8	Age range: 21-32	100%	Psychiatric medication History of alcoholism Neurological disorders	Alcohol Placebo	Right-handed
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)
Laties & 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	Participants were not allowed to eat up to two hours before the experiment

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 8 KS	FP and KS: Outpatients and inpatients referred by the current (neuro)psychologist FP: Frontal lesion resulting from different causes (e.g head injury, tumor) KS: Stable condition with severe anterograde amnesi and a different degree of retrograde amnesia AD: Matched in age and education to KS HC: Matched in age and education to FP
Ogden et al. (2011)	58	Female: 22.74 (3.96) Male: 22.28 (3.25)	51.72%	Initial BrAC higher than 0 Drank at least 10 units in the previous week Weighing at least 50 kg (female) or 60 kg (male)	Placebo Low alcohol dose High alcohol dose	NA
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

Rammsayer (1995)	60	24.4 (3.6)	100%	Tobacco use Chronic drug intake Allergy Current psychiatric treatment or history Endocrine or cardiovascular disease Acute infection or gastrointestinal disease More than 45 g/week of alcohol intake	15 extroverts - alcohol 15 extroverts - placebo 15 introverts - alcohol 15 introverts - placebo	Extroverts: High extraversion score demonstrated by 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
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
Rutschmann & Rubinstein (1966)	5	NR	100%	NR	NA	Within design, participants, over several weeks, performed several conditions based on (1) their knowledge of their temporal accuracy (i.e., knowledg or no knowledge)[5], (2) the durations used (i.e., 1s or 2s), (3) the drug administered (i.e., d-amphetamine sulfate, secobarbital, alcohol, and placebo), and (4) th dose (i.e., low or high). Participants were not allowed to eat up to four hours before the experiment

[5]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.

Sanchez-Roige et al. (2014)	44	21.18 (1.89)	50%	>0 on baseline breathalyzer Mental/neurological illness Alcohol/substance abuse Medication BrAC score above 1mg/dl	22 bingers 22 non-bingers	Bingers: Score of at least 32 on the Alcohol Use Questionnaire (Mehrabian & Russell, 1978) Non-bingers: Maximum score of 16 on the Alcohol Us Questionnaire
Sanchez-Roige et al. (2016)	64	21.98 (3.22)	46.88%	Alcohol/substance abuse Heavy smokers (>10 cigarettes per day)	24 FH+ 40 FH- Alcohol vs. placebo	FH+: Participants reporting one or more family histor of alcohol abuse on the Family Tree Questionnaire FH-: No such family history

Shaw & Aggleton (1994)	30	AD: 50.6 (43-68) EA: 41 (22-62) HC: 46.6 (20-59) KS: 57.7 (50-64)	90%	NR	9 AD 3 EA 11 HC 7 KS	AD: Alcohol dependent EA: Amnesiacs with symptoms resulting from encephalitis KS: Korsakoff syndrome patients
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
Stoltenberg et al. (2011)	439	22.49 (6.12)	35.3%	Non-Caucasian	NA	Participants were split based on the Michigan Alcoho Screening Test (Score higher than 5 being considere problematic; Selzer, 1971)

[6] 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

Terry et al. (2008)	36	24.3 (0.9)	22.22%	Medication Smoking more than 10 cigarettes per day Drinking less than 125 mg caffeine daily (caffeine condition) Drinking less than 5 or more than 35 units of alcohol per month	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 task, meaning that their performance increased after consuming a low dose of alcohol (no effect of the high dose)	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 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 a 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 a maximum twice a week	Marijuana Alcohol Placebo	No use of marijuana or other psychoactive drugs during the whole testing period	NR	NR	Heart rate Intoxication subjective measure	Production task (i.e., stating when 30, 60, and 120s had elapsed within a same 120s	Seconds	The alcohol administration led to an increase of the overall production	NR	Alcohol intoxication leads to time underestimation

						and no alcohol up to 48h before each test day. Within design (participants included in all the conditions)				segment – performed twice)		of the participants compared to the placebo condition		
Vinader-Caerols & Monleón (2014)	46	Female: 19.5 (0.48) Male: 19.36 (0.21)	47.85 %	Medication Mental disorder history Irregular sleep pattern History of substance abuse (including caffeine and tobacco) Being younger than 18 years body mass index not within normal range (18 – 28)	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 women and 4 for men over a short period in the last year Abstinent were included in the placebo group and Social drinkers in the alcohol group	Alcohol Use Disorders Identification Test BrAC	NR	Heart rate, blood pressure State-Trait Anxiety Inventory Stroop task Purdue Pegboard Test	Production task (10 × 10s)	Seconds	There was no effect of alcohol on the participants' time perception	NR	Alcohol does not affect time perception

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.

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 & 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. (2017)	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 & 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 & 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 & 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 & Tarter (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 (2008)	Y	Y	N	Y	Y	N	N	N	N	Y	Y	N	Y	Y	N	Y	Y	Y	N	N	55	FAIR
Rose & 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 & 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 & 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. (2008)	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 & 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?

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 & Ceballos (2014)	No alcohol administered						
Bech et al. (1973)	None	70g	BAC	60min post-consumption	95	NR	67 - 129
Caneto et al. (2017)	Body weight and gender	0.6 g/kg (female) 0.7 g/kg (male)	BrAC	0min – 25min – 55min post-consumption	80[7]	10[1]	NR
Cangemi et al. (2010)	No alcohol administered						
Cappon & Tyndel (1967)							
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[8]	0.59 g/kg	BAC	30min post-consumption	Auditory: 79 Visual: 76	NR	Auditory: 59-103 Visual: 49-102
Goudriaan et al. (2006)	No alcohol administered						
Goldfarb et al. (1974)							
Goldstone et al. (1977)							
Heishman et al. (1997)	Body weight	0, 0.25, 0.5, 1.0 g/kg	BrAC	0min – 30min – 60min – 120min post-consumption	30min low: NR 30min mid: NR 30min high: 90 120min low: 0 120min mid: 20 120min high: 70	NR	NR
Jones & Stone (1970)	Body weight	0.79 g/kg	BAC	60min post-consumption	NR	NR	60-110
Klahr et al. (2011)	Body weight	0.25 g/kg	BrAC	5min – 32min post-consumption	5min: 70[1,9] 32min: 50[1,2]	40[1,2] 30[1,2]	NR
Lapp et al. (1994)	Body weight	0, 0.44, 0.88 g/kg	BrAC	0min – 35min – 95min post-consumption	Low: 37[3] High: 78[3]	16.8[3] 29.4[3]	NR
Laties & Weiss (1962)	Body weight	0.50 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 – 10min post-consumption – post-testing	T1 (low): 52.5[10] T2 (low): 46.2[3] T1 (high): 58.8[3] T2 (high): 54.6[3]	25.2[3] 21[3] 21[3] 14.7[3]	NR

[7] Where a BAC percentage is reported, it has been converted to mg/dl through a multiplication by 1000.
[8] 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.
[9] No measurement provided; it was run with the "Digital Alcohol Breath Analyzer AlcoScan CA2000", whose output is usually the % of BAC.
[10] 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.

Parsons et al., (1972)	No alcohol administered						
Rammsayer (2008)	Body weight	0.65 g/kg	Saliva screening	70min post-consumption	Extroverts: 78.1 Introverts: 73.3	NR	NR
Rose & Grunsell (2008)	Body weight and Gender	0.6 g/kg (male) 0.5 g/kg (female)	BrAC	Baseline to post-completion	Bingers: 60.9[4] Non-bingers: 69.3[11]	2.1[4] 6.3[4]	48.3-73.5[4] 50.4-107.1[4]
Rutschmann & Rubinstein (1966)	Per m²	15.8 g/m² 31.6 g/m²	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	10min – 90min post-consumption	10min FH-: 1.04%[12] 90min FH-: 0.91%[5] 10min FH+: 0.95%[5] 90min FH+: 0.83%[5]	0.20%[5] 0.14%[5] 0.40%[5] 0.19%[5]	NR
Shaw & Aggleton (1994)	No alcohol administered						
Stam et al., (2020)							
Stoltenberg et al. (2011)							
Terry et al. (2008)	Body weight and Gender	0.12 or 0.37 g/kg (female) 0.14 or 0.42 g/kg (male)	BrAC	0min – 20min post-consumption	T1 low: 18.06[3] T2 low: 8.61[3] T1 high: 48.93[3] T2 high: 38.43[3]	5.67[3] 2.73[3] 10.71[3] 9.87[3]	NR
Tinklenberg et al. (1972)	Body weight	0.55 g/kg	BAC	60min post-consumption	66 (median)	NR	48 - 76
Tinklenberg et al. (1976)	Body weight	0.79 g/kg	NR	NR	NR	NR	NR
Vinader-Caerols & Monleón (2014)	None	38.4g (0.55 g/kg for male and 0.66 g/kg for female on average)	BrAC	Pre- and post-consumption	Men: 46.2[3] Women: 67.2[3]	3.36[3] 4.41[3]	NR

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

[11] 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.

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