THE IMPORTANT ROLE OF SLEEP IN RELATION TO ALCOHOL USE AND MEMORY CONSOLIDATION

By

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A THESIS SUBMITTED TO THE UNIVERSITY OF BIRMINGHAM FOR THE DEGREE OF DOCTORATE IN CLINICAL PSYCHOLOGY

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Thesis Overview

This thesis is submitted in partial fulfillment of the requirements for the degree of Doctorate of Clinical Psychology (ClinPsyD) at the University of Birmingham.

Volume I: Research Component

Volume I includes the research component, comprising of three papers; a systematic literature review, empirical paper and public domain briefing document. The systematic review found that short sleep duration and symptoms of insomnia may be early indicators that contribute to alcohol use among adolescents. The findings must be interpreted with caution in light of the limitations with regards to reduced internal and external validity, since half of the studies in the review employed a cross-sectional design. Nevertheless, the preliminary findings highlight the importance of adequate sleep in adolescents and its clinical implications are discussed.

The aim of the empirical paper was to investigate the effect of auditory cueing during wakefulness in a sample of typically developing young adults. The findings revealed that memory retention on a word-image association task improved following a night's sleep, irrespective of cueing. It is suggested that the natural process of sleep-specific memory consolidation aided in retaining information. The public domain debriefing paper summarises the main findings of the literature review and the empirical paper.

Volume II: Clinical Component

Volume II represents the clinical component, which consists of five clinical practice reports (CPRs). CPR I describes an assessment and formulation of a 38-year-old man who presents with symptoms of depression and anxiety. It was discussed from a cognitive-behavioural and psychodynamic perspective. CPR II presents a service evaluation of service users' experience of an outpatient chronic pain department. CPR III presents a single-case experimental design, which considers the case of a 3-year-old girl with Cornelia de Lange Syndrome presenting with sleep difficulties. CPR IV describes the assessment, formulation, and intervention of a case study of a 15-year-old boy with an adjustment disorder presenting with low mood and suicidal ideation. CPR V provides a summary of a presentation demonstrating leadership competencies, which discusses the processes involved in facilitating a staff support group in an older adults inpatient unit.

This thesis is dedicated to

Laudy El-Marj

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Miles apart yet close at heart. I could not have come this far without my family and friends. To dad, who has always stood by my side no matter what, I will forever be grateful for all your hard work and dedication to our family. To my wonderful mom and best friend, who believed in me and was there for me through it all, words cannot describe how much you have inspired me. I hope this makes you both proud. To my dear friends, especially Burlant, Nadine B., Meekae, and Michel T., thank you for supporting me and having faith in me that I can get through this, you've all helped me tremendously. A special thanks to Michel S. for supporting me, understanding me, and keeping me calm.

VOLUME I: RESEARCH COMPONENT

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CHAPTER 1: LITERATURE REVIEW

Do Sleep Problems Contribute

to Alcohol Use in Adolescents?

A Systematic Review

Abstract

Objectives. This systematic review aimed to examine research exploring whether sleep problems are early indicators of increased risk for alcohol use among adolescents.

Methods. A systematic search strategy on three databases; Ovid PsycINFO, Embase, and Web of Science retrieved 1,145 records. Following the application of inclusion and exclusion criteria, 27 studies were identified for review and were appraised using the NICE (2012) quality framework.

Results. There is moderate evidence suggesting that short sleep duration and symptoms of insomnia may be early indicators of increased alcohol use among adolescents. These findings need to be interpreted with caution in light of limitations. Half of the studies included in this review employed a cross-sectional design therefore temporal precedence cannot be inferred.

Conclusions. Further research employing longitudinal designs, and using more diverse samples are needed in order to achieve greater internal and external validity. In addition, more objective measures of sleep will need to be utilised in the future in addition to self-reports. This would enable more comprehensive conclusions regarding the relationship between sleep problems and alcohol use. Nevertheless, the preliminary findings from this review highlight the importance of adequate sleep in adolescents and its clinical implications are discussed.

Keywords: short sleep duration, sleep variability, insomnia, insufficient sleep, alcohol use, adolescents, risk-taking behaviour

INTRODUCTION

Why Sleep Matters

Sleep is beneficial to our physical and emotional wellbeing, and getting a good night's sleep helps us feel well rested and ready to take on a new day! Sleep plays a fundamental role in a number of cognitive and emotional processes, which include learning, memory consolidation, attention, decision-making, and emotional regulation (Stickgold, 2005). Sleep also aids in our physical restoration and mental health (Riemann & Voderholzer, 2003; Vyazovskiy, 2015). Conversely, insufficient sleep in the form of sleep deprivation or prolonged restricted sleep has been found to result in increased irritability, low mood, increased likelihood of risk-related behaviour, and human-error such as road accidents (Dahl and Lewin, 2002; Dinges, 1995; O'Brien & Mindell, 2005).

Given the longstanding evidence suggesting that sleep is vital for our health, researchers have naturally been interested in the consequences of sleep problems. Sleep problems include a range of difficulties and are characterized by disturbance in the individual's amount of sleep, quality of sleep, or in behaviours or physiological conditions associated with sleep (American Psychiatric Association, 2013). Sleep problems are a common feature of several mental health problems and mental health disorders, such as depression (American Psychiatric Association, 2013). Trouble falling asleep or staying asleep, typically referred to as insomnia, are one of the most common sleep problems and the major cause of disturbed night-time sleep amongst individuals (American Academy of Sleep Medicine, 2000). Research by The Sleep Council revealed that of 5,007 UK adults surveyed, 27% of Britons reported experiencing poor quality of sleep on a regular basis, and of those who sleep for less than 5 hours per night a third reported suffering from insomnia (The Sleep Council, 2013).

Sleep Problems in Adolescents

There is substantial evidence that suggests adolescents worldwide are not getting enough sleep. According to the National Sleep Foundation, children between the ages of 6 to 13 years old are recommended 9 to 11 hours of sleep, and adolescents between the ages of 14 to 17 years old are recommended 8 to 10 hours of sleep for optimal health (Hirshkowitz et al., 2015). However, a US-based study (Mcknight-Eily et al., 2011) found that in a sample of adolescents (N = 12,154), 68.9% reported obtaining less than 8 hours of sleep on a typical school night. Moreover, data analysed by the Centers for Disease Control and Prevention from the 2015 national surveys in the USA of more than 50,000 high school students found that about 73% of adolescents do not get sufficient sleep (defined as ≤ 7 hours; Wheaton, Jones, Cooper, & Croft, 2018). Adolescents exhibit a circadian preference for later sleep, which may partially be due to the biological processes and underlying mechanisms that take place during puberty (Giannotti, Cortesi, Sebastiani, & Ottaviano, 2002; Hasler & Clark, 2013). This is one possible explanation as to the cause(s) of insufficient sleep in this population. Taken together, the findings suggest that a substantial proportion of adolescents do not obtain sufficient sleep.

Insufficient sleep among adolescents has been associated with increased risk for obesity (Lowry et al., 2012), injuries, poorer academic performance (Wolfson & Carskadon, 1998), increased use of substances (Gromov & Gromov, 2009), and increased risk for anxiety and mood disorders (Alfano, Zakem, Costa, Taylor, & Weems, 2009). These adverse health and behavioural outcomes linked to insufficient sleep during this key developmental period suggests that interventions need to be directed towards improving sleep among youth.

Adolescence and Risk-Taking Behaviour

Adolescence is a period marked by multiple changes, which include physiological, intellectual, behavioural, emotional, hormonal, and social development to say the least. During this time, young people are susceptible to trying things for the first time, and risk-taking behaviour is not uncommon (O'Brien & Mindell, 2005). These behaviours include sexual risk-taking, safety and violence-related risk behaviours, as well as drug and alcohol-related risk-taking. Research in the last decade has been dedicated towards understanding the factors that may increase the likelihood of risk-taking behaviour in adolescents, and sleep problems have been implicated to be one of the many factors (Wheaton, 2016).

The Relationship Between Sleep Problems and Alcohol use

Adolescence is a crucial time for neurodevelopment during which the brain undergoes significant changes in the frontal region (Casey, Jones, & Hare, 2008). The cortex (PFC), a region in the brain involved in higher-order cognitive processes, including decision-making and planning, has been implicated in risk-taking behaviour among adolescents (Nilsson et al., 2005). In specific, the ventromedial prefrontal cortex (vmPFC), which is a part of the PFC, has been implicated in the processing of risk, emotional responses, and decision-making (Blakemore & Robbins, 2012).

According to the Somatic Marker Hypothesis, our somatic markers associated with emotions guide our decision-making (Damasio, 1991). In other words, decisions are influenced by negative and positive feelings associated with them. Therefore, it is possible that as a result of sleep loss and reduced metabolic PFC activity, the ability to use our emotions to guide moral judgments becomes impaired, thus increasing the likelihood of engaging in risk-taking behaviour.

Among the multiple risk-taking behaviours, alcohol initiation and frequency of alcohol use are commonly studied in the literature. Young people often experiment with alcohol for the first time during adolescence, which may possibly be due to perceived social acceptability and availability. One study found that in a sample of adolescents between the ages of 14 to 19 years old, 83.4% had at least one drink of alcohol in the past 30 days (O'Brien & Mindell, 2005). Data from the Health Survey England 2016 reported that approximately 64% of 17-year-old boys and 48% of girls drink on a weekly basis (Health and Social Care Information Centre, 2017). These figures suggest that alcohol use is prevalent among adolescents.

Rationale for Review

The relationship between sleep problems and alcohol use among adults is well-documented (Stein & Friedmann, 2006). In comparison, associations between sleep and alcohol use among adolescents is limited and factors that may influence this association remain underexplored. It is critical to understand the relationship between sleep problems and alcohol use during adolescence, particularly since both these problems are prevalent during this time (Gradisar, Gardner, & Dohnt, 2011), and due to their potential negative impact on social well-being, physical health, and brain development during a key developmental period. Several mental health difficulties begin during adolescence, suggesting that adolescents are an 'at-risk' population (Kessler et al., 2007). Also, early onset of alcohol use is one of the most robust predictors of future alcohol use problems in adolescents and adults (Ellickson, Tucker, & Klein, 2003; Grant & Dawson, 1997). Therefore, clarifying the relationship between sleep and alcohol during this stage of development is important in order to minimise potential long-term harm, and may help us to identify early intervention and prevention targets.

Aims of Current Literature Review

The main goal of this systematic review is to provide a review of the literature that has sought to examine the relationship between sleep problems and alcohol use in early and late adolescence, address the limitations, and identify gaps in current knowledge. The aim of this review is to answer the question 'do sleep problems contribute to alcohol use among adolescents?'

METHODOLOGY

A preliminary search was conducted to ensure a comparable review did not exist. The Cochrane Database of Systematic Reviews, and bibliographic databases (Ovid PsycINFO, Embase) were searched using a combination of the following search terms: "sleep problems", "sleep difficulties", "insufficient sleep", "substance use", "alcohol", and "adolescents". One review on sleep duration and risk-taking in adolescents is currently in press (Short & Weber, in press). However, there was no systematic review on sleep problems and alcohol use in adolescents during the initial search.

Search Strategy

The electronic bibliographic database searches were conducted between the 3rd of August, 2017 until the 12th of April 2018. The author also reviewed the reference sections of relevant papers for any additional manuscripts not found from the electronic database searches. Table 1 presents the search terms used on the following databases: Ovid PsycINFO, Embase, and Web of Science.

Table 1. *Search terms used during the systematic search.*

Search term 1	*AND*	Search term 2	*AND*	Search term 3
Sleep deprivation *OR* Insomnia *OR* Sleep difficulties *OR* Sleep prob* *OR* Sleep loss *OR* Sleep dis* *OR* Insufficient sleep *OR* Poor sleep		Alcohol *OR* Alcohol abuse Alcohol intoxication *OR* Alcohol use *OR* Alcohol consumption *OR* Alcohol onset *OR* Alcohol initiation *OR* Drink* *OR* Drinking behav* *OR* Drinking alcohol *OR* Substance use *OR* Substance abuse *OR* Risk taking		Adolescen* *OR* Early adolescence *OR* Youth *OR* Teen* *OR* Young person *OR* Young adult *OR* Young individual

Note: 'AND' and *'OR'* are Boolean operators used to combine search terms
'*' symbol represents truncation

Inclusion/Exclusion Criteria

The search was limited to full-text peer-reviewed articles in English language. The author reviewed studies that included a sample of adolescents. Adolescents in this review refer to young people between the ages of 10 to 19 years old, as defined by the World Health Organisation (WHO, 1980). Studies containing clinical samples were excluded, apart from those comprising participants with alcohol use disorder. Child samples were included if the study contained a follow-up during adolescence. Figure 1 is an illustration of the systematic process of study selection using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA; Moher, Liberati, Tetzlaff, & Altman, 2009). A total of 58 papers were assessed for eligibility, of which 35 papers were removed. Of the papers removed: 15 were outside the age range; 6 did not measure the relationship of the variables in question; 5 included a clinical sample; 4 papers were reviews; 3 looked at chronotype differences exclusively (i.e. the propensity to sleep at a particular time during a 24-hour period); and 2 could not be accessed.

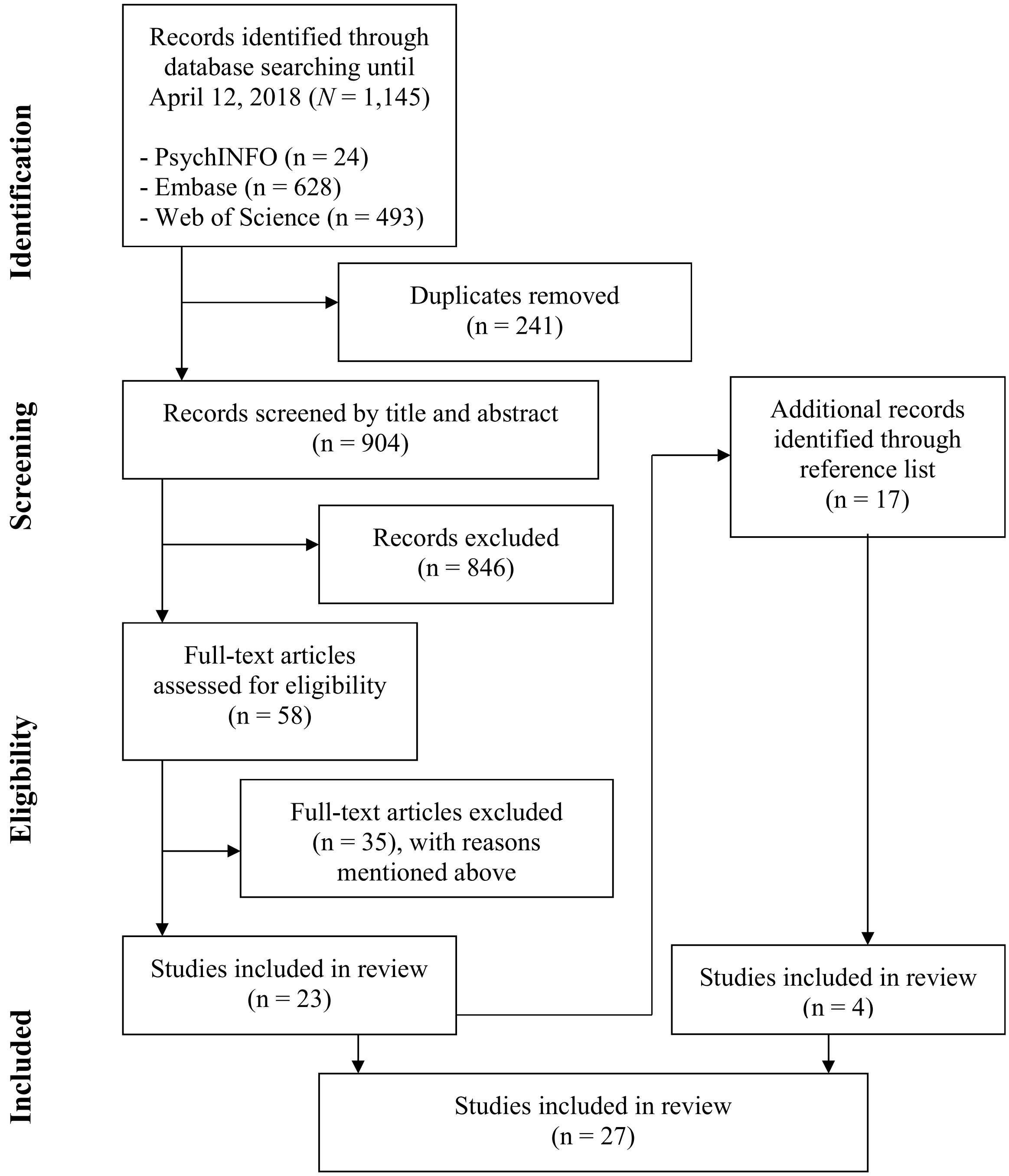

Figure 1. A flow diagram using PRISMA for the systematic process of study selection (adapted from Moher et al., 2009)

Search Outcome

A total of 27 articles were identified for inclusion in the review. Table 2 provides a detailed summary of each of the studies included in this systematic review, emphasising the participants, design of the study, relevant sleep and alcohol measures, and the general findings. The studies are listed in chronological order according to year of publication. Other measures utilised by the studies can be found in Appendix A.

Table 2. *Summary table of studies*

	Authors (year) & Country	Participants	Design	Measures	General Findings
1	Johnson & Breslau (2001) USA	*N* = 13,831 (51% males) Between the ages of 12–17 years Data analysed from the US National Household Survey on Drug Abuse	Longitudinal study between 1994-1996 using cross-sectional data	One item from the Youth Self Report was used to assess for ‘trouble sleeping’ in the past 6 months. Alcohol use and extent was assessed via an interview by asking whether used in the past year and in the past 30 days, and measuring the number of days used.	- When adjusting for internalising and externalising problems, the association between sleep problems and alcohol use reduced and was no longer statistically significant (p = 0.16), suggesting that this association may be partially attributed to psychiatric difficulties.

	Authors (year) & Country	Participants	Design	Measures	General Findings
2	Wong, Brower, Fitzgerald, & Zucker (2004) USA	*N* = 257 Boys only Sample recruited from community of high-risk families (alcohol and other substance-use disorders)	Longitudinal study At Time 1 (T1) the boys were 3 -5 years old At Time 2 (T2) they were 6 - 8 years old At Time 3 (T3) they were 9 - 11 years old At Time 4 (T4) they were 12 - 14 years old	2 items from the Child Behavior Checklist–Parent Version (mother ratings) were used to obtain a measure of ‘overtiredness’ and ‘having trouble sleeping’. (At ages 12-14) The Drinking and Other Drug Use History Questionnaire – Youth Version (DDHQ-Y) was used to asses frequency and quantity of alcohol use. 2 items used to assess the onset of drinking and drunkenness.	- While controlling for parental alcoholism and child’s age, the presence of early sleep difficulties (i.e. overtiredness and/or having trouble sleeping) at ages 3 to 5 increased the likelihood by 2.3 times of early onset of alcohol use at ages 12 to 14 in comparison to children without sleep problems. - There was no significant relationship found between early sleep problems and onset of drunkenness at adolescence.

	Authors (year) & Country	Participants	Design	Measures	General Findings
3	O'Brien, & Mindell (2005) USA (Philadelphia)	*N* = 388 (217 males) Between the ages of 14–19 years (M_{age} = 16.62, no SD provided) Participants were in grades 9 to 12recruited from 4 schools (public and private, urban and suburban)	Correlational study	Sleep Habits Survey was used to assess sleep/wake behaviours in the past 2 weeks. Sleep–Wake Behavior Problems was used to assess for erratic sleep behaviour over the past 2 weeks. Daytime Sleepiness Scale to assess daytime sleepiness. 6 sleep variables analysed: total sleep duration (weekday and weekend), weekend delay, weekend oversleep, time went to bed (weekday and weekend). 5 items from the Youth Risk Behaviour Survey were used to assess the frequency of alcohol use in the past 30 days.	- Participants who slept for less than 6 hr 45 min per night had reported increased alcohol use in comparison to those who obtained at least 8 hr 15 min of sleep/night. This was a non-significant trend. - A significant relationship was found for length of weekend delay and risk-taking behaviours. Specifically, students with greater weekend delay (2+ hours) reported higher scores of risk-taking behaviours, including alcohol use, in comparison to students with shorter weekend delay (≤1 hour).

	Authors (year) & Country	Participants	Design	Measures	General Findings
4	Wong, Brower, & Zucker (2009) USA	*N* = 386 *n* = 292 boys *n* = 94 girls (the majority of the girls joined project between were they were between 6 to 11 years) Sample recruited from community of high-risk families (alcohol and other substance-use disorders)	Longitudinal study At Time 1 (T1) participants were 3 - 5 years old At Time 2 (T2) they were 6 - 8 years old At Time 3 (T3) they were 9 - 11 years old At Time 4 (T4) they were 12 - 14 years old At Time 5 (T5) they were 15 - 17 years old	Two items to assess sleep problems using the Child Behavior Checklist–Parent Version (mother ratings) were used to obtain a measure of ‘overtiredness’ and ‘having trouble sleeping’. One item from the Drinking and Other Drug Use History Questionnaire – Youth Version (DDHQ-Y) was used to assess onset of alcohol use at ages 11 – 17.	- Controlling for parental alcoholism, sleep problems (i.e. overtiredness and trouble sleeping) in early childhood, at ages 3 to 8, increased the probability of early onset of alcohol use in girls from ages 15-17, and in boys from ages 8-14. - First study to examine gender differences on the effects of early sleep problems and onset of alcohol use.

	Authors (year) & Country	Participants	Design	Measures	General Findings
5	Wong, Brower, Nigg, & Zucker (2010) USA	*n* = 292 boys *n* = 94 girls Sample recruited from community of high-risk families (alcohol and other substance-use disorders)	Longitudinal study At Time 1 (T1) participants were 3 -5 years old At Time 2 (T2) they were 6 - 8 years old At Time 3 (T3) they were 9 - 11 years old At Time 4 (T4) they were 12 - 14 years old At Time 5 (T5) they were 15 - 17 years old	2 items to assess sleep problems using the Child Behavior Checklist (mother ratings) were used to obtain a measure of 'overtiredness' and 'having trouble sleeping' (when child was 3 to 8 years olds). 2 items to assess the same sleep problems were measured using the Youth Self Report (when child was 11 to 17 years old). The Drinking and Other Drug Use History Questionnaire - Youth Version (DDHQ-Y) and the Diagnostic Interview Schedule - Child Version were used annually between 11 to 17 years and once between 18 to 20 to obtain a measure of onset of alcohol, as well as frequency and quantity of alcohol use. Alcohol-related variables: binge-drinking, blackouts, driving under the influence of alcohol, and a number of lifetime alcohol-related problems.	- Controlling for age, parental alcoholism, adolescent sleep measures and response inhibition, children who were overtired between the ages of 3 to 8 were more likely than their counterpart to have engaged in all 4 alcohol-related problems by age 18 to 20.

	Authors (year) & Country	Participants	Design	Measures	General Findings
6	Pasch, Laska, Lytle, & Moe, (2010) USA (Minnesota)	*N* = 242 (48.8% male) (M_{age} = 16.4, no SD provided) High school students between grades 9 to 11 Youth were recruited from two existing cohorts and a convenience sample drawn from local communities	Cross-sectional study	To assess weekday and weekend sleep duration, items were adapted from the Night Eating Diagnostic Scale. Sleep patterns for weekend sleep delay and weekend oversleep were calculated. Two items were used to assess alcohol use: how many times they drank alcohol in past month and how many times they got really drunk in the past month.	- Longer weekday sleep duration was negatively associated with depressive symptoms, past month alcohol use, and drunkenness. - Later weekend bedtimes (i.e. weekend delay) as well as weekend oversleep, in comparison to those of weekdays, were associated with increased risk of past month alcohol use, and past month drunkenness.

	Authors (year) & Country	Participants	Design	Measures	General Findings
7	Pieters, Van Der Vorst, Burk, Wiers, & Engels (2010) Netherlands	N = 431 (195 males) Between the ages of 11–14 years (M_{age} = 13.66, SD = 0.55) Data analysed was derived from a larger study on cognitive and psychological risk factors related to alcohol use in adolescents	Cross-sectional study	Sleep problems were assessed using 2 subscales of the Adolescent Sleep-Wake Scale: trouble going to bed and trouble falling asleep. The cognitive subscale of the Adolescent Sleep Hygiene Scale was also used. The Morningness⁄Eveningness scale for children was used to measure circadian preference. Two items relating to alcohol use: frequency per year and quantity consumed per occasion.	- Pubertal development was found to be positively associated with sleep problems (i.e. trouble going to bed, falling asleep, and high cognitive load before bedtime) and preference for later bedtimes, which in turn was found to be associated with increased likelihood of alcohol use. - These associations remained significant even after adjusting for internalising and externalising problems.

	Authors (year) & Country	Participants	Design	Measures	General Findings
8	Yen, King, & Tang (2010) Taiwan (Southern region)	*N* = 8319 Participants were categorised as ≤15 years old vs. ≥15 years old (*n* = 4288). No age range provided. Adolescents were recruited from senior high and vocational schools from urban and rural districts	Cross-sectional study	Sleep duration in the past month was assessed (using self-report & parents' report). One item of the Questionnaires for Experience in Substance Use (Q-ESU) was used to assess whether participants drank alcohol every week in the past year.	- While adjusting for depression, short (<6 hours) and long sleep durations (>8 hours) were significantly associated with regular alcohol consumption in adolescents. - The effect size for short sleep duration was larger than for long sleep duration.

	Authors (year) & Country	Participants	Design	Measures	General Findings
9	McKnight-Eily et al., (2011) USA	*N* = 12,154 (49.7% female) High school students in grades 9 to 12 were recruited from public and private schools Data from the national Youth Risk Behaviour Survey were analysed	Cross-sectional study	Sleep duration was assessed by the question, "On an average school night, how many hours of sleep do you get?" (<8h was defined as insufficient sleep and ≥8 h as sufficient sleep). Current alcohol use was assessed by one item – 'During the 30 days before the survey had at least one drink of alcohol on ≥1 day'.	- More than two thirds of adolescents in the current study (68.9%) reported insufficient sleep <8 h. - After adjusting for sex, age, race/ethnicity, insufficient sleep (<8 h) was found to be associated with higher odds of engaging in health-risk behaviours, including alcohol use (OR: 1.64, 95% CI, 1.46–1.84).

	Authors (year) & Country	Participants	Design	Measures	General Findings
10	Pasch, Latimer, Cance, Moe, & Lytle (2012) USA (Minnesota)	*N* = 704 (51 % female) Between the ages of 10–17 years (M_{age} = 14.68, SD =1.83) Participants recruited from two independent samples of adolescents from cohort studies.	Cross-sectional and longitudinal study (2-year follow-up)	Sleep duration on weekdays and weekends were assessed using items adapted from the Night Eating Diagnostic Scale. Sleep patterns for weekend sleep delay and weekend oversleep were calculated. Alcohol use was assessed by one item: 'how many times in the past month have you tried alcohol?'.	- Shorter sleep duration during the week was found to be associated with an increased likelihood of alcohol use while controlling for confounding variables such as pubertal development, body mass index, and symptoms of depression. - Larger weekday-weekend bedtimes were associated with an increased likelihood of alcohol use. - Weekend sleep delay (later bedtime on the weekend) at baseline was associated with an increased likelihood of alcohol use at 2-year follow-up. - Alcohol use at baseline was associated with an increased likelihood of less weekend sleep at follow-up.

	Authors (year) & Country	Participants	Design	Measures	General Findings
11	Huang, Ho, Lo, Lai & Lam (2013) Hong Kong	*N* = 33,692 (44.9% boys) Between the ages of 11–18 years (M_{age} = 14.8, SD = 1.9) Data analysed from the Hong Kong Student Obesity Surveillance Project in which participants were recruited from 42 schools	Cross-sectional study (Epidemiology study)	Sleep problems in the past 30 days were assessed, namely: symptoms of insomnia (difficulty initiating sleep – DIS, early morning awakening-EMA and difficulty maintaining sleep – DMS), difficulty breathing during sleep, and snoring. Frequency of alcohol use assessed by 1 item 'how often do you drink alcohol in a typical week?'	- Alcohol consumption (i.e. in this case frequency of alcohol use) was positively associated with DMS. - Less than weekly and weekly drinkers in comparison to non-drinkers were more likely to report DMS in a dose–response manner.

	Authors (year) & Country	Participants	Design	Measures	General Findings
12	Morioka et al. (2013) Japan	*N* = 98,867 (49.3% males) No age range provided. Participants were recruited from junior high and senior high schools, and were between grades 7 to 12. The highest percentage of participants were in grade 11 (20.4%)	Cross-sectional study	Symptoms of sleep disturbance in the past 30 days were assessed. 2 items were used to assess subjectively insufficient sleep (SIS) and short sleep duration (SSD). 3 items were used to assess for symptoms of insomnia: difficulty initiating sleep (DIS), difficulty maintaining sleep (DMS), & early morning awakening (EMA). Frequency and amount of alcohol used in the past 30 days were assessed.	- In both boys and girls, the prevalence of SIS, SSD, DIS, DMS, and EMA symptoms increased with the frequency and amount of alcohol use. - While controlling for confounding variables, each sleep disturbance – apart from SIS and EMA –increased as the number of days alcohol consumed increased or the amount of alcohol consumed increased.

	Authors (year) & Country	Participants	Design	Measures	General Findings
13	Hasler, Martin, Wood, Rosario, & Clark (2014) USA (Pittsburg)	*N* = 696 Between the ages of 12–19 years *n* = 347 with Alcohol Use Disorder (AUD; M_{age} = 16.69, SD = 1.26) *n* = 349 without AUD (M_{age} = 15.77, SD = 1.70) Participants were recruited from clinical and community settings.	Longitudinal case-control design study (baseline, 1-, 3-, 5-year follow-up)	Sleep measures were drawn from the Health Problems Checklist (HPC). 4 items assessed for insomnia: trouble staying asleep, early morning waking, trouble falling asleep, and restless sleep. 1 item assessed for hypersomnia: sleeping too much. 2 items from the HPC assessed for sleep variability: weekday and weekend sleep duration The number of DSM-IV alcohol-related symptoms were assessed. The Drug Use Screening Inventory was used to assess frequency of alcohol use in the past month.	- Larger weekday–weekend differences in sleep duration at baseline predicted increases in alcohol symptoms at 3- and 5-year follow-ups in the group without AUD. - In the group without AUD, more symptoms of insomnia predicted an increase in alcohol symptoms at 1-year follow-up.

	Authors (year) & Country	Participants	Design	Measures	General Findings
14	Wong, Rowland, & Dyson (2014) USA (Northwestern)	*N* = 171 (100 females) Between the ages of 11 –17 years (M_{age} = 14.05, SD = 1.46) Participants were junior-high and high-school students recruited from two schools.	Cross-sectional study	Trouble falling asleep or staying asleep was measured using the Insomnia Severity Index, and the Sleep Problem Questionnaire – in the past 2 weeks. The Sleep Disorders Questionnaire was used to measure symptoms of insomnia; night-time breathing; leg movement in the past 6 months. One item was used to assess how often participants used alcohol (0 "never;" 1 "once or twice;" 2 "occasionally but not regularly;" 3 "regularly in the past;" 4 "regularly now").	- Adolescents who reported sleep problems were more likely to report using alcohol in comparison to adolescents who did not report sleep problems. - Sleep problems were found to be associated with lower effortful control (i.e. the ability to suppress a dominant response) and identified self-regulation (e.g. attention and behaviour); however these variables themselves were not found to be associated with alcohol use.

	Authors (year) & Country	Participants	Design	Measures	General Findings
15	Daly, Jameson, Patterson, McCurdy, Kirk, & Michael (2015) USA (North Carolina rural area)	*N* = 987 (51.9% females) Participants were between grades 9 to 12 Data analysed from the Youth Risk Behavior Survey (YRBS), wherein participants were recruited from 2 rural school districts	Cross-sectional study	One item from the YRBS was used to assess sleep duration: "On an average school night, how many hours of sleep do you get?" One item from the YRBS was used to assess for frequency of alcohol use in the last 30 days: "On how many days did you have at least one drink of alcohol?"	- Students (39.8%) in lower grade levels (9^{th} -10^{th}) who reported short sleep durations (≤ 6h) were less likely than students (51.7%) in upper grades (11^{th} -12^{th}) to report alcohol use.

	Authors (year) & Country	Participants	Design	Measures	General Findings
16	Pieters et al. (2015) Netherlands	N = 555 (290 females) Between the ages of 11 –16 years (M_{age} = 13.96, SD= 0.78) Participants were recruited through schools in the province of Gelderland, the Netherlands	Longitudinal study Time 1 (T1) beginning of 2008 Time 2 (T2) end of 2008	Two items from the Adolescent Sleep-Wake Scale (ASWS) and one item from the Adolescent Sleep Hygiene Scale (ASHS) were used. The subscales assessed problems going to bed, falling asleep, and cognitive problems (e.g. thinking of things to do before bedtime). Frequency of alcohol use in the past month was measured on a 6-point likert scale.	- One of the first studies to explore the bi-directional relationship between sleep, substance use, and internalising and externalising problems in adolescence. - Sleep problems at T1 predicted alcohol use as well as internalising and externalising problems at T2. - Conversely, alcohol use at T1 predicted fewer sleep problems at T2.

	Authors (year) & Country	Participants	Design	Measures	General Findings
17	Sivertsen, Skogen, Jakobsen, & Hysing (2015) Norway	*N* = 9328 (54% female) Between the ages of 16 –19 years (M_{age} = 17.9, SD = 0.8) First large population-based study conducted in 2012	Cross-sectional data used	Sleep variables included bed-times and wake-times during the weekday and weekend to calculate: sleep duration, sleep deficit, and bedtime variability. Items on difficulties initiating and maintaining sleep, as well as sleepiness were assessed. Frequency and amount of alcohol consumed in the past 14 days was measured. CRAFFT questionnaire was used to identify problematic alcohol use.	- All 4 sleep variables short sleep duration, sleep deficit, large bedtime differences and insomnia were significantly associated with higher odds of all measures of alcohol and drug use/misuse – partly attenuated by sociodemographic factors and co-existing symptoms of depression and ADHD. - Strongest effect in the current study found between larger weekend-weekday bedtime difference (>4 hours) and increased likelihood of intoxication (OR = 3.0).

	Authors (year) & Country	Participants	Design	Measures	General Findings
18	Wong, Robertson, & Dyson (2015) USA	*N* = 6,504 Data analysed from the largest national longitudinal study of adolescent health (ADD HEALTH)	Longitudinal study Time 1 (T1) in 1994 to 1995 (M_{age} = 15.99, SD = 1.75) Time 2 (T2) in 1996 (M_{age} = 16.02, SD = 1.62) Time 3 (T3) in 2001 to 2002 (M_{age} = 21.82, SD = 1.81)	Two items were used to assess having trouble falling sleeping/staying asleep in the past 12 months (i.e. symptoms of insomnia) and hours of sleep (sleep duration). 4 alcohol-related problems were assessed over the past 12 months: interpersonal problems, binge drinking, driving under the influence of alcohol, and getting into a sexual situation one later regretted due to drinking.	- Lower number of hours of sleep at T1 negatively predicted all 4 alcohol-related problems at T2. - Trouble falling asleep at T1 positively predicted the odds of alcohol-related interpersonal problems, and driving while drunk at T2. - Trouble falling asleep at T2 positively predicted the odds of alcohol-related interpersonal problems, and driving while drunk, at T3.

	Authors (year) & Country	Participants	Design	Measures	General Findings
19	Hasler, Kirisci, & Clark (2016) USA (Pittsburg)	*N* = 707 (71.1% males) Between the ages of 9 – 13 years at baseline (M_{age}=11.39, SD= 0.91) Participants were recruited (by contacting their biological fathers) from treatment programs, advertising, and random-digit dialling	Longitudinal study (followed over 7 visits approximately every 3 years through the age of 30) Visit 1: participants were between ages 12–14 years Visit 2: 16 years Visit 3: 19 years Visit 4: 22 years Visit 5: 25 years Visit 6: 28 years Visit 7: 30 years	Sleep variables were measured using two subscales of the Dimensions of Temperament Survey–Revised: Activity-Sleep which assessed restless sleep, and Rhythmicity-Sleep which assessed variability in sleep timing. An adaptation of the Lifetime Alcohol Use History was used to assess for the onset of alcohol use.	- More restless sleep predicted an earlier onset of alcohol use (11% faster). - Variability of sleep timing was not predictive of the onset of alcohol use. However, more variable sleep timing predicted an earlier onset of alcohol use disorder.

	Authors (year) & Country	Participants	Design	Measures	General Findings
20	Mike, Shaw, Forbes, Sitnick, & Hasler (2016) USA (Western Pennsylvania)	*N* = 186 *n* = 145 (participants who used alcohol) *n* = 140 (participants who used cannabis) Data analysed were drawn from a cohort of 310 boys of low socio-economic status	Longitudinal study	Mothers completed the Child Sleep Questionnaire (CSQ) when participants were 11 years old. Sleep variables included: sleep duration, sleep latency, mid-sleep disturbance, late-sleep disturbance, maternal impression of sleep quality, day disturbance, and sleep efficiency. Interview using the Lifetime Drug and Alcohol Use History when participants were 20 and 22 years old.Alcohol-specific variables included age of first use, intoxication, and repeated use.	- After controlling for race, socioeconomic status, neighbourhood danger, active distraction, as well as internalising and externalising problems, shorter sleep duration and poorer (lower) sleep quality at age 11 were each found to be associated with earlier use, intoxication, and repeated use of alcohol throughout adolescence.

	Authors (year) & Country	Participants	Design	Measures	General Findings
21	Reichenberger, Hilmert, Irish, Secor-Turner, & Randall (2016) USA (rural North Dakota)	*N* = 322 (44% girls) Between grades 9 to 12 and between the ages of 14 – 19 years Participants were recruited from 4 secondary schools Data analysed from the Rural Adolescent Health Survey	Cross-sectional study	Sleep duration was assessed by asking participants about the time they went to bed and the time they woke up. Alcohol use was assessed by asking participants how often they had at least 1 drink in the past month and how often they had 5+ drinks within a couple of hours in the past month.	- Adolescents who reported drinking alcohol in the past 30 days also reported significantly less sleep (*M*= 7.87, SD = 1.09) than adolescents who did not drink in the past 30 days (*M*= 8.16, SD = 0.87). - Adolescents who reported binge drinking (5+ drinks in 1 hour) in the past 30 days were found to sleep fewer hours in comparison to adolescents who did not binge drink.

	Authors (year) & Country	Participants	Design	Measures	General Findings
22	Chen, Bo, Jia, & Liu (2017) China	*N* = 2090 Between grades 7 to 12 (M_{age} =15.5, SD= 2.1) Participants were recruited from three public high schools	Cross-sectional study	The Adolescent Health Questionnaire (AHQ) was used to obtain data on sleep patterns and difficulties, and alcohol use. Items included: sleep duration during the weekday and weekend, overall sleep quality in the past month, and 4 items examining symptoms of insomnia (difficulty initiating sleep, difficulty returning to sleep, early morning awakening and difficulty maintaining sleep) 3 items relating to alcohol use were used: age of alcohol initiation, frequency of ever being drunk, and frequency of consuming alcohol in the past 30 days.	- After controlling for demographics, and internalising and externalising problems, it was found that adolescents who slept <8 hours per night on weekdays were significantly more likely to drink alcohol than adolescents who slept 8> per night on weekdays. - In addition, adolescents who slept <6 hours per night on weekends were found to be at increased risk for getting drunk.

	Authors (year) & Country	Participants	Design	Measures	General Findings
23	Hasler et al. (2017) USA	*N* = 729 (51% females) Between the ages of 12 – 21 years (M_{age} = 15.9, SD = 2.4) Data was collected and analysed from the National Consortium on Alcohol and Neurodevelopment in Adolescence (NCANDA) study	Longitudinal study (1-year follow-up)	Composite Scale of Morningness 4-item version used to assess circadian preference. 1 item from the Pittsburgh Sleep Quality Index to assess for sleep quality. Cleveland Adolescent Sleepiness Questionnaire 5-item version used to assess daytime sleepiness. Sleep Timing Questionnaire was used to calculate sleep duration. Customary Drinking and Drug Use Record used to assess frequency of alcohol use and maximum number of drinks in an occasion during the past year. Estimated blood alcohol concentration levels were calculated to obtain a measure for 'binge drinking'.	- Later weekday bedtime, shorter weekday sleep duration, and greater eveningness at baseline predicted heavier binge drinking at 1-year follow-up, while adjusting for internalising and externalising symptoms. - No significant association was found for daytime sleepiness, rise times, weekend sleep duration, and weekend delay at baseline and alcohol use at 1-year follow-up.

	Authors (year) & Country	Participants	Design	Measures	General Findings
24	Marmorstein (2017) USA	*N* = 127 (64 males) Between the ages of 10 –14 years (M_{age} = 13.2 years, SD = 0.8) Data analysed were drawn from the Camden Youth Development Study	Longitudinal study however only cross-sectional data used	The Pittsburgh Sleep Quality Index and the Child and Adolescent Sleep Habits Questionnaire were used to assess initial insomnia, sleep irregularity, sleep disturbances, and daytime sleepiness. Frequency of alcohol use in the past 4 months was rated on a 5-point likert scale.	- Insomnia was associated with frequency of alcohol use; this association still remained significant after controlling for psychopathology considered (symptoms of conduct disorder, ADHD, and depression) and parental monitoring. - Daytime sleepiness was also found to be associated with frequency of alcohol use. This association remained after adjusting for symptoms of ADHD but not after adjusting for symptoms of conduct disorder, depression, or parental monitoring.

	Authors (year) & Country	Participants	Design	Measures	General Findings
25	Miller, Janssen, & Jackson (2017) USA (Rhode Island)	*N* = 829 (52% female) Between the ages of 12 – 16 years (M_{age} = 12.6 years, SD 1.02) Participants were recruited from a sample of five cohorts of adolescents from six schools	Longitudinal study (over 4 years)	Items from the School Sleep Habits Survey were used to measure sleep duration, bedtime delay, and daytime sleepiness. Onset of alcohol use and onset of heavy episodic drinking were assessed, using measures designed based on recommendations of the National Institute of Alcohol Abuse and Alcoholism. The Rutgers Alcohol Problems Index (RAPI) was used to assess onset of alcohol-related consequences (e.g. not being able to do homework).	- After controlling for age, sex, and internalising and externalising behaviours, shorter sleep duration and greater daytime sleepiness in year 1 increased the likelihood of early onset of alcohol use (i.e. first full drink), engaging in heavy drinking, and alcohol-related consequences by year 4.

	Authors (year) & Country	Participants	Design	Measures	General Findings
26	Nguyen-Louie et al. (2017) USA (San Diego)	*n* = 95 youth (47% female) At Time 1 participants were between 12 – 14 years old Participants were middle school students recruited through fliers	Longitudinal neuroimaging project (spanning 8 years) At Time 1 participants were (M_{age}=13.4, SD = 0.7), At Time 2 (M_{age}=15.1, SD = 0.9), At Time 3 (M_{age}=19.8, SD = 0.9) years old	Sleep Habits Questionnaire (added at a later time so not all parents completed this) Sleep scales included: - The Sleepiness Scale which assessed for daytime sleepiness in the past 2 weeks - The Sleep/Wake Problems Behavior Scale which assessed for the frequency of erratic behaviours relating to sleep/waking in the past 2 weeks The Superscience Morningness/Eveningness Scale which assessed for chronotype. The Customary Drinking and Drug Use Record, an interview based assessment, was used to assess lifetime of alcohol use (completed by participant and other informant e.g. parent).	- Controlling for erratic sleep/wake behaviour and chronotype, greater daytime sleepiness predicted higher alcohol use. - Controlling for daytime sleepiness and erratic sleep/wake behaviors, higher evening chronotype tendencies predicted significantly higher alcohol use. - Controlling for daytime sleepiness and chronotype, more erratic sleep/wake behaviours predicted significantly lower alcohol use. - In follow-up analyses examining the effects of each sleep behaviour in its own path-analytic model, it was found that higher evening chronotype tendencies, greater daytime sleepiness, and more erratic sleep/wake behaviours each predicted significantly higher alcohol lifetime use.

	Authors (year) & Country	Participants	Design	Measures	General Findings
27	Warren, Riggs, & Pentz (2017) USA	*N* = 709 (50% females) Between the ages of 8 – 11 years in 4th grade (M_{age}= 9.27, SD = 0.47) Data analysed was from the Pathways to Health, a randomised controlled trial on the prevention of obesity-related behaviours	Longitudinal study	Four items from the Sleep Habits Survey were used to assess bed-time and wake-time during the weekday and during the weekend to obtain a measure of average sleep duration, weekend-weekday wake-time delay, weekend-weekday bed-time delay. One item on alcohol use drawn from a national drug use survey was used: "Have you ever tried alcohol (beer, wine, liquor that is not for religious purposes)?" Self-report of >1 sip of alcohol was used to indicate lifetime alcohol use.	- A significant positive association was found between weekend bed-time delay and alcohol use initiation at 6th grade. - Weekend wake-time delay and average nightly sleep duration were not found to be directly associated with lifetime alcohol use.

Overview of Identified Studies

The studies ranged in publication year from 2001 to 2017. The majority of the studies (20) reviewed were conducted in the USA across different states (Daly et al., 2015; Johnson & Breslau, 2001; Hasler et al., 2014; Hasler et al., 2017; Hasler, Kirisci, & Clark, 2016; Marmorstein, 2017; McKnight-Eily et al., 2011; Mike et al., 2016; Miller, Janssen, & Jackson, 2017; Nguyen-Louie et al., 2017; O'Brien & Mindell, 2005; Pasch et al., 2010; Pasch et al., 2012; Reichenberger et al., 2016; Warren, Riggs, & Pentz, 2017; Wong et al., 2004; Wong et al., 2010; Wong, Brower, & Zucker, 2009; Wong, Rowland, & Dyson, 2014; Wong, Robertson, & Dyson 2015); two in the Netherlands (Pieters et al., 2010; Pieters et al., 2015); one in Norway (Sivertsen et al., 2015); one in Taiwan (Yen, King, & Tang, 2010); one in China (Chen et al., 2017); one in Japan (Morioka et al., 2013); and one in Hong Kong (Huang et al., 2013).

Sample sizes varied between 95 and 98,867 participants. Thirteen studies were comprised of a longitudinal design, thirteen comprised a cross-sectional design, and one was a correlational study. The age range was from 3 to 30-years-old, as one longitudinal study included 7 follow-ups through to the age of 30 (Hasler et al., 2016). Five of the studies included a high-risk sample (i.e. children of parents with alcohol/substance use disorder), with the remaining studies comprising typically developing early to late adolescents in public or private schools.

Quality Appraisal

A critical appraisal of the methodological quality of each study was undertaken. This review utilised the National Institute for Health and Care Excellence (NICE) quality appraisal checklist for quantitative studies reporting correlations and associations, which enables the reviewer to appraise a study's internal and external validity (NICE, 2012). The NICE 2012 checklist appraises five main areas: population, method of selection, outcome measures, analysis conducted, and finally an overall rating is provided for internal and external validity (see Appendix B for detailed criteria of the five main areas). Each item on the checklist is awarded one of five possible grades (see Table 3). Two items from the checklist were excluded from the table as they were not applicable to any of the study designs included in the current review: 'were all important outcomes assessed?' and 'is the setting applicable to the UK?'.

Table 3. *Possible grading using the NICE (2012) quality appraisal checklist*

Grade	Explanation of grade
++	The study has been designed or conducted in such a way to minimise the risk of bias
+	The study may have not addressed all potential sources of bias or the answer to the checklist question is not clear from the way the study is reported
-	There may have been aspects of the study design in which significant sources of bias may persist
Not Reported (NR)	The study under review fails to report how they might have considered the aspect in question
Not Applicable (NA)	Study design aspects that are not applicable given the study under review

In order to reduce the risk of bias and to increase reliability, a second rater appraised a sample of six studies and any differences in ratings were then discussed until 100% consensus was reached. Tables 4-6 present the ratings awarded for each of the studies, and is colour coded to simplify reading, where green denotes the criterion has been met, yellow denotes the criterion that has slightly been met and red denotes the criterion has not been met.

Table 4. *Ratings of studies 1 to 10 using the NICE (2012) Quality Appraisal Checklist*

		1) Johnson & Breslau (2001)	2) Wong et al. (2004)	3) O'Brien & Mindell (2005)	4) Wong et al. (2009)	5) Wong et al. (2010)	6) Pasch et al. (2010)	7) Pieters et al. (2010)	8) Yen et al. (2010)	9) Mcknight-Eily et al. (2011)	10) Pasch et al. (2012)
Population	Source population or source area well described?	++	++	++	++	++	++	++	++	++	++
	Eligible population or area representative of the source population or area?	+	+	++	+	+	++	++	++	+	+
	Selected participants or areas represent the eligible population or area?	+	++	++	++	++	+	++	++	++	++
Method of Selection	Selection bias minimised?	**NR**	++	+	++	++	+	++	++	++	++
	Selection of explanatory variables based on sound theoretical basis?	++	++	++	++	++	++	++	++	++	++
	Confounding factors identified and controlled?	-	-	-	+	+	+	+	+	++	-
Outcome	Outcome measures and procedures reliable?	+	+	+	+	+	+	+	+	+	+
	Follow-up time meaningful?	+	+	**NA**	+	+	**NA**	**NA**	**NA**	**NA**	+
Analyses	Sufficiently powered?	++	+	+	+	+	+	++	++	++	++
	Multiple explanatory variables considered in the analysis?	++	++	+	++	++	++	++	++	++	+
	Analytical methods appropriate?	++	++	+	++	++	+	++	+	+	+
	Precision of association given or meaningful?	++	+	+	++	++	+	+	+	++	+
	Internal validity	+	+	++	+	+	+	+	+	+	+
	External validity	++	+	+	+	+	+	+	++	++	+

Table 5. *Ratings of studies 11to 20 using the NICE (2012) Quality Appraisal Checklist*

		11) Huang et al. (2013)	12) Morioka et al. (2013)	13) Hasler et al. (2014)	14) Wong et al. (2014)	15) Daly et al. (2015)	16) Pieters et al. (2015)	17) Sivertsen et al. (2015)	18) Wong et al. (2015)	19) Hasler et al. (2016)	20) Mike et l. (2016)
Population	Source population or source area well described?	++	++	++	++	++	++	++	+	++	++
	Eligible population or area representative of the source population or area?	++	++	+	+	+	+	++	++	+	+
	Selected participants or areas represent the eligible population or area?	++	++	+	+	+	+	+	+	++	+
Method of Selection	Selection bias minimised?	++	++	+	-	+	**NA**	++	**NA**	++	+
	Selection of explanatory variables based on sound theoretical basis?	++	++	+	++	+	++	++	++	++	++
	Confounding factors identified and controlled?	+	+	-	+	-	+	++	+	+	+
Outcomes	Outcome measures and procedures reliable?	+	+	+	+	+	+	++	+	+	+
	Follow-up time meaningful?	**NA**	**NA**	+	**NA**	**NA**	+	**NA**	-	+	+
Analyses	Sufficiently powered?	++	++	+	+	++	++	++	++	++	+
	Multiple explanatory variables considered in the analysis?	++	+	+	++	+	++	++	++	++	++
	Analytical methods appropriate?	++	+	++	+	++	++	+	+	++	++
	Precision of association given or meaningful?	+	++	+	+	+	++	++	++	++	++
	Internal validity	+	+	+	+	+	+	+	+	+	+
	External validity	+	++	+	-	+	+	++	++	++	+

Table 6. *Ratings of studies 21 to 27 using the NICE (2012) Quality Appraisal Checklist*

		21) Reichenberger et al. (2016)	22) Chen et al. (2017)	23) Hasler et al. (2017)	24) Marmorstein (2017)	25) Miller et al. (2017)	26) Nguyen-Louie et al (2017)	27) Warren et al. (2017)
Population	Source population or source area well described?	+	++	++	+	++	++	++
	Eligible population or area representative of the source population or area?	+	++	++	+	++	+	+
	Selected participants or areas represent the eligible population or area?	+	++	++	+	++	++	++
Method of Selection	Selection bias minimised?	-	++	++	-	++	+	++
	Selection of explanatory variables based on sound theoretical basis?	++	++	++	++	++	++	++
	Confounding factors identified and controlled?	-	+	+	+	+	+	+
Outcomes	Outcome measures and procedures reliable?	+	+	+	+	+	+	+
	Follow-up time meaningful?	**NA**	**NA**	++	**NR**	++	+	+
Analyses	Sufficiently powered?	+	++	++	+	++	-	++
	Multiple explanatory variables considered in the analysis?	+	++	++	++	++	++	++
	Analytical methods appropriate?	++	**NA**	++	++	++	+	+
	Precision of association given or meaningful?	+	++	+	+	++	+	+
	Internal validity	+	+	+	+	+	+	+
	External validity	+	-	+	-	++	-	+

RESULTS

The systematic review of the literature identified a number of key themes in the findings of the studies; namely; sleep duration, insomnia, variability in sleep timing, and daytime sleepiness.

Sleep Duration

Thirteen studies explored the relationship between sleep duration and alcohol use. O'Brien and Mindell (2005) found that adolescents between the ages of 14 to 19 years old who slept for less than 6 hr 45 min per night reported increased alcohol use in comparison to those who obtained at least 8 hr 15 min of sleep per night. However, this was a non-significant trend. Similarly, Reichenberger et al. (2016) found that adolescents (N = 322) in grades 9 to 12 who reported drinking alcohol in the past 30 days also reported sleeping significantly less (M_{age} = 7.87) than adolescents who did not drink in the past 30 days (M_{age} = 8.16). Similar findings were also reported in a cross-sectional study including a sample of US high school students (N = 242) between grades 9 to 11 (M_{age} = 16.4). Longer weekday sleep duration (M = 7.7 h, SD = 0.9, range: 4.8-10) was found to be negatively associated with past month alcohol use, drunkenness, and symptoms of depression (Pasch et al., 2010). Another cross-sectional study using a large sample of Taiwanese adolescents (N = 8319), found that short (< 6 hours; n = 1093) and long (> 8 hours; n = 648) sleep durations were significantly associated with increased alcohol consumption in the past year while controlling for symptoms of depression (Yen et al., 2010).

McKnight-Eily and colleagues (2011) used data from the Youth Risk Behaviour Survey (N = 12,154) to analyse the relationship between sleep and alcohol in US high school students between grades 9 to 12 recruited from public and private schools. Insufficient sleep (< 8 hours) was found to be associated with higher odds of engaging in alcohol use (AO = 1.64; 95% CI 1.46–1.84). This was a cross-sectional study, which therefore limits our ability to draw any causal conclusions. However, the researchers used only one item to assess for current alcohol use, which may limit the reliability and validity of the finding. Also, the quality appraisal of the study (see Table 4), identified this study as having low internal validity.

In a study comprised of a sample of US adolescents (N = 704) between the ages of 10 to 17 years (M_{age} = 14.68), cross-sectional analyses revealed that shorter sleep duration during the week was associated with an increased likelihood of alcohol use in the past month at baseline, while controlling for pubertal development, body mass index, and symptoms of depression (Pasch et al., 2012). In a large-scale epidemiological Japanese study (Morioka et al., 2013) including adolescents between grades 7 to 12 (N = 98,867), short sleep duration (< 6 hours) was associated with an increase in the frequency and amount of alcohol used in the past month in both boys and girls. As with all cross-sectional design studies, the findings are limited, as we cannot assume the direction of the relationship of this association. Short sleep duration may be attributable to alcohol intake; however, it is also possible that participants used alcohol as a means to resolve their sleep disturbances.

Wong and colleagues (2015) conducted a longitudinal study in the USA (N = 6504) and collected data from participants at three time points; time 1 (T1) in 1994 to 1995 (M_{age} = 15.99), time 2 (T2) in 1996 (M_{age} = 16.02), and time 3 (T3) in 2001 to 2002 (M_{age} = 21.82). The results showed a significant negative correlation between number of hours of sleep at T1, and alcohol-related interpersonal problems (e.g. getting into a fight with parents) and binge-drinking at T2.

In a large population-based cross-sectional study (Sivertsen et al., 2015) conducted in Norway (N = 9328), short sleep duration (< 5 hours) was found to be associated with higher odds of alcohol use (OR = 2.3) in adolescents between the ages of 16 to 19 (M_{age} = 17.9) in a dose-response manner. The relationship was partly attenuated by sociodemographic factors and co-existing symptoms of depression and ADHD. The sleep and alcohol measures used were well-defined in the current study. The quality appraisal (see Table 5) identified this study as having a number of strengths. Similarly, in a longitudinal study (Mike et al., 2016) involving a sample of urban boys (*n* = 145) of low socioeconomic status, mothers were asked to complete the Child Sleep Questionnaire (CSQ) when participants were 11-years old. The participants were then interviewed at ages 20 and 22. The findings suggested that shorter sleep duration (≤ 8.75 hours) is a risk factor for earlier alcohol use, intoxication, and repeated use even when accounting for other covariates including race, socioeconomic status, and externalising and internalising behaviours. Although the study provides initial evidence for sleep's developmental role in alcohol use, the findings need to be interpreted with caution, as they may not be generalised to other populations. Also, there were other confounding variables that were not controlled for in the current study, which include parental use, peer use, and access to substances. Consequently, this study was not highly appraised, and is deemed to have low to moderate internal and external validity (see Table 5).

In another longitudinal study conducted in the USA examining the relationship between sleep and substance use in adolescents between the ages of 12 to 16 years (M_{age} = 12.6) it was found that longer sleep duration in year 1 in comparison to shorter sleep duration was associated with decreased odds of early alcohol use, (Hazard Ratio = 0.87, 95% CI = 0.79-0.96, *p* = 0.004), heavy drinking, (HR = 0.80, 95% CI = 0.70-0.91, *p* = 0.001), and alcohol-related consequences (HR = 0.82, 95% CI = 0.70-0.96, *p* = 0.01) at 4-year follow-up (Miller at al., 2017). After adjusting for internalising and externalising symptoms, Hasler and colleagues (2017) found that shorter weekday sleep duration at baseline predicted heavier binge drinking at 1-year follow-up in a sample (*N* = 729) of US adolescents between the ages of 12 to 21 years. In both studies, the researchers controlled for externalising and internalising problems behaviours, as well as psychiatric symptoms, which suggests that the association found between sleep duration and alcohol is not entirely due to psychopathology. Chen and colleagues (2017) found that in a large sample (*N* = 2090) of Chinese adolescents between grades 7 to 12 those who slept for less than 8 hours per night on weekdays were more likely to drink alcohol in comparison to those who slept for more than 8 hours per night on weekdays. Additionally, adolescents who slept for less than 6 hours per night on weekends were found to be at increased risk of getting drunk. These associations were independent of demographics, and internalising and externalising problems. Alcohol measures in the current study included age of alcohol initiation, frequency of ever getting drunk, and frequency of alcohol use in the last 30 days. However, information on the quantity of alcohol consumed was lacking.

Insomnia

A total of 12 studies explored the relationship between symptoms of insomnia and alcohol use. When adjusting for internalising and externalising behaviours, Johnson and Breslau (2001) found that the association between trouble sleeping in the past 6 months and alcohol use reduced in a large sample of adolescents (*N* = 13,831) between the ages of 12 to 17 years. In a longitudinal study (Wong et al., 2004) comprising of a sample of boys only (*N* = 257), having trouble sleeping at ages 3 to 5 years increased the likelihood of early onset of alcohol use at ages 12 to 14 years in comparison to children without sleep problems, while controlling for parental alcoholism and child's age. In their follow-up study (Wong et al., 2009) which included girls (*n* = 94; *n* = 292 boys), trouble sleeping in early childhood at ages 3 to 8 years, increased the probability of early onset of alcohol use in girls from ages 15 to 17 years and in boys from ages 8 to 14 years while controlling for parental alcoholism. This was the first study to report on gender differences with respect to sleep problems and subsequent alcohol use. Hasler et al. (2016) found that more restless sleep at baseline predicted an increased risk (up to 11% faster) of earlier onset of alcohol use in young people between the ages of 9 to 13 years.

In a cross-sectional study conducted in Hong Kong, the frequency of alcohol use in a typical week was positively associated with difficulty maintaining sleep in a sample of adolescents (*N* = 33,692) between the ages of 11 to 18 years (M_{age} = 14.8; Huang et al., 2013). Trouble falling asleep or staying asleep was also found to be associated with alcohol use in a sample of junior and senior high school students (*N* = 171) between the ages of 11 to 17 years. It was found that self-regulation mediated the effects of these sleep difficulties on alcohol use and other substances in this sample (Wong et al., 2014). In a further study, Wong et al. (2015) analysed data from a large national study of adolescent health (*N* = 6,504) and participants were assessed at three time points namely; time 1 (T1) in 1994 to 1995 (M_{age} = 15.99), time 2 (T2) in 1996 (M_{age} = 16.02), and time 3 (T3) in 2001 to 2002 (M_{age} = 21.82). Trouble falling asleep at T1 positively predicted alcohol-related interpersonal problems, and driving while drunk at T2. Trouble falling asleep at T2 positively predicted alcohol-related interpersonal problems, and driving while drunk at T3. In a Dutch longitudinal study (Pieters et al., 2015) comprised of youth (*N* = 555) between the ages of 11 to 16 years old (M_{age} = 13.96), problems going to bed, falling asleep, and cognitive problems (e.g. thinking of things to do before bedtime) at the beginning of 2008 (T1) predicted alcohol use and internalising and externalising problems at the end of 2008 (T2). Conversely, alcohol use at T1 predicted fewer sleep problems at T2.

Symptoms of insomnia increased with the frequency and amount of alcohol use in a sample of Japanese boys and girls between grades 7 to 12 (Morioka et al., 2013), as well as in a sample of Norwegian adolescents (N = 9328) between the ages of 16 to 19 years (Sivertsen et al., 2015). However, the association in the latter study was partly attenuated by sociodemographic factors and symptoms of depression and ADHD. In another study (Hasler et al., 2014), symptoms of insomnia at baseline predicted a significant increase in alcohol symptoms at 1-year follow-up in adolescents without AUD ($n = 349$; $M_{age} = 15.77$). In a more recent cross-sectional US study (Marmorstein, 2017), after controlling for symptoms of conduct disorder, ADHD, depression, and parental monitoring, symptoms of insomnia were found to be associated with the frequency of alcohol use in the past 4 months in a sample of early adolescents (N = 127) between the ages of 10 to 14 years.

Variability in Sleep Timing

A total of 10 studies explored the relationship between sleep variability and alcohol use. O'Brien and Mindell (2005) found that students who reported greater weekend delay (i.e. sleeping later on the weekend, 2+ hours) also reported higher alcohol use, in comparison to students with shorter weekend delay (≤1 hour). In a cross-sectional study comprising of US high-school students, later weekend bedtimes (i.e. weekend delay) as well as weekend oversleep, in comparison to those of weekdays, were associated with increased likelihood of past month alcohol use, and past month drunkenness (Pasch et al., 2010). In another US study (Hasler et al., 2017), after adjusting for internalising and externalising symptoms, later weekday bedtime at baseline predicted heavier binge drinking at 1-year follow-up in a sample of adolescents.

In a cross-sectional study (Pieters et al., 2010) conducted in the Netherlands, pubertal development (i.e. more mature early adolescents) was found to be associated with later bedtimes, which in turn was found to be associated with an increased likelihood of alcohol use amongst youth between the ages of 11 to 14 years. These associations remained even after adjusting for internalising and externalising behaviours. In a US-based cross-sectional and longitudinal study (Pasch et al., 2012), youth who were using alcohol at baseline had a larger discrepancy between weekend-weekday bed-time in comparison to youth who were not using alcohol. Also, the researchers found that greater weekend sleep delay at baseline was positively associated with alcohol use at 2-year follow-up. In a more recent longitudinal study (Warren et al., 2017) comprised of a sample ($N = 709$) of 8 to 11 year olds in 4th grade ($M_{age} = 9.27$), direct associations between weekend bedtime delay in 4th grade and alcohol use initiation at 6th grade were found. Interestingly, the researchers also found that inhibitory control may be a mediating factor in this relationship, such that students who reported greater inhibitory control were less likely than those with less inhibitory control to use alcohol at 6th grade. In the study by Sivertsen and colleagues (2015), larger differences in weekend-weekday bedtime (> 4 hours) were found to be associated with frequent alcohol intoxication in a sample of Norwegian adolescents. Interestingly, this was the strongest effect the researchers found in their study.

In a longitudinal case-control design study (baseline, 1-, 3-, 5-year follow-up), Hasler and colleagues (2014) investigated the relationship between sleep difficulties in adolescents with ($n = 347$) and without alcohol use disorder (AUD; $n = 349$) recruited from clinical and community settings. The researchers found that larger weekday–weekend differences in sleep duration at baseline predicted increases in alcohol symptoms at 3- and 5-year follow-ups in the group without AUD. However, in another US-based longitudinal study (Hasler et al., 2016) comprised of participants between the ages of 9 to 13 who were followed over seven visits through to age 30 years, no significant relationship between variability of sleep timing and the onset of alcohol use was found. However, the researchers found that variability of sleep timing predicted an earlier onset of AUD by 18%.

However, contradictory to the majority of findings, a longitudinal study found that more erratic sleep/wake behaviour was associated with lower alcohol use (Nguyen-Louie et al., 2017). This study had low overall statistical power due to the relatively small sample size (*n* = 95), and as such the findings need to be interpreted with caution (see Table 6).

Daytime Sleepiness

A total of 5 studies explored the relationship between daytime sleepiness and alcohol use. Marmorstein (2017) found greater daytime sleepiness was found to be associated with an increase in the frequency of alcohol use in a sample of early adolescents. Interestingly, this association still remained significant after adjusting for symptoms of ADHD, but not after adjusting for symptoms of conduct disorder, depression, or parental monitoring. In one longitudinal study, the researchers found that greater daytime sleepiness in year 1 predicted initiation of alcohol use, heavy drinking (defined as having 3+ drinks in one sitting), and alcohol-related consequences (e.g. not being able to do homework) at year 4 in a sample of adolescents (Miller et al., 2017). Unlike the study by Marmorstein (2017), this association remained significant above and beyond internalising and externalising symptoms, which suggests that this association may not be entirely due to psychopathology. Nguyen-Louie et al. (2017) found that greater daytime sleepiness predicted higher alcohol use in a longitudinal study using a sample of US adolescents (n = 95), while controlling for erratic sleep/wake behaviour and chronotype. In follow-up analyses examining the effects of each sleep variable in their own path-analytic model, it was found that greater daytime sleepiness predicted significantly higher alcohol lifetime use. Considering the small sample size, it may be that the overall statistical power and external validity of the study is reduced. Two studies in this review did not find a significant association between daytime sleepiness and alcohol use (Hasler et al., 2017; O'Brien & Mindell, 2005).

DISCUSSION

Overview

Taken together, some of the findings from this review suggest that shorter sleep duration is associated with an increased likelihood of alcohol use (Chen et al., 2017; Mcknight-Eily, 2011; Mike et al., 2016; Morioka et al., 2013; O'Brien & Mindell, 2005; Pasch et al., 2012; Sivertsen et al., 2015; Yen et al., 2010) and alcohol-related interpersonal problems (Miller et al., 2017; Wong et al., 2015) among adolescents. However, the extent of this association differed amongst studies. Some studies showed a prospective association between sleep problems and earlier onset of alcohol use. However, the nature of the sleep problem differed amongst studies with some suggesting that overtiredness and trouble falling asleep in early childhood (Wong et al., 2004; Wong et al., 2009) increases the probability of earlier onset of alcohol use during adolescence, and others suggesting shorter sleep duration prospectively predicted the onset of adolescent alcohol use (Mike et al., 2016; Miller et al., 2017). In one study, more restless sleep predicted an earlier onset of alcohol use up to 11% faster (Hasler et al., 2016). A small but growing body of evidence suggests that sleep problems may possibly precede alcohol use.

Studies have shown that adolescents have significant differences in bedtime and wake-times on weekdays versus weekends, which may be rooted in their biological mechanism of the circadian system during puberty (Wolfson & Carskadon, 1998). Consequently, variability in sleep timing may result in insufficient sleep or oversleep. Findings from this review suggest that sleep variability (i.e. inconsistent weekend-weekday bedtime difference) may contribute to alcohol use among adolescents (O'Brien & Mindell, 2005; Pasch et al., 2010; Pasch et al., 2012; Pieters et al. 2010; Sivertsen, 2015; Warren et al., 2017). Some of these studies demonstrated a prospective relationship between sleep variability and subsequent alcohol use (Hasler et al., 2014; Hasler et al., 2017; Nguyen-Louie et al., 2017), with one study linking weekend bedtime delay in 4th grade to onset of alcohol use in 6th grade (Warren et al., 2017).

Some studies showed that symptoms of insomnia (Huang et al., 2013; Marmorstein, 2017; Morioka et al., 2013; Sivertsen et al., 2015; Wong et al., 2014) and greater daytime sleepiness (Marmorstein, 2017; Miller et al., 2017; Nguyen-Louie et al., 2017) were associated with higher odds of alcohol use. Only a few studies demonstrated a prospective relationship between symptoms of insomnia and subsequent alcohol use (Hasler et al, 2014; Pieters et al., 2015) and alcohol-related interpersonal problems (Wong et al., 2015).

It is also important to note that a number of longitudinal studies included in this review did not show an association between specific sleep parameters and alcohol use among adolescents (Hasler et al., 2016; Hasler et al., 2017; Warren et al., 2017; Wong et al., 2004). Also, one longitudinal study (Pieters et al., 2015) showed a relationship between sleep and alcohol in the opposite direction, in which alcohol use at time 1 predicted fewer sleep problems at time 2. In another study, when confounding variables (i.e. internalising and externalising behaviours) were taken into account, the association between alcohol and sleep decreased (Johnson & Breslau, 2001), suggesting that the link between sleep and alcohol may be partially explained by the presence of psychiatric difficulties. These studies may have failed to show the expected predictive relationship possibly due to the weak methodological designs employed, which did not control for a number of moderating and/or confounding variables that may have influenced the link between sleep and alcohol. Also, sleep patterns and circadian rhythms may differ between early adolescents versus late adolescents, which may in part explain why some studies did not show a relationship. Effect sizes were not explicitly included in the studies reviewed; however, this may have been calculated and may have allowed us to draw conclusions as to the magnitude of the differences reported.

Although sleep has multiple parameters, the most studied in the literature include total night-time sleep duration, differences in sleep times between weekdays and weekends, and insomnia. Overall, the findings suggest that sleep patterns (bedtimes and wake-times) and duration may be important early markers for adolescent alcohol use.

The purpose of this review was to answer the question ‘do sleep problems contribute to alcohol use among adolescents?’. Taken together, while controlling for confounding variables, such as internalising (e.g. emotional difficulties) and externalising behaviours (e.g. conduct disorders), there is evidence to suggest that aspects of poor sleep may contribute to subsequent alcohol use among adolescents (Hasler et al., 2016; Miller et al., 2017; Mike et al., 206; Pasch et al., 2012, Pieters et al., 2015; Wong et al., 2009; Wong et al., 2015). It is important to note that caution must be made when interpreting the data given that a number of studies in this review employed weak designs (i.e. mainly cross-sectional associations), used different measures, and relied on self-reports.

Potential Mechanisms

Processes involved in self-regulation, executive functioning, and decision-making may further explain the relationship between sleep problems and alcohol use (Wong et al., 2014). Neuroimaging studies have shown that insufficient sleep and poor sleep quality are related to an imbalance between affective and cognitive control systems (Telzer, Fuligini, Lieberman, & Galván, 2013; Yoo et al., 2007). Specifically, it has been suggested that sleep deprivation is associated with reduced functional connectivity between the vmPFC and amygdala (i.e. an area in the brain responsible for emotional regulation). It may be that changes in affect associated with sleep deprivation make it difficult for adolescents to inhibit their risk-taking behaviour, such as engaging in alcohol use (Edwards, Reeve, & Fishbein, 2015). It may also be that reduced executive functioning makes adolescents more susceptible to peer pressure or less likely to consider the negative outcomes associated with risk-taking behaviours. There is evidence that suggests the developing adolescent brain is characterised by immature impulse control; therefore, the effects of inadequate sleep on the likelihood to engage in alcohol use may be intensified during adolescence. The exact underlying neural mechanisms that mediate the relationship between sleep problems and alcohol use are still unclear and future research should focus on identifying self-regulatory processes that explain this relationship. As Conroy (2017) suggested, it is likely that the onset of alcohol use and other illicit drugs during adolescence is influenced by a number of factors other than poor sleep alone. Parental style and supervision (i.e. parental monitoring), childhood behavioural/conduct disorders, cultural values, ongoing hormonal and brain changes during puberty, and adverse childhood events are all potential factors that may moderate the relationship between sleep and alcohol use, and future studies need to control for these factors.

Methodological Considerations and Limitations

The studies reviewed are not without limitations. Several studies employed a cross-sectional design, which are not without limitations. Firstly, it does not allow for temporal analysis. Secondly, it restricts our ability to infer any causal relationship between sleep difficulties and alcohol use. Also, the majority of the studies included in this review were comprised of predominantly White/Caucasian adolescents. To increase external validity, future studies would benefit from including a more diverse sample. Some of the studies included a sample of high-risk participants (i.e. adolescents of parents with a history of alcohol use) while others included a sample of healthy adolescents, and two included a sample of youth with low socio-economic status. Therefore, these findings have limited generalisability and will need to be interpreted with caution.

Only a few studies have investigated the relationship between sleep difficulties in adolescents with and without AUD. A particular strength of the study by Hasler et al. (2014) is that it is the largest study to date to examine sleep complaints among adolescents with AUDs. Also, the methodological design employed allowed for temporal analyses. However, it is important to note, there were several limitations in the latter study. Firstly, the researchers did not control for cannabis-use disorder in the AUD group. Secondly, there was a significantly larger attrition rate in the AUD group. Thirdly, males were more likely to drop out by 5-year follow-up in both groups. Fourthly, the analysis did not consider on-going treatment in the AUD group.

Fifthly, the assessment of sleep problems was based on retrospective self-reports. It may be that the association between sleep problems and alcohol use is due to their association with psychiatric problems. For instance, Johnson and Breslau (2001) found that the association between trouble sleeping and alcohol use reduced after adjusting for internalising and externalising behaviours, suggesting that the association may be partially attributed to psychiatric difficulties.

Studies in this review used self-report or parent-report questionnaires to assess different aspects of sleep, such as sleep quantity and trouble falling asleep. The use of self- or parent-report measures of sleep is a major limitation and the data may be subject to bias or memory distortions due to retrospective entries. More broadly within the context of sleep literature, there is a lack of validated sleep measures for children and adolescents. Some sleep measures (e.g. CSQ, see Mike et al., 2016) utilised in the studies had low internal consistency and may not be a reliable representation of sleep difficulties, making the psychometrics questionable. However, some studies (O'Brien & Mindell, 2005; Pieters et al., 2010; Sivertsen et al., 2015; Wong et al., 2014) used valid and reliable measures of sleep such as the Sleep Habits Survey, or scales that were drawn from well-validated measures (Hasler et al., 2017). Nonetheless, given that all studies used subjective measures, they were awarded a grade of '+' for outcome measures on the quality framework (see Tables 4-6). The inclusion of sleep self-reports in addition to more objective and reliable measures of sleep, such as actigraphy, polysomnography, sleep diaries, or diagnostic interviews may increase reliability. However, in studies involving large cohorts the use of objective sleep measures may be impractical.

A number of studies did not assess for the quantity of alcohol use, which would be essential for future studies to include. There is variability in the literature as to what constitutes insufficient sleep. For instance, McKnight-Eily and colleagues (2011) defined insufficient sleep as 8 hours or less, while other sleep researchers used 6 hours or less as a cut-off (Daly et al., 2015; Morioka et al., 2013; Yen et al., 2010). Therefore, caution must be made when interpreting the findings and drawing conclusions.

The relationship between daytime sleepiness and alcohol use amongst adolescents is less clear in the literature and scarce. For instance, in the study by Marmorstein (2017) the association between greater daytime sleepiness and alcohol use was no longer significant after adjusting for symptoms of conduct disorder, depression, or parental monitoring. This suggests that this relationship may partially be due to the presence of symptoms of mental health problems or parental monitoring. Furthermore, the findings from the same study may not be generalised to other populations and has low external validity due to the following reasons; firstly, 71 % of the sample were Hispanic with the remaining being African-American. Secondly, the sample was comprised of low-income, minority youth. Thirdly, the study may be deemed as having low statistical power due to a relatively small size. Nonetheless, this study is an important contribution to the sleep literature as it is the first to focus on youth from a lower socioeconomic background. As of present, it is difficult to draw any firm conclusions regarding the association between daytime sleepiness and alcohol use in adolescents and further research is needed to elucidate this relationship.

Daytime napping is common amongst adolescents, especially after returning from school (Giannotti et al., 2002). However, none of the studies included in this review took into account time spent napping during the day, which may effect night-time sleep quality and quantity. Studies including both children and adolescents in a longitudinal design study (e.g. Wong et al. 2004; Wong et al., 2009) while controlling for confounding variables may potentially shed light on the mechanisms by which sleep patterns affect alcohol use and vice versa. It is interesting to note that none of the studies was conducted in the UK, which may suggest that adolescent sleep is a neglected research topic in the UK. Once again, the findings reported here need to be interpreted with caution, as they may not necessarily be applicable to a sample of UK adolescents.

Research Implications

This review focused on investigating whether sleep problems may be early indicators of increased risk for alcohol use in young people. However, there are numerous studies that have focused on the reverse. On the whole, longitudinal research (e.g. Miller et al., 2017; Nguyen et al., 2017) is lacking and more prospective studies are needed to clarify the bidirectional relationship between sleep problems and alcohol use.

Gender differences were not discussed in this paper, as this was beyond the scope of the current review. However, the findings regarding gender-based differences in the impact of sleep problems on alcohol use has been inconsistent in the literature. For instance, in one study (Pasch et al., 2010) in the gender-stratified model, shorter duration of weekday sleep was associated with increased alcohol use in the past month for boys, but not for girls. In another study (Huang et al. 2013), the association between weekly drinking and difficulty maintaining sleep was significant for both boys and girls; however, the association was found to be stronger in boys. Moreover, it has been suggested that being male and of low socioeconomic status (SES) may be a risk factor for subsequent alcohol use (Warren et al. 2017; Yen et al., 2010). Therefore, further research warrants an investigation on the relationship between gender, SES, sleep problems, and alcohol use. Additionally, youth who are more developed or mature report more sleep problems (Pieters et al., 2010). It would be noteworthy to further explore the nature of sleep difficulties in early adolescence vs. in late adolescence, as this review comprised the broad range.

Potential individual and family factors that may affect the association between sleep-related problems and alcohol use among adolescents remain largely unexplored. Some studies (Chen et al., 2017; Miller et al., 2017, Pieters et al., 2010; Pieters et al., 2015) discussed in this review controlled for internalising and externalising behaviours. However, future work needs to include other variables such as parental monitoring, peer influence, environmental features in the bedroom (e.g. room ambience or sharing the bedroom with siblings), use of electronic media, and self-regulation. Taken together, findings should be interpreted within the context of internal (e.g. developmental changes in sleep architecture) and external (e.g. school start times) factors that may contribute to adolescent sleep-related difficulties.

Binge drinking has been shown to be a risk factor for the development of later alcohol use problems (Chassin, Pitts, & Prost, 2002) and it is currently on the rise among youth (Patrick & Schluenberg, 2014). Therefore, it may be worthwhile for future research to focus on the relationship between sleep and binge drinking particularly in adolescence as they are deemed to be an at-risk population. Lastly, it is important to note that ‘circadian rhythms and/or preference’ were not included as part of the search criteria and therefore relevant articles may have been overlooked and not included in this systematic review.

Clinical Implications

Developing good sleep habits early in adolescence may act as a protective factor, preventing youth from engaging in alcohol use and other possible risk-related behaviours. Improving sleep quality and quantity may be important targets of intervention to decrease alcohol use in adolescents. Fortunately, sleep problems are a modifiable risk factor and there are means to address this potential vulnerability both at the individual and systemic levels.

Parental Monitoring and Sleep Schedules. In a survey by the National Sleep Foundation, approximately 71% of parents reported that they believed that their children were obtaining sufficient sleep (National Sleep Foundation, 2006). This indicates a lack of awareness amongst parents regarding insufficient sleep amongst adolescents. Studies (DiClemente et al., 2001; Ledoux, Miller, Choquet, & Plant; 2002) have shown that lower levels of parental monitoring are associated with increased risk for the onset of substance use in adolescents. Sleep variability during the weekdays and weekends may reflect a lack of parental monitoring and control over sleep schedules, which would still be developmentally appropriate during early adolescence. Sleep variability has also been found to be associated with multiple other problems, apart from alcohol use, such as mood disorders and academic problems (O'Brien & Mindell, 2005; Pasch et al., 2010). Given the evidence provided, encouraging adolescents to monitor their amount of sleep and to maintain more consistent weekday-weekend sleep schedules may be a potential prevention approach in reducing the risk of alcohol use. Also, it may be useful for future studies to investigate whether parental monitoring is a common risk factor for both sleep and substance problems.

Health Education and Screening. Classes during the early years targeted at educating young people and parents about the importance of sleep hygiene and the potential consequences of poor sleep and risk-related behaviours, including drinking, may be useful. In a recent systematic review and meta-analysis of 7 studies, it was found that school-based sleep education programmes were associated with longer sleep duration and improved mood among adolescents post-treatment. However, these improvements were not found at follow-up (Chung, Chan, Lam, Lai, & Yeng, 2017). Given the limited number of studies, future studies aimed at comprehensively assessing early adolescent sleep health education as a protective factor from late adolescent alcohol use is needed. In addition, it may be helpful for practitioners working with young people to routinely gather information on sleep habits, which may possibly serve as a screening tool for mental health and alcohol use and other substances. Screening questionnaires that evaluate sleep duration and hygiene may be less threatening than direct questions regarding mental health problems, which are stigmatised among youth. Incorporating sleep hygiene, which involves promoting earlier bedtimes, into the treatment protocol for youth with mood disorders and/or substance use problems may produce better clinical outcomes.

Delayed School Start Times. From a policy standpoint, adolescents may benefit from delayed school start times. Delayed school start times are associated with a host of positive outcomes such as increased total night-time sleep, improved academic performance, improved performance on computer-tasks requiring attention, reduced daytime sleepiness and symptoms of depression (Lufi, Tzischinsky & Hadar, 2011; Owens, Belon & Moss, 2010). Furthermore, the American Academy of Pediatrics (2014) recognises insufficient sleep in adolescence as a fundamental public health issue that affects the health and safety of students and recommends that schools start classes no earlier than 8:30am to allow students to obtain adequate sleep. However, this shift has not been made possible across all nations possibly due to issues relating to feasibility and practicality.

Mindfulness. There is evidence suggesting that emotional regulation and inhibitory control mediates the relationship between sleep problems and alcohol use outcomes (e.g. Pasch 2010; Wong et al., 2009); as such, it may be helpful to discuss interventions targeted to increase these factors, which in turn may help to reduce the likelihood of engaging in alcohol use. Mindfulness-based approaches are one way to train individuals to increase inhibitory control and emotional regulation that have shown to be effective (Tang, Tang, & Posner, 2016). Therefore, fostering this skill may act as a 'protective factor' by preventing youth from engaging in risk-taking behaviour, such as alcohol use. However, research on the impact of mindfulness-based approaches in children and adolescents with sleep problems is still limited (Bei et al., 2012).

Conclusion

There is moderate evidence suggesting that short sleep duration and symptoms of insomnia may be early indicators of increased alcohol use among adolescents. These findings need to be interpreted with caution in light of limitations. It is clear that there is a need for future research to employ more longitudinal design studies to explore the relationship between specific sleep problems and subsequent alcohol use, which appears to vary according to the nature of the sleep problem. Also, further research is needed to clarify what and how neurological, cognitive, or emotional processes may mediate the relationship between sleep problems and alcohol use in adolescents. This systematic review has shed light on the importance of adequate sleep in an at-risk population, and highlighted clinical implications and interventions that could potentially have ameliorative long-term effects.

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CHAPTER 2: EMPIRICAL PAPER

Auditory Cueing During Wakefulness and Its Effect on Memory Retrieval in Typically Developing Young Adults

Abstract

Objectives. The purpose of the study was to investigate the effect of auditory cueing during wakefulness, and to explore its impact on memory performance. It was hypothesised that auditory cueing may elicit a 'decline' in memory (i.e. reduced performance on memory recall tasks).

Methods. 27 female participants between the ages of 18 to 22 years old (M_{age} = 19.29, SD =1.06) were recruited through a University online Research Participation Scheme. Participants completed self-report sleep measures and took part in a number of behavioural tasks over two consecutive days, with the main outcome measures being performance on a delayed (T2) and next-day memory retrieval task (T3).

Results. The results revealed no main effect for cueing, F (1, 26) = 0.33, p = .57, suggesting that whether words had been cued or not this did not significantly impact subsequent performance on memory retrieval tasks. Also, the results revealed no significant interaction effect, F (1, 26)= 0.19, p = .67, indicating that whether words were cued or not did not have a significant effect on memory retrieval at either T2 or T3. Descriptive analyses showed that on average participants correctly remembered uncued words more than cued words at T2 and T3; however, this did not reach statistical significance. The results demonstrated a main effect for retrieval time, F (1, 26) = 53.55, p < .001, indicating that participants retained more information at T3 (M = 79.34 %) than at T2 (M = 62.09 %).

Conclusions. The findings revealed that participants retained more information following a night's sleep, irrespective of cueing. It may be that the natural process of sleep-specific memory consolidation aided in retaining information. However, we cannot rule out that repeating the retrieval tasks at different time points may have aided in learning. Future studies investigating the effect of cueing during wakefulness using different manipulations are warranted.

Keywords: auditory cueing, memory recall, associative memory, memory retention

INTRODUCTION

Memory Consolidation and Reactivation

Long-term memory formation relies on two processes; encoding (or learning) and consolidation (Alberini, Bambah-Mukku, & Chen, 2012). After initial learning, individual memories exist in a fragile state and undergo change before transferring into our long-term memory storage and becoming 'fixed' or permanent. The processes whereby newly acquired information undergoes changes to become more stable and enduring is known as memory consolidation (Müller & Pilzecker, 1900), which has been shown to be accentuated during the offline period of deep Slow Wave Sleep (SWS; Walker, 2009). Consequently, this suggests that memory remains vulnerable to disruption for a period of time after initial learning.

The time interval after initial learning, including sleep and awake resting states, may be important for successful learning and may represent a hitherto underexplored window into human memory enhancement. There is growing evidence that suggests that the delivery of auditory or olfactory cues, a procedure referred to as targeted memory reactivation (TMR), during sleep can promote consolidation and 'boost' memories (Antony, Gobel, O'Hare, Reber, & Paller, 2012; Rudoy, Voss, Westerberg, & Paller, 2009), thereby strengthening individual memories.

TMR is based on evidence that suggests that hippocampal neuronal networks that are activated when learning new information during wakefulness are spontaneously re-activated during subsequent SWS (Peigneux et al., 2004). It has been shown that cueing (or TMR) elicits the same hippocampal replay as spontaneous reactivations as well as modulations in slow oscillations and spindles (Schreiner & Rasch, 2014), thereby strengthening memory representations. Taken together, the evidence suggests that sensory input may induce reactivation of specific memories that is supported by changes in neural mechanisms thereby contributing to the stabilisation of memories (van Dongen et al., 2012).

The effect of TMR has been shown to depend on prior learning. For instance, in one study (Creery, Oudiette, Antony, & Paller, 2015) where the researchers were interested in exploring the optimal conditions for cueing, young adults (N = 20) learned the spatial locations of objects in the presence of a sound on a computer screen prior to taking a 90-minute nap. During SWS, half of the objects were cued (i.e. participants were re-exposed to the sounds played during initial learning). Shortly after waking, participants repeated the same object-location task as in initial learning. The results revealed that if initial learning is extremely poor or near-perfectly memorised, then there is no effect on subsequent memory retrieval of using cue presentations during sleep. However, TMR during sleep produced benefits for objects with strong sound-object-location associations made during the learning phase.

TMR During Wakefulness

Studies have shown that presenting olfactory (Diekelmann, Büchel, Born, & Rasch, 2011; Rasch, Büchel, Gais, & Born, 2007) or auditory cues (Antony et al., 2012; Rudoy et al., 2009) to participants while they are sleeping can enhance memory formation. Specifically, re-exposure to externally induced cues of previously learned associations during sleep was shown to improve subsequent memory recall and recognition, without participants being aware of that manipulation. However, the evidence is less clear with regards to cueing during awake rest, with some studies showing no effect (Rasch et al., 2007; Rudoy et al., 2009; Schreiner & Rasch, 2015) and others suggesting that it 'weakens' or aids in more forgetting of memories (Diekelmann et al., 2011).

In a study by Schreiner and Rasch (2015), German-speaking participants learned Dutch-German word pairs before being placed into one of two conditions: active waking (n = 16) or passive waking (n = 16), where they were re-presented with previously learned Dutch words. In the active waking group, cueing was presented while participants performed a working memory task, during which they were instructed to focus on the task (i.e. to ignore the auditory cues). Participants in the passive waking group were instructed to pay attention to the replay of the words. The results revealed that re-exposure to Dutch words did not improve later recall of the German translation in either the active or the passive waking group in comparison to uncued words. In another study (Rasch et al., 2007), participants learned an object-location task (i.e. visuospatial memory) and a finger-tapping task (i.e. procedural memory) in the presence of an odour during the evening. Following this, participants in the wakefulness group (n = 18) were re-exposed to the odour (versus 'vehicle' which is no odour) while they completed a vigilance task for approximately an hour. Participants then went to sleep as they typically would and memory retrieval was assessed the next morning. The results revealed that odor cues during wakefulness versus vehicle presentation did not effect the retention of visuospatial memories nor procedural memory. Taken together, the findings from these two studies suggest that there is no effect of word or olfactory cueing during wakefulness on subsequent memory retrieval.

Conversely, in the study by Diekelmann et al. (2011) participants (N = 24) learned an object-location task in the presence of an odour. Participants were then placed into one of two conditions: wakefulness (n = 12) or SWS where they were re-presented with the odour. A particular strength in the current study is that the researchers had a control condition, in which each participant was also presented with an odourless vehicle (i.e. no reactivation) in a balanced order. Following this, participants completed an interference task without odour presentation and were then tested on initial recall of the object-location task. The results revealed that participants' recall of the object-location task significantly improved after odour reactivation during SWS (84.18 ± 4.68%) in comparison to odourless vehicle (60.80 ± 4.24%). However, participants in the wake group demonstrated significantly reduced recall on the object-location following odour-cues (41.43 ± 4.68%) in comparison to the odourless vehicle (59.39 ± 4.24%). The researchers suggested that reactivation during wakefulness may have returned memories into an active or labile state making them susceptible to interference and forgetting, as evidenced by reduced recall.

Clinical Relevance

TMR may be a gateway to developing new therapies in various clinical populations. It could be a promising tool to strengthen or weaken memories depending on when and how it is applied. There is growing evidence that suggests that TMR during sleep can improve subsequent declarative memory (Diekelmann, Biggel, Rasch, & Born, 2012; Schreiner & Rasch, 2015). In that respect, it may be that TMR can potentially be used as a non-invasive, non-pharmacological intervention in individuals with memory difficulties, such as Mild Cognitive Impairment (MCI) or Alzheimer's Disease (AD). One of the most common early noticeable changes for persons with MCI or AD is their tendency to become more forgetful (Peterson, 2003; Reisberg, Gordon, McCarthy, & Ferris, 1985). Currently, there is no evidence to suggest that there is any pharmacological treatment to help individuals from 'forgetting'. However, using TMR during sleep may be a gateway for keeping information from being forgotten.

There are theories that suggest that traumatic events are processed and stored differently (van der Kolk, 2002). From a clinical standpoint, it is possible that TMR may be used as an early intervention strategy in individuals who experience trauma. By weakening traumatic memory traces via cueing during awake resting states, this method of re-exposure may lead to hypo-consolidation (i.e. weakening the traumatic experience before they sink in too deeply into memory), which in turn may prevent symptoms of PTSD from emerging later on (e.g. flashbacks and nightmares). In persistent PTSD, a sense of current threat arises from disturbance of autobiographical memory characterised by poor elaboration and contextualization, and strong associative memory (Ehlers & Clark, 2000). That being said, it is not uncommon for individuals with PTSD to experience extreme distress in response to cues in the environment (e.g. specific sounds) that are perceived as current threat. Perhaps a novel psychotherapeutic approach may be to use cueing to consolidate new re-evaluated non-threat memories. This approach may be considered somewhat similar to exposure therapy. However, the manipulations involved in cueing operate at an unconscious level and so may in fact be less distressing for the client. It is important to emphasise that more research is needed before we able to safely use TMR in clinical populations.

Objective and Hypothesis

It is still unclear in the literature what the optimal conditions are that influence certain memories to become more stable and enduring over time, and whether experimental cueing can ‘rescue’ specific memories from being forgotten and/or weaken others. Therefore, this study will contribute by filling in the gaps in the current literature by providing us with a better understanding of TMR manipulation during wakefulness and its impact on subsequent memory.

This study was part of a wider study investigating the effect of auditory cueing during awake and sleep conditions (Cairney, Guttesen, El Marj, & Staresina, 2018). The objective of this study was to investigate the effect of auditory cueing during wakefulness, and to explore its impact on memory performance. It was hypothesised that auditory cueing during wakefulness would be detrimental to subsequent memory recall. It was assumed cueing during wakefulness might return memories into an active or labile state making them susceptible to interference, as in the study by Diekelmann et al. (2011). It was expected that participants would perform poorly on the delayed retrieval task and the next-day retrieval task for words that were cued in comparison to words that were not cued.

METHODOLOGY

Participants

Twenty-seven undergraduate students between the ages of 18 to 22 with no history of any neurological disorders, specific learning difficulties/disabilities or visual or hearing impediments were recruited via a University online Research Participation Scheme for psychology undergraduate students. Participants were compensated for their participation by obtaining either 3.5 credits or £22. Informed written consent was obtained from each participant after they read the study information sheet (see Appendix C & D). Ethical approval for this study was obtained from the University of Birmingham (see Appendix E).

Sleep Questionnaires

Sleep questionnaires were included to obtain a measure of the quality and quantity of sleep. It was decided that participants with poor sleep hygiene would be excluded from our analysis. The Epworth Sleepiness Scale (ESS) is a self-report questionnaire that measures level of daytime sleepiness. Participants were asked to rate the likelihood of dozing off in eight different situations (e.g. ‘Watching TV’) on a 4-point likert scale, with 0 representing ‘no chance of dozing’ and 3 representing ‘a high chance’. The test-retest reliability is 0.88, which suggests the ESS has a high level of internal consistency (Johns, 1992; 1993).

The Pittsburgh Sleep Quality Index (PSQI) is a 19-item questionnaire that is used to assess sleep quality over the past month. Items are rated on a 4-point likert scale, with 0 representing ‘no difficulty’ and 3 representing ‘severe difficulty’. Global PSQI scores were calculated, with a range of 0 to 21 points, with lower scores indicating better quality of sleep and higher scores indicating severe sleep difficulties. The test-retest reliability is 0.89 and validity is 0.86, suggesting the PSQI is an acceptable measure for distinguishing good and poor sleepers (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989).

The Stanford Sleepiness Scale (SSS; Hoddes, Dement, & Zarcone, 1972) is a self-report questionnaire that measures level of alertness. Participants were asked to rate their level of alertness on a 7-point likert scale, with 1 indicating ‘feeling active, alert and wide awake’ and 7 indicating ‘no longer able to fight sleep’ (see Appendix F). The test-retest reliability is 0.88, and the validity using the Wilkinson addition and vigilance tests is a correlation of 0.68 (Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973).

Procedure

The experiment involved 4 main phases; namely, pre-familiarisation, encoding, retrieval, and offline. Participants were provided with written instructions and completed a practice run prior to the start of each experimental task (see Appendix G for instructions). All testing took place in the psychology testing cubicles at the university. During the experimental tasks, audio recordings were played at a standardised volume via a set of Advent speakers, which were connected to the computer. The behavioural tasks were run on the computer using MATLAB version R2016b and Psychtoolbox version 3.0.13.

Testing was conducted over two consecutive days. On day one, testing took place between 8:30AM-12:00PM during which participants completed the sleep questionnaires prior to the behavioural experiments. Participants encoded pairwise associations before an initial retrieval task (T1), in which adjective recognition memory was assessed (i.e. old/new). Then, recognised adjectives were assessed by asking participants to recall the associated image (i.e. object or scene). The correctly recalled adjective-object and adjective-scene pairs were randomly assigned to either cued condition or non-cued condition (equally distributed). Adjectives in the cued condition were replayed during the offline phase. Additionally, adjectives to-be-cued were intermixed with a number of control adjectives (i.e. new words not seen during encoding), which were half the number of stimuli in the cued condition. Following T1, participants completed a working memory task during which cues were presented. Following this, participants were asked to leave the laboratory and to return 4.5 hours later. Once they returned, they completed a delayed retrieval task (T2). On day two (i.e. after 24 hours), participants returned to the laboratory and completed the retrieval (T3) and discrimination tasks, and were debriefed about the nature of the study. It is important to note that participants were not informed on day one that their memory would be tested on day two.

Pre-familiarisation. There were two tasks for the pre-familiarisation phase, with each task lasting for appproximately 6 minutes. The purpose the pre-familiarisation phase was to expose participants to stimuli they would later be asked to associate together during the encoding phase. For the first task, participants were visually presented with one of 100 adjectives displayed for 2.5 s on the computer screen while simultaneously hearing the spoken word of the adjective. Participants were instructed to indicate whether the adjective had a positive or negative connotation by pressing the left or right arrow keys, respectively (see Figure 1). The list of adjectives in the current study was adapted from the study by Staresina and colleagues (2011).

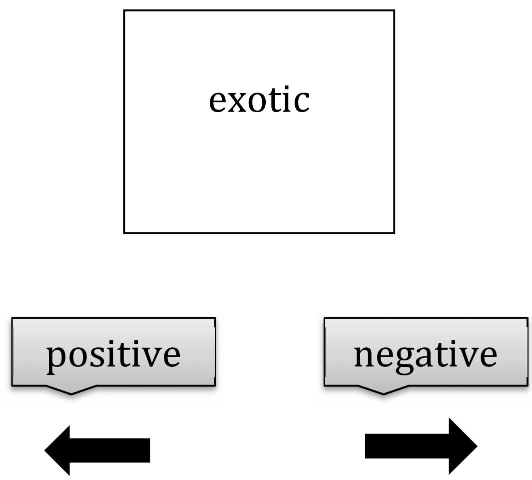

Figure 1. An illustration of the adjective task during the pre-familiarisation phase.

For the second task, participants were presented with either one of 50 objects or one of 50 scene images displayed for 2.5 s on the computer screen along with their caption. Participants were instructed to determine whether the image was an object or a scene by pressing on the left and right arrow keys, respectively (see Figure 2). Each trial was separated by an inter-stimulus interval (ISI) with a fixation cross for 1.5 s (± 100 ms random jitter). The purpose of using object and scenes was to be able to decode category-specific patterns in the sleep/EEG version of the study. The adjectives were used because they were neutral and unlikely to evoke a particular brain pattern that might interfere with object vs. scene decoding.

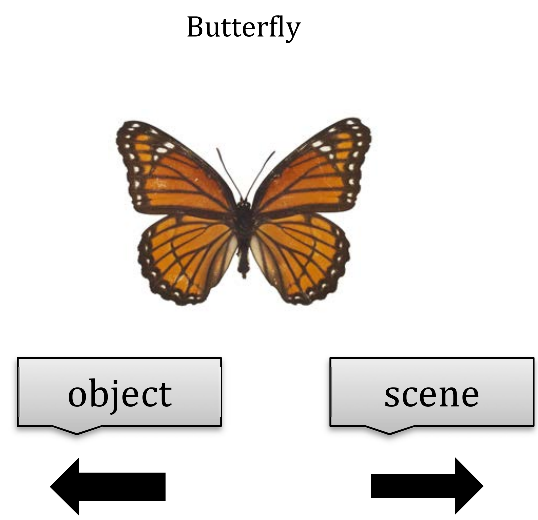

Figure 2. An illustration of the object-scene task during the pre-familiarisation phase.

Encoding. During the encoding phase, participants were presented with object/scene images for 4.5 s on the computer screen along with hearing an adjective being spoken (100 adjective-image pairs). Participants were instructed to create a meaningful link between the adjective and image to facilitate encoding before indicating whether the association between the two was 'realistic' or 'bizarre' by pressing on the left or right arrow keys, respectively (ISI = 1.5s ± 100 ms). The purpose of instructing participants to indicate whether the association they made was realistic or bizarre was simply to facilitate the process of linking an adjective and image together. Using a paired associate task was chosen because associative memory is known to benefit from sleep (Lehmann, Seifritz, & Rasch, 2016). This task lasted for approximately 12 minutes (see Figure 3).

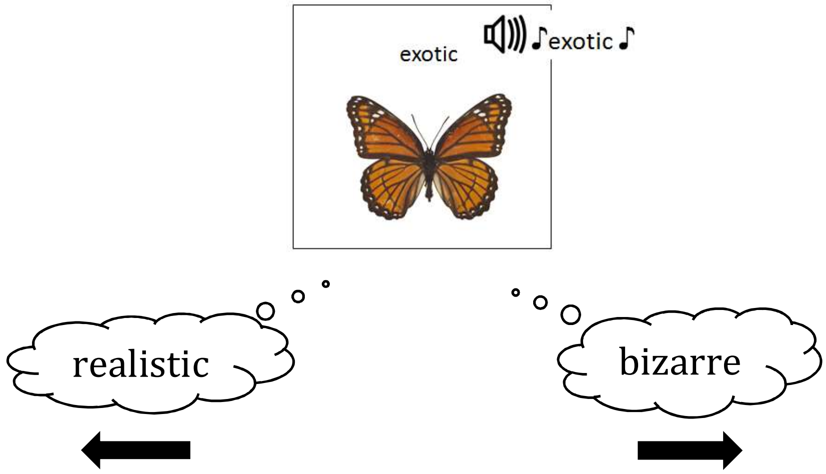

Figure 3. An example of the task during encoding.

Retrieval. Following the encoding phase, participants completed a retrieval task in order to obtain a baseline measure of cued recall. Adjectives (100 adjectives from encoding intermixed with 50 new adjectives that participants had not been exposed to before) were acoustically and visually presented on the computer screen for 2 s. Participants were instructed to indicate whether the adjective was old (i.e. previously seen) or new by pressing the left or right arrow keys, respectively. If participants indicated that the adjective was 'new', this resulted in progression to the next word. However, if participants indicated that the adjective was 'old', they were then asked to indicate which category (object/scene) the adjective was previously associated with by pressing on the left or right arrow keys, respectively. If participants had forgotten which image the adjective had been previously paired with, they pressed the downward arrow key indicative of 'I don't know'. In order to ensure that their responses were not mere guesses, if participants identified that an association had been made, they were then asked to describe the image (i.e. object or scene) that had been paired with the adjective. Participants were instructed to type '?' if they were unable to recall or describe the image (see Figure 4). This method of assessing retrieval allows us to look at different levels of memory: recognition memory, associative memory, and semantic memory.

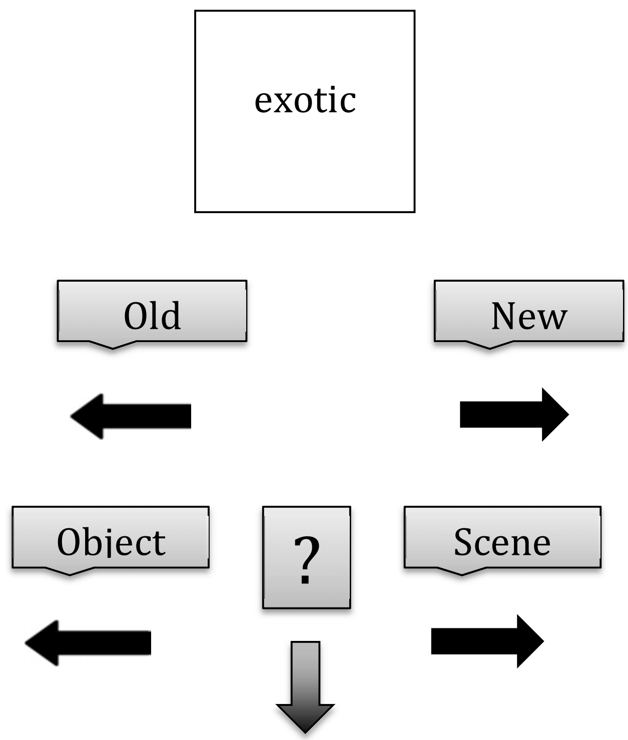

Figure 4. An illustration of the retrieval task.

Offline. The total duration of the offline phase was 90 minutes in order to match the sleep condition of the wider study (see Cairney et al., 2018). Similar to the study by Schreiner and Rasch (2015), participants were asked to play an online game (Bubble Shooter) for 30 minutes, during which no sounds were being played. Following this, participants completed a 1-back working memory task for 30 minutes. For the 1-back task, a series of random numbers between 0 and 10 were presented one after another in the centre of the screen. Their task was to identify if the current number was the same (i.e. target) or different (i.e. non-target) compared to the prior digit by pressing on the right or left arrow keys, respectively. For instance, in the series *...5…3*, the ‘3’ is not a target as the number one digit prior is a ‘5’. However, in the series *…9…9,* the second ‘9’ is a target number as it appeared one digit prior (see Figure 5). During the 1-back task, half of the adjectives previously exposed to the participants during encoding were presented continuously. Following the 1-back task, participants played Bubble Shooter for the remaining 30 minutes.

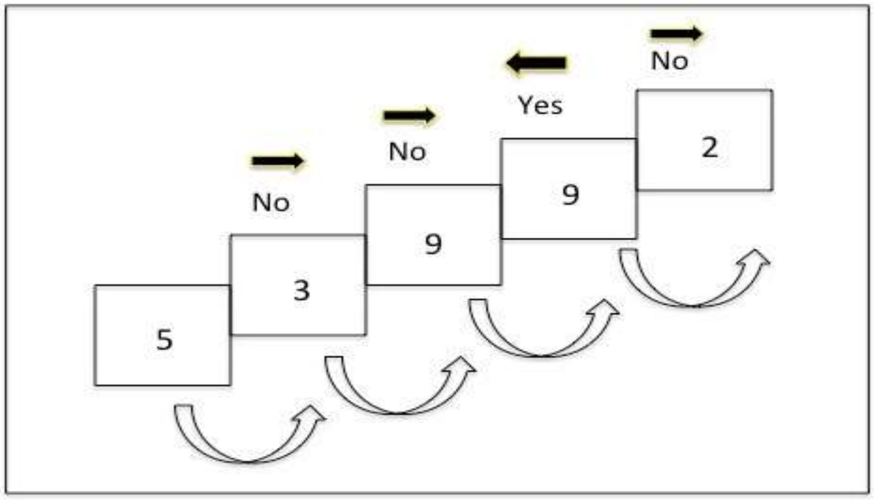

Figure 5. An example of the 1-back task.

Discrimination. Immediately after completing T3 (on the second day), we assessed whether participants were able to consciously attend to the auditory cues presented during the offline phase. In order to verify whether participants attended to the auditory cues that were presented the day before during the offline phase, participants were re-presented (auditory and visual) with all of the adjectives they heard during the encoding phase. Participants were asked to indicate whether the adjective was replayed during the offline phase by pressing the left or right arrow keys (see Figure 6). This part lasted for approximately 5 minutes.

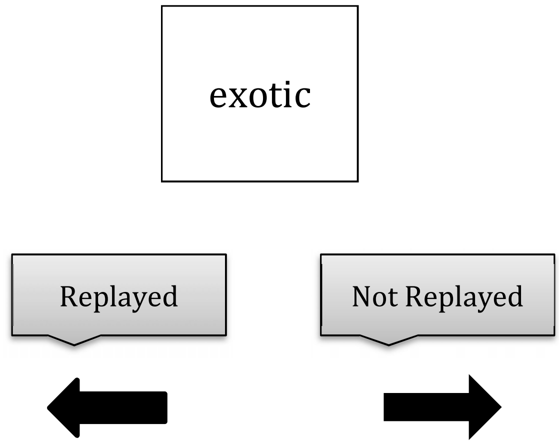

Figure 6. An illustration of the discrimination task.

Data Analysis

An ‘adjusted memory score’ was used to penalise a participant’s tendency to guess. For instance, consider that in the old/new recognition memory task there are 100 old items and 100 new lures. If a participant presses ‘old’ on every trial, their HIT rate would be 100%. However, if we take into account the false alarm rate, which for arguments sake we’ll say is 100%, we would be able to conclude that the participant was merely guessing. Therefore, by subtracting the proportion of incorrect source judgments from the proportion of correct judgments we were able to clean up the memory score from guesses.

We used the percentage of memory based on previous performance to allow us to capture memory retention from one testing session to the next. Using percentages rather than raw scores is a more accurate representation of memory retention, and this method minimises variance across participants. For instance, consider a participant remembers 100 trials on day 1 and 50 on day 2, while another participant remembers 50 trials on day 1 and 25 on day 2. In both cases, they would have 50% retention on day 2. However, if we were to input the raw scores, the variance would be much larger across participants.

RESULTS

Participants

A total of 27 native English speakers took part in the study (M_{age} = 19.29, SD = 1.06). All participants were female, with the majority being right-handed (3 left-handed). Descriptive statistics for sleep measures are presented in Table 1. One participant reported taking medicine (prescribed/over the counter) to aid in sleep and 6 participants reported having trouble staying awake while driving, eating meals, or engaging in social activity in the past month.

Table 1. *Descriptive statistics for sleep measures.*

Sleep Measures	***M***	***SD***
ESS	7.04	3.27
SSS	2.33	0.92
Global PSQI	5	-
Hours of sleep per night in the past month	7.46	0.95
Minutes taken to fall asleep each night	23.15	18.34
Hours spent in bed	8.83	1.29

Behavioural Analysis

To obtain a measure for category memory retrieval, we calculated the proportion (%) of target categories recalled at T1 that were subsequently recalled at T2, and the proportion (%) of target categories that were recalled at T2 that were subsequently recalled at T3 (i.e. after one night's sleep). In this manner, we are able to capture 'memory retention' across time. Descriptive statistics for category recall response distributions at T2 and T3 for cued and uncued words can be found in Appendix H.

An adjusted memory score was used instead of raw scores. Adjusted memory scores were calculated by subtracting the percentage of incorrect responses from the percentage of correct responses for cued and uncued words, which resulted in a more accurate measure of memory retention (i.e. for correctly recalled words). The data was inspected and the variables were normally distributed. An alpha level of .05 was used for all statistical tests. All tests were two-tailed.

For the main analysis, a 2 x 2 repeated-measures analysis of variance (ANOVA) was performed to measure the percentage of memory retention. The two within-subjects factors were cueing (Cued/Uncued) and retrieval time (T2/T3). This resulted in 4 conditions, namely: CuedT2; UncuedT2; CuedT3; UncuedT3. The results showed that there was a significant main effect for retrieval time, F (1, 26) = 53.55, $p < .001$; participants retained more information at T3 (M= 79.34 %, 95% CI 73.12–85.49) than at T2 (M= 62.09%, 95% CI 54.49–69.69). There was no significant main effect for cueing, F (1, 26) = 0.33, p = .57, indicating that whether words were cued or not, this did not impact on performance on memory retrieval. Also, there was no significant interaction effect, F (1, 26)= 0.19, p = .67, indicating that whether words were cued or not they did not have a significant effect on memory retrieval at either T2 or T3.

Follow-up *t*-tests were warranted. A paired samples *t*-test was conducted to compare adjusted memory scores (i.e. memory retention) at T2 for cued and uncued conditions. There was no significant difference in the scores for memory retention at T2 for cued (M = 61.58, SD = 20.62) and uncued (M = 62.60, SD = 23.78) conditions; t (26) = 0.23, p = 0.82. Another paired samples *t*-test was conducted to compare memory retention at T3 for cued and uncued conditions. The results indicated no significant difference in the scores for adjusted memory performance at T3 for cued

(*M* = 77.76, SD = 20.29) and uncued *M* = 80.93, SD = 18.42) conditions; *t* (26) = 0.71, *p* = 0.48 (see Figure 7 and Appendix I).

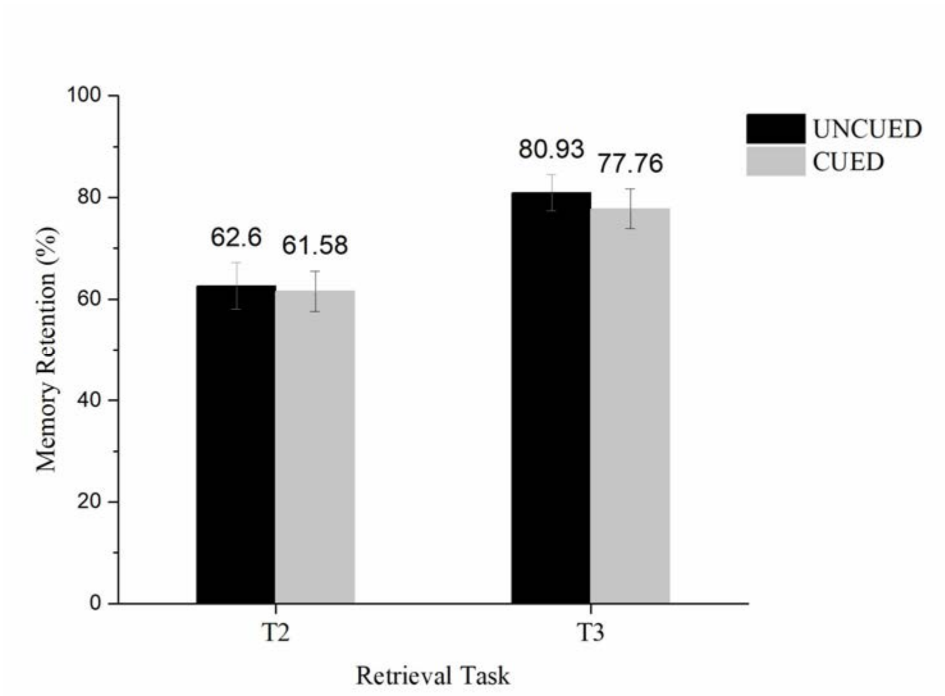

Figure 7. A bar graph illustrating the mean (± SEM) for percentage of memory retention at T2 and T3 for uncued and cued words.

DISCUSSION

Overview

The purpose of this study was to investigate the effect of auditory cueing during wakefulness on memory retrieval. It was predicted that participants would perform poorly on both the delayed retrieval task and the next day retrieval for words that were cued versus uncued. However, the results showed that words that were cued in comparison to words that were not cued did not have an effect on subsequent memory recall. Similarly, Schreiner and Rasch (2015) found that word cueing had no beneficial effect on memory recall in either active or passive waking conditions. One explanation for the null finding may be that reactivation during wakefulness may have destabilised or disrupted the memory trace, and returned them to a susceptible state, making them prone to interference (Rodriguez-Ortiz & Bermúdez-Rattoni, 2007).

Among the previous studies conducted, the most similar to the current study in terms of experimental paradigm and procedure, is that by Schreiner and Rasch (2015). In the current study, the retention interval (i.e. the offline phase) was a total of 90 minutes, which involved a 1-back working memory task. Following this, participants were tested on the retrieval test 4.5 hours after the offline phase (i.e. T2 or delayed retrieval test) as well as the next day (i.e. T3 which was 24 hours after initial learning). In comparison, in the study by Schreiner and Rasch (2015), the retention interval was for 3 hours, during which participants performed a 0-back, 1-back, and 2-back working memory task, which may have led to participant fatigue. Following this, memory retrieval was assessed only once, 24 hours after cueing. In comparison, in the current study memory retrieval was assessed twice after cueing (i.e. delayed and next day retrieval). As such, it could be argued that the current study employed a stricter experimental paradigm, and that the findings contributed to the literature by filling in the gaps of cueing during wakefulness and subsequent performance on associative memory.

Our results revealed a significant main effect for retrieval time, indicating that participants retained more information on the next day memory retrieval task (T3) in comparison to the delayed retrieval task (T2) irrespective of whether words had been cued or not. Similarly, in the study by Schreiner and Rasch (2015), improved memory performance was found following a night's sleep. Taken together, our results suggest that memory decline was less dramatic from T2 to T3 than from T1 to T2. It is suggested that post-learning sleep may have augmented consolidation processes, optimising memory stability and improving retention the following day (as shown in Figure 7).

Sleep quality and quantity, as well as level of alertness were assessed by the self-report measures administered prior to testing. The results from the sleep measures indicated that on average participants were alert prior to the start of the experiment, and did not experience sleep difficulties (PSQI global score = 5). On average, participants obtained 7.5 hours of sleep per night over the last month (see Table 1). This suggests that performance on the behavioural tasks is unlikely to be attributable to daytime sleepiness, insufficient sleep, or poor sleep quality. Therefore, even when participants are well rested, cueing during wakefulness did not have benefits on memory recall. These measures were only used on day one. In the future, it may be helpful to use these measures at the start of testing on day two as well. Additionally, alongside subjective sleep measures, it may be helpful to include more objective measures of sleep quality and quantity such as by using actigraphy (e.g. Actiwatch ©).

The findings here lend further support to the growing literature which suggests that the benefits of TMR for the purposes of strengthening memories may possibly only be demonstrated when elicited during post-learning sleep states (see Cairney et al., 2018). The Active Systems of Consolidation theory postulates that memories are temporarily stored in the hippocampus where they are reactivated, strengthened, integrated, and redistributed to long-term storage in neocortical networks during SWS (Born & Wilhem, 2012), suggesting that memory consolidation is a sleep-specific process rather than a result of passive or active waking states (Rasch & Born, 2013; Stickgold & Walker, 2013). The lack of effect of cueing during wakefulness in our current study is in line with this hypothesis.

Methodological Considerations and Limitations

There are a number of limitations that need to be addressed. The current study only included a sample of females; as such, the findings may be limited and may not be generalisable to males. It would be useful for future studies to include an equal sample of males and female and to explore whether there are any gender differences, although previous studies did not report any differences (Schreiner & Rasch, 2015). Potential confounding variables that were not controlled for in the current study that may need to be taken into account in future studies include caffeine and/or alcohol use as they may effect level of alertness and in turn behavioural performance.

Following the offline phase, participants were asked to leave the laboratory and to return after 4.5 hours to complete T2. It may be that during this time window participants were exposed to various auditory stimuli that disrupted the on-going plasticity process that is triggered by cueing. Therefore, we are unable to rule out the possibility that what happened in the time frame between cueing and re-testing may have contributed to the results found in the current study. It may be useful for future studies to reconsider this aspect of the experimental paradigm. For example, to control for this, participants could watch a silent movie in the laboratory.

Other variables that may have influenced the findings that were not controlled for in the current study include the intention to remember, the importance of the information for the future, and expectancy of future testing. For instance, in one study (Oudiette et al., 2013) participants (N = 60) were assigned to one of four conditions: sleep-cued, sleep-uncued, wake-cued and wake-uncued. Participants learned the locations of 72 objects, whilst hearing a characteristic sound associated with each object. In order to bias this learning, the objects were provided with either high-value numbers or low-value numbers to indicate future rewards for remembering the correct location. During cueing, only objects that were associated with low-values were presented. Interestingly, across all conditions participants correctly recalled more high-value (30.5 ± 0.6) than low-value objects (23.6 ± 0.9), which suggests that the process of sleep consolidation may be biased towards information of future relevance.

In another study (Wilhelm et al., 2011) exploring the expectancy of future retrieval testing on retention performance during sleep and wake on word-pairs and object-location tasks (both declarative), as well as the (procedural) finger sequence tapping task, the results revealed that the expectancy of a retrieval test after the sleep retention interval led to a significant improvement in the retention and behavioural performance of declarative and procedural memory tasks. In comparison, participants that were not told that there would be a delayed recall test (i.e. unexpected group) did not improve in wake nor sleep retention. Once again, the evidence suggests that sleep preferentially consolidates memories that are relevant for future behaviour. In the current study, participants were not made aware that there would be a delayed retrieval task, which may partially explain the findings.

Participants were exposed to the word-object stimuli on 3 occasions (T1, T2, T3); as such, it is also possible that enhanced performance on the next-day retrieval task (T3) is due to re-exposure of the words at T2 which may have reactivated memories and contributed to the observed benefits at T3.

Research Implications

At present, it is difficult to draw comprehensive conclusions as to the effect of TMR during wakefulness on memory since there are inconsistencies in the literature. Possible explanations for these discrepancies may be attributed to the different experimental paradigms used from one study to the other, the mode of cueing (e.g. frequency, duration), the type of cueing (e.g. olfactory, auditory), and the type of memory being assessed (e.g. declarative, procedural). Thus, cueing appears to have an impact on memory stability depending on when and how it is presented.

Oudiette et al. (2013) found that objects with low-value associations were 'rescued' from being forgotten when cueing occurred during sleep and wakefulness. Interestingly, the main difference observed between conditions was that the entire category set of low-value associations was retained post-sleep in the sleep condition; however, only cued low-value associations were rescued from 'forgetting' in the wakefulness condition. This demonstrates that that is the only study thus far to imply that there may be potential benefits of TMR during wakefulness by strengthening individual memories deemed as less valuable.

The majority of the studies have focused on how TMR during sleep can strengthen memories. Equally as important, recent studies have turned their attention towards investigating whether TMR can aid in weakening memories. Although there appears to be initial evidence suggesting that TMR during sleep and wakefulness may be used to induce weakening memories (Diekelmann et al., 2011; Simon, Gómez, & Nadel, 2018), a lot more research is needed to determine this relationship and the parameters under which this can occur. It would be useful for future research to explore this avenue as it has important clinical implications. Weakening memories via TMR may be an innovative psychological treatment approach for PTSD where weakening traumatic memories may actually be beneficial and can help to promote an improved quality of life. Thus far, TMR has mostly been examined in typically developing adults. It would be important for future research to examine the effects of TMR in different populations that may potentially benefit from it such as children, older adults, and psychiatric patients. However, further research is first needed with typically developing individuals using a variety of different experimental paradigms prior to safely exploring the effects of TMR on clinical populations.

The behavioural effects of TMR have mostly been studied in relation to declarative memory. There have been conflicting results with regards to TMR and emotional memory, with some studies (Hauner, Howard, Zelano, & Gottfried, 2013) showing TMR facilitated in the extinction of conditioned fear responses in rodents and in humans, while others showing that it led to fear enhancement (Diekelmann, & Born, 2015). Therefore, further studies are needed to explore the effects of TMR with other types of memories, such as procedural and emotional memory, as this remains unclear.

We do not presently know the long-term effects of TMR since most studies have focused on assessing memory recall 12 to 24 hours after TMR (Diekelmann et al., 2011; Oudiette et al., 2013; Rasch et al., 2007; Schreiner & Rasch, 2015). It would be helpful for future studies to determine whether the beneficial effects of TMR last beyond 24 hours, and if so to what extent, and whether there are any negative side effects.

Clinical Implications

It is well demonstrated that sleep aids in the process of learning and memory consolidation (Stickgold, 2005), and the findings here further highlight the importance of the role of sleep in memory consolidation. Conversely, insufficient sleep has been linked to having a detrimental effect on learning, memory, and academic performance (Owens, 2014). Taken together, adequate and sufficient sleep is key for memory consolidation and retention of information, and may be an important target of intervention for persons with learning and/or memory difficulties. Moreover, sleep disturbances are a common feature in various mental health difficulties and disorders, once again highlighting the importance of addressing sleep difficulties (Anderson & Bradley, 2013). At the preventative level, providing psychoeducation to parents, teachers, and young people on sleep's fundamental role may be helpful in order to minimise the potential debilitating effects of poor sleep quality and quantity on mental and physical health, as well as learning and memory function.

The prospect of sleep being a gateway to enhance or weaken information is quite exciting and holds significant clinical implications. Once we have a better understanding of the mechanisms supporting TMR and episodic memory, we may be able to start improving specific memory deficits such as those resulting from neurodegenerative diseases such as AD or possibly alleviate the effects arising from unwanted memories as seen in PTSD.

Conclusion

The findings revealed that performance on the retrieval task improved following a night's sleep, irrespective of cueing. It may be that the natural process of sleep-specific memory consolidation aided in retaining information. However, we cannot rule out that repeating the retrieval tasks at different time points may have aided in learning. TMR has been shown to be an effective tool to aid sleep-dependent memory consolidation, with most prominent results being in the declarative and visuospatial domain. As discrepancies exist in the literature, extensive research is warranted to demonstrate the efficacy (or lack thereof) of TMR during wakefulness and subsequent memory recall before we are able to draw any firm conclusions. It is important to continue to address all questions depicted in the research agenda by Schouten and colleagues (2017) before we are able to apply TMR in educational or clinical settings, such as what are the neural mechanisms involved in TMR and what is the endurance of TMR's beneficial effect?. Future research on the underlying neural processes and mechanisms involved in TMR during SWS and wakefulness is warranted. Nevertheless, in the future, TMR might prove to be a useful non-invasive method for cognitive benefits in various populations, such as with individuals with memory difficulties or children with learning difficulties.

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CHAPTER 3: PUBLIC DISSEMINATION DOCUMENT

Systematic Review:

Are Sleep Problems Early Indicators of

Increased Risk for Alcohol Use Among Adolescents?

Background

It is critical to understand the relationship between sleep problems and alcohol use during adolescence, particularly since both these problems are prevalent during this time (Gradisar, Gardner, & Dohnt, 2011). The National Sleep Foundation recommends that adolescents between the ages of 14 to 17 years old obtain 8 to 10 hours of sleep for optimal health (Hirshkowitz et al., 2015). However, data analysed by the Centers for Disease Control and Prevention (CDC) from the 2015 national surveys in the USA of more than 50,000 high school students found that about 73% of adolescents do not get sufficient sleep (defined as ≤ 7 hours; Wheaton, Jones, Cooper, & Croft, 2018). At the same time, young people often experiment with alcohol for the first time during adolescence. Data from the Health Survey England (2016) reported that approximately 64% of 17-year-old boys and 48% of girls drink on a weekly basis (Health and Social Care Information Centre, 2017). It would be useful to understand the relationship between sleep problems and alcohol use in adolescents due to their potential negative impact on social well-being, physical and mental health, as well as on brain development during a key developmental period (Alfano, Zakem, Costa, Taylor, & Weems, 2009; Kessler et al., 2007).

Aim

The aim of this review was to answer the question 'do sleep problems contribute to alcohol use among adolescents?'.

Methods

A systematic search strategy was conducted on three databases; Ovid PsycINFO, Embase, and Web of Science. Key search terms included, 'sleep problems', 'insufficient sleep', 'alcohol use', 'adolescents'.

Results

The search identified 1,145 records. Following the application of inclusion and exclusion criteria, 27 studies were identified for review and were appraised using the National Institute for Health and Care Excellence (NICE, 2012) quality framework.

Main findings

- Shorter sleep duration was found to be associated with an increased likelihood of alcohol use and alcohol-related interpersonal problems among adolescents. However, the extent of this association differed amongst studies.
- A small but growing body of evidence suggests that sleep problems may precede alcohol use. There is preliminary evidence demonstrating a prospective association between sleep problems and earlier onset of alcohol use.
- A few studies demonstrated a prospective relationship between inconsistent weekend-weekday bedtime differences (i.e. sleep variability) and subsequent alcohol use in adolescents.
- Symptoms of insomnia were found to be associated with higher odds of alcohol use in adolescents.
- The relationship between daytime sleepiness and alcohol use amongst adolescents is inconsistent and less clear in the literature.

Conclusions and Implications for Research and Clinical Psychology

Longitudinal research using more diverse samples is lacking and more prospective studies are needed to clarify the relationship between sleep problems and alcohol use to address the issues of causation and bidirectionality. Also, more objective measures of sleep, alongside self-reports, will need to be utilised in the future. This would enable more comprehensive conclusions of the findings regarding the relationship between sleep problems and alcohol use. Nevertheless, the findings from this review highlight the importance of adequate sleep in adolescents and its clinical implications are discussed. Developing good sleep habits early in adolescence may act as a protective factor, preventing youth from engaging in alcohol use and other possible risk-related behaviours. Fortunately, sleep problems are a modifiable risk factor and there are means to address this potential vulnerability both at the individual and systemic levels. Psychoeducation material during the early years targeted at educating young people about the importance of sleep hygiene and the potential consequences of poor sleep and risk-related behaviours, including drinking, may be useful. It may be helpful for practitioners working with young people to routinely gather information on sleep habits, which may possibly serve as a screening tool for mental health and alcohol/substance use. Screening questionnaires that evaluate sleep duration and hygiene may be less threatening than direct questions regarding suicidal ideation or depression, which are stigmatised among youth. Additionally, from a policy standpoint, adolescents may benefit from delayed school start times (Lufi, Tzischinsky & Hadar, 2011; Owens, Belon & Moss, 2010).

Research Study:

Auditory Cueing During Wakefulness and Its Effect on Memory Retrieval in Typically Developing Young Adults

Background

After initial learning, individual memories exist in a fragile state and undergo change before transferring into our long-term memory storage and becoming 'fixed' or permanent (Müller & Pilzecker, 1900). Consequently, this suggests that memories remain in a susceptible state for a period of time after initial learning. Strong research evidence has shown that delivering sensory input or external cues (e.g. sounds or smells), during sleep, can promote consolidation and 'boost memories' (Antony, Gobel, O'Hare, Reber, & Paller, 2012; Creery, Oudiette, Antony, & Paller, 2015). Conversely, the evidence is less clear with regards to using cues during awake states and subsequent memory, with some studies showing no effect on memory and others suggesting that it 'weakens' memories (Diekelmann, Büchel, Born, & Rasch, 2011; Schreiner, & Rasch, 2015). It is still unclear in the literature what the optimal conditions are that influence certain memories to become more stable and enduring over time, and whether experimental cueing can 'rescue' specific memories from being forgotten. Therefore, this study will contribute by filling in the gaps in the current literature by providing us with a better understanding of memory processes and manipulation.

Aim

The aim of the study was to investigate the effect of auditory cueing during wakefulness, and to explore its impact on memory performance. It was hypothesised that auditory cueing may elicit a 'decline' in memory (i.e. reduced performance on memory retrieval tasks).

Methods

Participants. 27 female participants between the ages of 18 to 22 years old (M_{age} = 19.29, SD =1.06) were recruited through a University online Research Participation Scheme.

Procedure. Participants completed self-report sleep measures and took part in a number of behavioural tasks over two consecutive days. After initial learning of a word-image association task, participants were re-presented with half of the words while completing a working memory task. The words that were re-presented through speakers are referred to as 'auditory cues'. Immediately following this, participants completed the same word-image association task (i.e. delayed retrieval), and once more the following day (i.e. next-day retrieval). The main outcome measures were performance on the delayed (T2) and next-day memory retrieval task (T3).

Results

The results revealed that whether words were cued or not they did not have a significant effect on memory retrieval, $F(1, 26) = 0.33$, $p = .57$, and this did not differ at neither T2 nor T3, $F(1, 26) = 0.19$, $p = .67$. Descriptive analyses showed that on average participants correctly remembered uncued words more than cued words at T2 and T3; however, this did not reach statistical significance. The results demonstrated that participants retained more information at T3 (M = 79.34 %) than at T2 (M = 62.09 %), $F(1, 26) = 53.55$, $p < .001$.

Main Findings

The findings showed that words that were cued in comparison to words that were not cued during wakefulness did not have an effect on subsequent memory recall, similar to the findings by Schreiner and Rasch (2015). One explanation for the null finding may be that reactivation during wakefulness may have destabilised the memory trace, returning them to a susceptible state, making them prone to interference (Rodriguez-Ortiz & Bermúdez-Rattoni, 2007). The findings revealed that memory retention on a word-image association task improved following a night's sleep.

Conclusions and Implications for Research and Clinical Psychology

It may be that the natural process of sleep-specific memory consolidation aided in retaining information. However, we cannot rule out that repeating the word-image task at different time points may have aided in learning and may partially explain enhanced memory recall performance the next day. Adequate and sufficient sleep is key for memory consolidation and retention of information (Stickgold, 2005), and may be an important target of intervention for persons with learning and/or memory difficulties. Moreover, sleep disturbances are a common feature in various mental health difficulties and disorders, once again highlighting the importance of addressing sleep difficulties (Anderson & Bradley, 2013). At the preventative level, providing psychoeducation to parents, teachers, and young people on sleep's fundamental role may be helpful in order to minimise the potential debilitating effects of poor sleep quality and quantity on mental and physical health, as well as learning, and memory function. Extensive research is warranted to demonstrate the efficacy (or lack thereof) of cueing during wakefulness and subsequent memory recall before we are able to draw any firm conclusions.

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VOLUME I

APPENDICES

Appendix A

Other Measures Included in the Reviewed Studies

	Studies	Measures
1	Johnson & Breslau (2001)	• Youth Self Report – a version of Achenbach's Child Behavior Checklist – was used to measure psychiatric and behavioural problems. Internalising scales included subscales of somatic complaints and symptoms of anxiety/depression; Externalising scales included delinquent behaviour; and aggressive behaviour. • An interview was conducted to examine use of cigarettes and any illicit drug in the past year.
2	Wong et al. (2004)	• Child Behavior Checklist (CBCL) mother ratings were used to assess attention problems, symptoms of anxiety and depression, and aggression in late childhood (ages 9 to 11). • The Drinking and Other Drug Use History Questionnaire Youth Version (DDHQ-Y) was used to measure use of cigarettes, marijuana and other illicit drugs (e.g. inhalants, amphetamines, and cocaine). • Parental alcoholism was assessed using the following measures when children were between the ages of 3 to 5 years: Short Michigan Alcohol Screening Test; Diagnostic Interview Schedule Version III; Drinking and Drug History Questionnaire.
3	O'Brien & Mindell (2005)	• Kandel-Davies' scale was used to assess symptoms of depression. • The Youth Risk Behaviour Survey was used to assess a number of risk-taking behaviours: a) safety behaviors b) violence behaviors c) tobacco use d) marijuana use e) drug use and f) sexual behaviors.

	Studies	Measures
4	Wong et al. (2009)	• Child Behavior Checklist (CBCL) mother ratings were used to asses internalising and externalising problems (at ages 3-14 years). • The Drinking and Other Drug Use History Questionnaire Youth Version (DDHQ-Y) as well as Diagnostic Interview Schedule – Child Version were used to measure onset of cigarettes, marijuana and other illicit drugs (e.g. inhalants, amphetamines, and cocaine; at ages 11 to 17 years). • Parental alcoholism was assessed using the following measures when children were between 3 to 8 years: Short Michigan Alcohol Screening Test; Diagnostic Interview Schedule Version III; Drinking and Drug History Questionnaire.
5	Wong et al. (2010)	• The Stopping Task was used to measure response inhibition when participants were 15 and 17 years old. • The Drinking and Other Drug Use History Questionnaire -Youth Version (DDHQ-Y) and the Diagnostic Interview Schedule - Child Version were used annually between 11 to 17 years and once between 18 to 20 to obtain a measure of onset and frequency of illicit drug use.
6	Pasch et al. (2010)	• Substance use questions assessed ever and current cigarette smoking status, and past month marijuana use. • Past month school truancy (i.e. skipping class or school) was assessed. • Kandel-Davies scale was used to assess symptoms of depression. • Other variables included: pubertal development assessed by the Pubertal Development Scale; Body Mass Index; parental level of education; gender; school-grade.

	Studies	Measures
7	Pieters et al. (2010)	• A pubertal development self-rating scale was used to estimate the level of pubertal maturation. • Two subscales of the Strengths and Difficulties Questionnaires (SDQ) were used to assess emotional (i.e. internalising problems) and conduct problems (externalising problems).
8	Yen et al. (2010)	• The Questionnaires for Experience in Substance Use (Q-ESU) was used to assess illicit drug use in the past year. • The Kiddie Schedule for Affective Disorders and Schizophrenia questionnaire was used to assess for suicidal ideation and attempt. • Three items from the Adolescent Aggressive Behaviors Questionnaire were used to assess for the occurrence of violence in the past year. • One item from the Adolescent Sexual Experience Questionnaire was used to assess for engaging in unprotected sex. • Three items were used to assess for the occurrences of truancy, tattooing and criminal behaviours. • The Center for Epidemiological Studies' Depression Scale (CES-D) was used to assess symptoms of depression.

	Studies	Measures
9	McKnight-Eily et al. (2011)	• Other health-risk behaviours examined were: drank soda/pop; physical activity; watching TV or playing video games; getting into a physical fight; current cigarette use; current marijuana use; current sexual activity; feeling sad or hopeless; suicidal ideation.
10	Pasch et al. (2012)	• Tobacco and marijuana use were assessed for by asking whether the student had or had not tried the substance in the past month. • Other measures included: depressive symptoms using the Kandel-Davies scale; pubertal development using the Pubertal Developmental Scale; socio-economic status; race/ethnicity; Body Mass Index; and age.
11	Huang et al. (2013)	• Other measured included: sex, age, parental education, cigarette smoking, physical activity, height, weight, and depression and anxiety status (using non-standardised questionnaires).
12	Morioka et al. (2013)	• The Japanese version of the General Health Questionnaire (GHQ-12) was used to assess mental health.
13	Hasler et al. (2014)	• Information about alcohol use/other substance-use disorders was gathered by revised sections of the Structured Clinical Interview for DSM-IV Axis I Disorders. • Assessed whether participants were daily tobacco users – dichotomous item (yes/no). • The Beck Depression Inventory was used to assess for symptoms of depression.

	Studies	Measures
14	Wong et al. (2014)	• The Early Adolescence Temperament Questionnaire-Revised was used to measure effortful control (i.e. the ability to inhibit a dominant response). • The Academic Self-Regulation Questionnaire was used to assess identified regulation. • Academic performance was gathered from students and teachers. • Patterns of Adaptive Learning Survey was used to assess classroom disruptive behaviour. • Other substances measured (using a non-standardised questionnaire) included: smoking, tobacco chewing, marijuana.
15	Daly et al. (2015)	• Items from the Youth Risk Behavior Survey (YRBS) were used to obtain information on demographic characteristics, mental health (depression and suicidal behaviour) and other substance use behaviors (cigarettes and marijuana).
16	Pieters et al. (2015)	• Cigarette smoking and smoking marijuana were assessed (rated on a 9-point scale). • The Strengths and Difficulties Questionnaire was used to measure internalising and externalising problems. • A self-rating scale for pubertal development was used.

	Studies	Measures
17	Sivertsen et al. (2015)	• Frequency and amount of illicit drug use were assessed. • CRAFFT questionnaire was used to identify problematic drug use. • Mood and Feelings Questionnaire (short-version) was used to assess for symptoms of depression • Symptoms of ADHD were measured using subscales from the official Norwegian translation of the Adult ADHD Self-report Scale.
18	Wong et al. (2015)	• Illicit drug use (i.e. marijuana, cocaine, inhalants, or other illegal drugs) and illicit drug-related problems (e.g. 'have you driven high on drugs?') were assessed.
19	Hasler et al. (2016)	• An adaptation of the Lifetime Alcohol Use History was used to obtain information on age of first use of cannabis and cocaine. • Information about alcohol use/other substance-use disorders was gathered by revised sections of the Structured Clinical Interview for DSM-IV Axis I Disorders. • Major depression was assessed by the Schedule for Affective Disorders and Schizophrenia. • Diagnoses of parental substance use disorder were made by DSM-III-R.

	Studies	Measures
20	Mike et al. (2016)	• The Child Behavior Checklist was used to assess internalising and externalising problems (maternal ratings used). • Me and My Neighborhood questionnaire was used to assess for neighborhood danger. • The Hollingshead four-factor index score was used to measure family socioeconomic status. • Emotional regulation was accounted for using a delay-of-gratification task when child was 3.5 years old.
21	Reichenberger et al. (2016)	• The frequency of tobacco use behaviours over the past month was assessed. • The frequency of illicit drug use was assessed. • Risky sexual behaviour was assessed. • The frequency of seatbelt used was assessed.
22	Chen et al. (2017)	• The Adolescent Health Questionnaire was used to obtain data on tobacco use, as well as health and demographic characteristics. • The Youth Self-Report was used to obtain a measure of internalising and externalising problems.

	Studies	Measures
23	Hasler et al. (2017)	• The Customary Drinking and Drug Use Record was used to asses for past and recent substance use. • The Achenbach System of Empirically Based Assessments was used to assess for psychiatric symptoms using the internalising and externalising scales. • To assess for other psychiatric symptoms, participants between the ages of 12-17 years completed the Youth Self-Report. Participants aged 18+ years completed the Adult Self-Report. Parents of participants between the ages of 12-17 years also completed the Child Behavior Checklist.
24	Marmorstein (2017)	• The Mood and Feelings Questionnaire was used to assess symptoms of depression. • Conduct Disorder Rating Scale was used to assess symptoms of conduct disorder. • The Perceived Parental Monitoring Scale and the Monitoring-personal interview were used to assess parental monitoring. • The Child and Adolescent Symptom Inventory-4th edition, Revised was used to collect teacher's reports of symptoms of ADHD.
25	Miller, Janssen, & Jackson (2017)	• Onset of smoking and marijuana use was assessed. • Parents completed the Child Behavior Checklist, which was used to obtain a measure of internalising and externalising problems. • The Multidimensional Anxiety Scale for Children was used to assess social anxiety.

	Studies	Measures
26	Nguyen-Louie et al. (2017)	• A Structured Clinical Interview was administered at baseline and follow-ups to assess academic functioning, major medical illnesses, and extracurricular activities. • The Customary Drinking and Drug Use Record, an interview based assessment, was used to assess lifetime use of cigarettes and marijuana (completed by participant and other informant e.g. parent or sibling). • The Family History Assessment Module was used to assess familial density of alcohol use and other substances. • Parents were administered the Child Behavior Checklist at Time 1 to gather information on internalising and externalising symptoms. • Delis–Kaplan Executive Function System was used to measure inhibitory control. • Pubertal Development Scale administered at Time 2, along with the sleep measures. • Hollingshead Index of Social Position was used to obtain an index of socioeconomic status.
27	Warren, Riggs, & Pentz (2017)	• Items from the Behavioral Rating Inventory of Executive Function-Self-Report were used to assess executive function. • One item was used to assess for lifetime cigarette use.

Appendix B

Detailed Criteria of the NICE (2012) Quality Appraisal Checklist

Population	Source population or source area well described? - *Was the country, setting, location, population demographics etc adequately described?*
	Eligible population or area representative of the source population or area? - *Was the recruitment of individuals, clusters or areas well defined?* - *Was the eligible population representative of the source? Were important groups underrepresented?*
	Selected participants or areas represent the eligible population or area? - *Was the method of selection of participants from the eligible population well described?* - *What % of selected individuals or clusters agreed to participate? Were there any sources of bias?* - *Were the inclusion or exclusion criteria explicit and appropriate?*
Method of Selection	Selection of exposure group. Selection bias minimised? - *How was selection bias minimised?*
	Selection of explanatory variables based on sound theoretical basis? - *How sound was the theoretical basis for selecting the explanatory variables?*
	Confounding factors identified and controlled? - *Were there likely to be other confounding factors not considered or appropriately adjusted for?* - *Was this sufficient to cause important bias?*
Outcomes	Outcome measures and procedures reliable? - *Were outcome measures subjective or objective?* - *How reliable were outcome measures?* - *Was there any indication that measures had been validated?*
	Follow-up time meaningful? - *Was follow-up long enough to assess long-term benefits and harms?* - *Was it too long, e.g. participants lost to follow-up?*
Analyses	Sufficiently powered? - *A power of 0.8 (i.e. it is likely to see an effect of a given size if one exists, 80% of the time) is the conventionally accepted standard.* - *Is a power calculation presented? If not, what is the expected effect size? Is the sample size adequate?*
	Multiple explanatory variables considered in the analysis? - *Were there sufficient explanatory variables considered in the analysis?*
	Analytical methods appropriate? - *Were important differences in follow-up time and likely confounders adjusted for?*
	Precision of association given or meaningful?
	Internal validity
	External validity

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Appendix C

Participant Information Sheet

Thank you for volunteering to take part in the study "*Object-scene learning*".

What is the purpose of the study?
Your participation will help us understand how human memory functions in healthy participants, and which strategies are particularly helpful for making information stay in our long-term memory. You will be fully debriefed about the purpose of the study by the end of the experiment.

Can I participate in the study?
You are eligible to participate if you 18-35 years old, are a native English speaker, have normal hearing, no history of neurological disorders, and no diagnosis of Specific Learning Difficulties and/or Learning Disabilities.

What will I have to do?
Prior to the start of the experiment, we will ask you to complete short questionnaires that look at your sleep pattern and level of alertness. Another way for us to look at your day- and night-time activity, is by asking you to wear a wrist watch called 'Actiwatch' between the end of today's session and the beginning of tomorrow's session. There is no risk associated with wearing the Actiwatch, however if you prefer not to wear the watch then please just let the researcher know.

During the experiment, we will ask you to perform a number of different tasks while sitting in front of a computer screen. For example, we might ask you to watch a series of object-scene picture pairs, and to indicate whether you can picture in your mind's eye that the object and scene can 'go together'. Later on, we might ask you to try to remember which objects and scenes were originally paired together. All pictures will be emotionally neutral and will not cause any distress. During each part of the experiment, we will record your responses given on the keyboard in order to evaluate your task performance. We will provide you with detailed descriptions of the tasks before the experiment begins. Don't worry, we included a practice session so that you may get the hang of each task before the experiment begins.

We're also interested in looking at drinking behaviour, so if you don't mind sharing some information about that then we'll provide you with a short questionnaire at the end of the study (as with all your data, this information will be anonymised and kept confidential). If you prefer not to disclose that information and would rather only take part in the experimental tasks of this study then that's completely fine!

How much of my time will participation involve?
Overall, the experiment will last for approximately for three hours and a half.
On day one testing will last for about three hours, and on day two testing will last for about twenty-five minutes.

Credits or cash?

We consider your time valuable and as a way to thank you for taking the time to participate in our study we would like to offer you either 3.5 credits or £22. Please indicate your preference on the consent form.

What happens with my data?

Data will be stored in an anonymous format on the University's protected *Birmingham Environment for Academic Research (BEAR)* network, using an ID different from your RPS ID. All information collected during the experiment will be treated confidentially. Only authorised personnel involved in the project will be allowed to access this information. The information will be retained by the University of Birmingham and will only be used for research, statistical and audit purposes. By supplying this information, you are consenting to the University storing your information for the purposes stated above. The information will be processed by the University of Birmingham in accordance with the provisions of the Data Protection Act 1998. No identifiable personal data will be published.

You may withdraw from the study at any point, if you so wish, with no penalty. In case you decide to withdraw, your data will simply be discarded and not further analysed. You can also decide to withdraw your data from any further analysis up to one week after completion of the study.

When we have completed the study, we will produce a summary of the findings which we will be more than happy to send to you if you are interested. Please inform the researcher if you are interested in the outcome of the study. We are also hoping to publish the results.

What are the possible disadvantages and risks of taking part?

There are no known risks of taking part in the study.

What are the possible benefits of taking part?

We cannot promise the study will help you but the information we get from the study will help to increase the understanding of how memory functions.

Whom can I contact?

If you have further questions about this study, please contact the principal investigator of this research project, Dr Bernhard Staresina, either via phone [redacted], or email [redacted]

Do you have any questions?

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Appendix D

Consent Form

Experiment: Object-scene learning

Credit or cash? ◯ credit ◯ cash

Name: ______________________________

Participant ID (for internal use): ______________________________

Age: ______________________________

Handedness: ◯ left ◯ right ◯ both

Gender: ◯ female ◯ male

Native English speaker: ◯ yes ◯ no

History of neurological disorders: ◯ yes ◯ no

Diagnosis of Specific Learning Difficulties and/or Disability: ◯ yes ◯ no

Impaired hearing: ◯ yes ◯ no

please turn

Consent

I confirm that I have read and understand the participant information sheet for the study "*Object-scene learning*". I have had the opportunity to ask questions if necessary and have had these answered satisfactorily.

I understand that my participation is voluntary and that I have the right to withdraw my consent or discontinue participation at any time without giving a reason, and without penalty. The procedures of the experiment have been explained to me.

I understand that my personal data will be processed only for the purposes detailed in the information sheet, and in accordance with the Data Protection Act 1998. The data will only ever be shared with researchers involved in this specific project. My individual privacy will be maintained in all published and written data resulting from the study.

Based upon the above, I agree to take part in this study.

________________________	________________	________________
Name of participant	Date	Signature
________________________	________________	________________
Name of researcher	Date	Signature

Appendix G

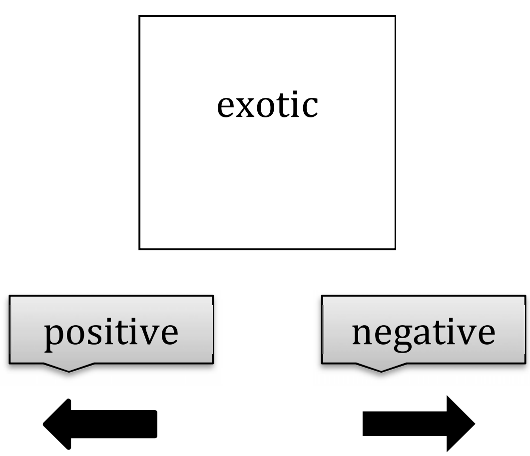
Instructions for Behavioural Tasks

WELCOME AND THANK YOU FOR PARTICIPATING!

We are interested in understanding how people process objects, scenes, and sounds. Overall, there are 6 parts to this experiment. You will be required to complete all of the tasks on a computer. We will go through each part one at a time. Instructions will be given before the start of each task and you will have the chance to practice the tasks before beginning the experiment.

Part I: Word processing

For this part of the experiment, you'll see a series of adjectives on the computer screen while hearing their spoken pronunciations through the speakers. Your task is to indicate whether the adjective has a **positive or a negative connotation** for you. Each adjective will remain on the screen for 2.5 seconds. Press the **left arrow key** for ***positive adjectives***, and the **right arrow key** for ***negative adjectives***. This part will last ~6 minutes.



Do you have any questions?

Part II: Object or Scene?

For this part of the experiment, you will see images on the computer screen of either an object or a scene along with their caption. Your task is to indicate whether the image is an **object** or a **scene**. Each image will remain on the screen for 2.5 seconds. Please try your best to give the correct response as quickly as you can. Press the **left arrow key** for ***object***, and the **right arrow key** for ***scene***. This part will last ~6 minutes.

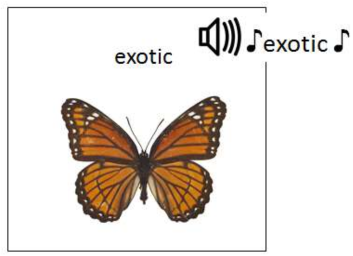
Butterfly

Campsite

Do you have any questions?

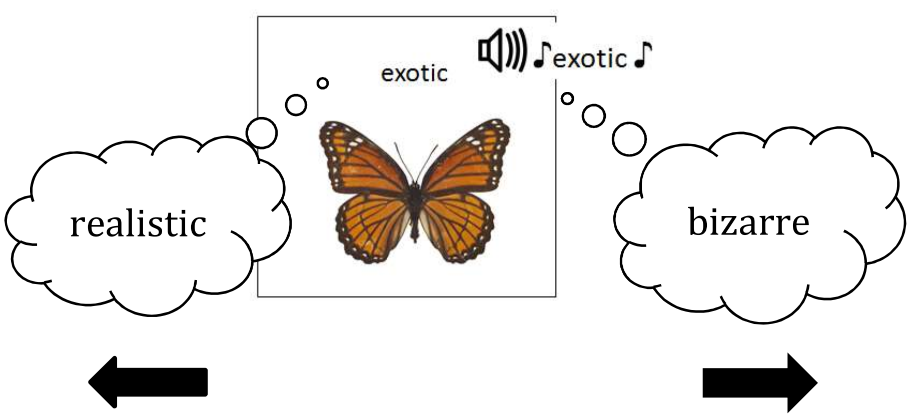
Part III: Imagery Task

During this part of the experiment, you will see images on the computer screen of either an object or a scene along with an adjective. At the same time, you will hear this adjective being spoken (e.g. 'exotic').



Your task is to come up with an image or a story in your mind to **closely link the adjective and the shown image**. For instance, you might see the image of a butterfly together with the adjective 'exotic'. In that case, you might think this is a good fit because butterflies are somewhat exotic animals. On other occasions, the link will not be so obvious and you have to use your imagination to make a meaningful link between the adjective and the image.

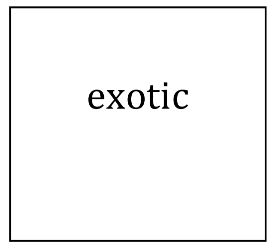
Please press the **left arrow key** if you find that this vivid mental image in your mind is **REALISTIC** and press the **right arrow key** if you find that this mental image is **BIZARRE**. You'll have 4.5 seconds to give your response. If you take longer than 4.5 seconds to give a response, then the trial will be coded as invalid, so please make sure to **enter your response within 4.5 seconds**. This part will last for ~8 minutes.



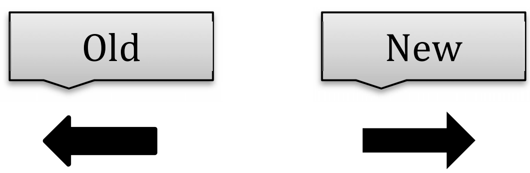
Do you have any questions?

Part IV: Memory Task

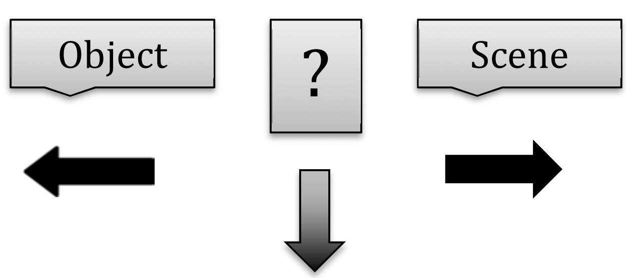
In this part of the experiment, your memory for the previous Imagery Task will be tested. First, you will see an adjective on the computer screen:



The adjective will remain on the screen for 2 seconds. **Please use this time to thoroughly assess your memory for this adjective**. Have you seen it before? If so, what image was it shown with? After those 2 seconds, you'll see up to 3 response screens: Your first task is to indicate whether you think the adjective is **OLD** or **NEW**, i.e., whether you have seen it in the previous imagery part or not. Press the **left arrow key** if the adjective is **OLD** and press the **right arrow key** if the adjective is **NEW**.



Next, if you press the left arrow key **(**i.e., you think you have seen the adjective before**)**, you will be asked whether the adjective was previously paired with an **object or a scene** image. Press the **left arrow key** if you think the adjective was paired with an **OBJECT** and the **right arrow key** if the adjective was paired with a **SCENE**. If you are finding it difficult to recall whether an object or a scene was paired with the adjective then press the **downward arrow key**.



Finally, if you press the left or right arrow keys, you task will then be to *briefly describe in a few words the object or scene that was previously associated with the adjective*. If you are finding it difficult to recall the exact object or scene image previously seen with the adjective, you may type '?'.

This part will last for ~20 minutes.

Do you have any questions?

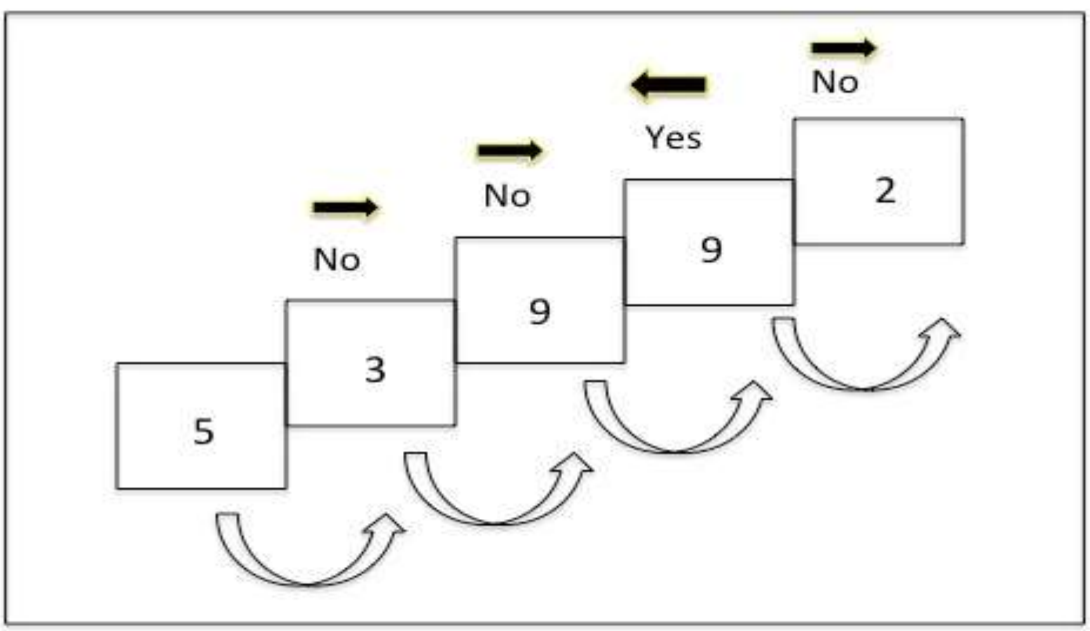
Part V: Numbers Task

During this part of the experiment, you will see a series of random numbers between 0 and 10 presented one after another on the screen. Your task is to identify if the current number is a *target number*. A target number is a number that is the same as the number **one digit prior**. For instance, in the series *...5...3*, the '3' is **NOT** a target as the number one digit prior is a '5'. However, in the series *...9...9,* the second '9' **IS** a target number as it has appeared one digit prior.

Press the **left arrow key** for **target numbers** and the **right arrow key** for **non-target** numbers.

You'll have to pay close attention to perform well. To give you feedback on your performance, the fixation cross following each new number will be green for correct responses and red for incorrect responses. Each number will remain on the screen for 1 second. Please try your best to give the correct response as quickly as you can.

Incidental to the task, you will occasionally hear adjectives in the background. There is no need to pay attention to those sounds. The task is divided into 6 blocks, each lasting 5 minutes, so altogether this part will last ~30 minutes.



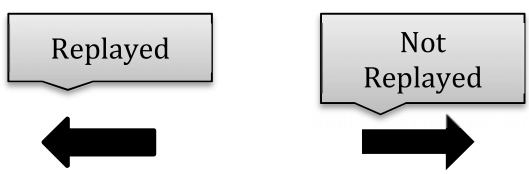
Do you have any questions?

Discrimination Task

In this part of the experiment, you will be re-presented with all of the adjectives you heard during the learning task, one after another.

You will be asked to guess whether or not each adjective was replayed to you while you were performing the numbers task.

Press the **left arrow key** if you think the adjective **WAS** replayed to you during the numbers task and the **right arrow key** if you think the adjective **WAS NOT** replayed to you during the numbers task. This part will last for ~5 minutes.



Do you have any questions?

Appendix H

Supplementary Data: Response Distributions at T2 and T3

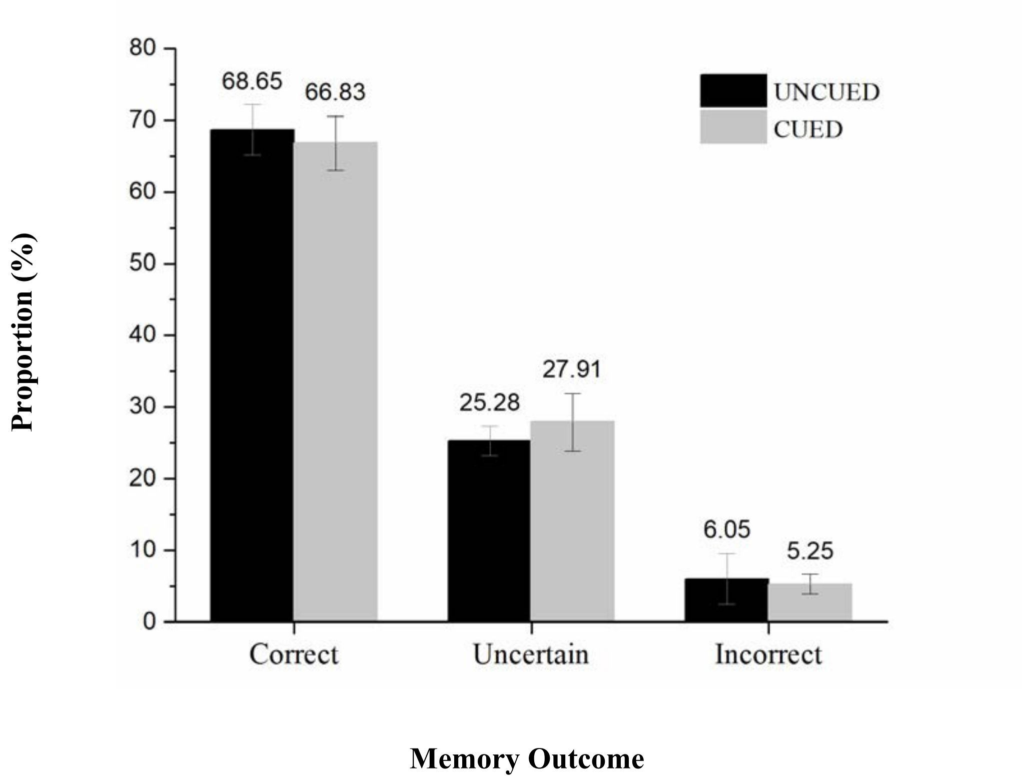


Figure 8. An illustration of the mean (± SEM) memory outcome at T2 (i.e. the proportion (%) of T1-recalled categories that were also recalled at T2) for uncued and cued words.

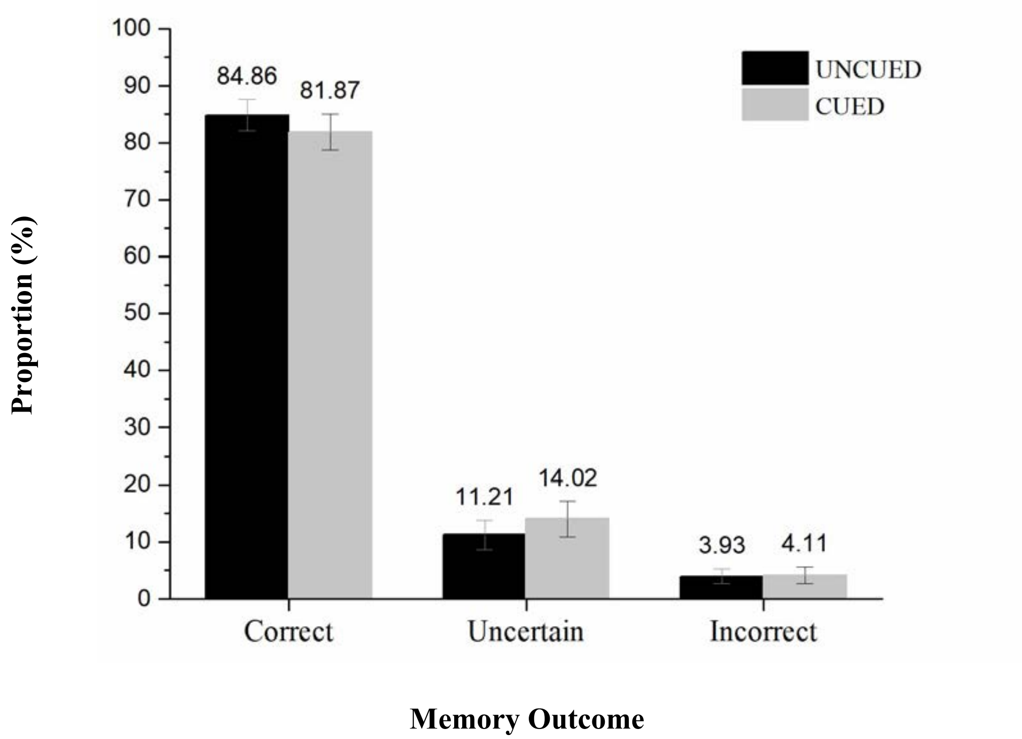


Figure 9. An illustration of the mean (± SEM) for memory outcome at T3 for uncued and cued words (i.e. the proportion (%) of T2-recalled categories that were also recalled at T3).

Appendix I

Supplementary data: An Illustration of Memory Retention

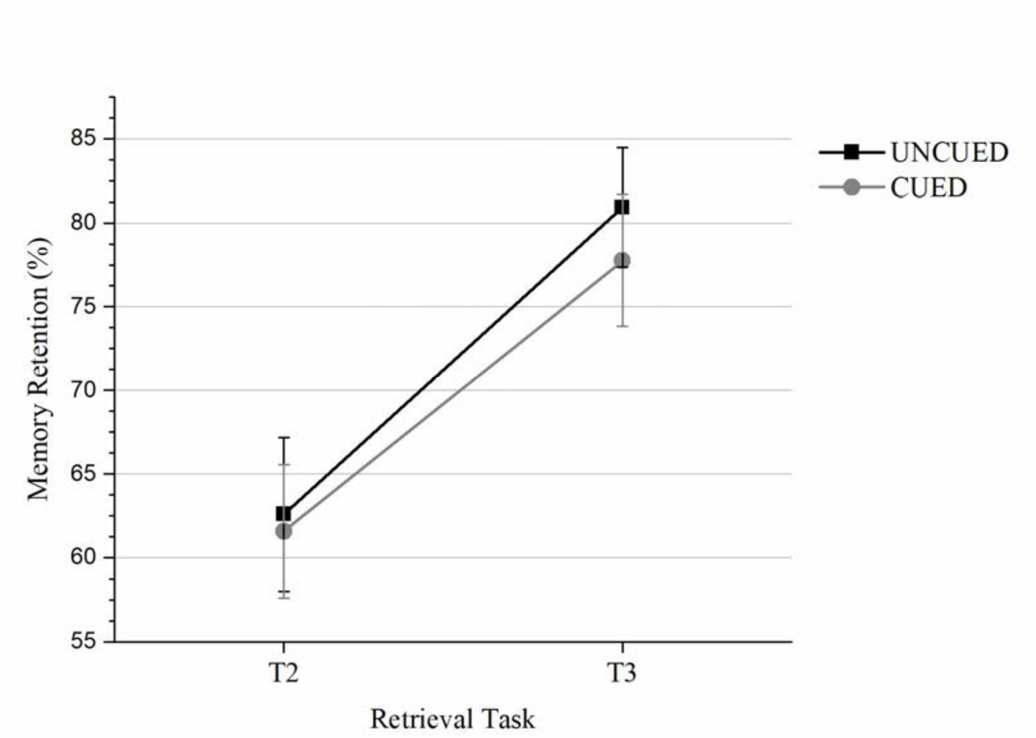


Figure 10. An illustration of the mean (± SEM) for memory retention at T2 and T3 for uncued and cued words.