The Temporal Association of Caffeine and Sleep in Young Adults

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Sarah Suckling

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ABSTRACT:

Background:

Young adults commonly experience poor sleep health due to various factors such as screen use, delaying bedtime, and high consumption of caffeine. Caffeine, a widely used psychostimulant, is known to negatively affect sleep quality by making it harder to fall asleep and reducing the time spent in REM sleep. Good sleep health is crucial for optimal mental and physical well-being and daytime performance.

Despite young adults being one of the largest consumers of caffeinated products, particularly energy drinks, there's limited research on how this affects the sleep health of young adults, especially in New Zealand. Studies have revealed a bidirectional relationship between caffeine and sleep health, where reliance on caffeine during waking hours can lead to poorer sleep quality, creating a cycle of dependence.

Aim: This study aimed to investigate the temporal associations between caffeine intake and sleep outcomes in young adults (18-25 years). This was investigated by assessing whether caffeine intake (dosage and timing) affected the subsequent nights sleep outcomes (duration, quality and timing), and whether sleep outcomes (duration, quality and timing) could affect the following days caffeine intake.

Method: This study used GTX actigraphy and diary data to assess 7-days of sleep and caffeine intake information from 52 young adults (mean age**:** 22.06 ± 2.043 years, 87% female). Diary data reported subjective sleep outcomes and caffeine intake and timing and actigraphy data was scored and analysed on computer software (Actilife, Version 6.1.2) then merged and aligned with diary data. Mixed linear regression models were used to analyse whether caffeine dosage and timing could predict sleep outcomes for the subsequent night's sleep. Lagged effects were used to assess whether sleep duration, quality and timing could predict the following days caffeine intake. Both within person and between person variables were assessed.

Results: Our results found as people consumed more than their personal average caffeine intake across the 7-days they slept longer, but, as people consumed more than the group average, their sleep was shorter. We also found that when someone slept longer than their personal average across the 7-days, they consumed more caffeine the next day, and when people slept longer than the group average they consumed more caffeine the following day. No association was found between caffeine timing and sleep outcomes, or caffeine intake on sleep efficiency and mid-point of sleep. Nor was any association found between sleep efficiency or mid-point of sleep on caffeine intake the following day.

Conclusion: We found that caffeine consumption can adversely affect sleep duration, and sleep duration can predict the following days caffeine intake, creating a cyclic effect. Further research is required to determine how caffeine dosage and timing can impact other sleep variables such as quality and sleep timing. Due to the adverse effects that inadequate sleep duration can have on health and wellbeing and the extensive research on how caffeine intake can lead to shorter sleep duration, it would be valuable for remedies to be put in place to reduce caffeine intake in young adults.

Keywords: sleep duration; sleep timing; sleep maintenance efficiency; subjective sleep quality; sleep caffeine; young adult; actigraphy; diary

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NREM: Non rapid eye movement

REM: Rapid eye movement

EEG: Electroencephalogram

EOG: Electrooculogram

EMG: Electromyogram

SWS: Slow wave sleep

SE: Sleep efficiency

SOL: Sleep onset latency

WASO: Wake after sleep onset

CVD: Cardiovascular disease

PSG: Polysomnography

PSQI: Pittsburgh sleep quality index

SD: Standard deviation

FDANZ: Food and Drug Administration Australia and New Zealand

mg: Milligram

g: Gram

mg/kgbw/day: Milligram per kilogram bodyweight per day.

5-HT: Extracellular serotonin

CYP1A2: Cytochrome P450 1A2

AHR: Aryl hydrocarbon receptor

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CHAPTER 1 INTRODUCTION

1.1 Introduction

Humans spend approximately one third of their life asleep (Bucher et al., 2019; Walker, 2009), without which a healthy and functioning lifestyle could not occur. Sleep, much like wakefulness, has many functions (Tasali et al., 2008). Research shows that these functions occur in both the brain and body, optimising a multitude of processes, including immune function (Imeri & Opp, 2009), memory consolidation (Walker, 2009), emotional regulation (Cartwright, 2010), cognition (Diekelmann, 2014) and performance (Watson, 2017). Growing research continues to reveal that insufficient sleep can adversely affect individuals' health, well-being and functioning at both a personal, social and societal level (Grandner, 2019). Insufficient sleep can impact our lives at a personal level through our health and well-being, and at a social and societal level through our ability to interact appropriately with others and maintain relationships, and through being able to meet and maintain adequate performance standards in jobs and/or academic study. Sleep health is a growing field of research, and Buysse's definition is an accepted definition consisting of multiple dimensions (sleep duration, sleep efficiency, sleep timing, alertness/sleepiness, and sleep quality (Buysse, 2014).

The age range from 18-25 years is often one of the most transitional and solidifying periods within a person's lifetime as significant physical, cognitive, and emotional development and changes occur in the brain at this age. Brain developments include stronger neural connections, enhanced neural communication, and pre-frontal cortex development, which is responsible for decision making, planning and impulse control, allowing young adults to make more complex decisions and better regulate their behaviour (Fuster, 2002). Cognitive development includes improved higher-order thinking and metacognition skills resulting in improved abstract reasoning, problem solving skills, critical thinking, and abilities to plan, monitor and assess their own learning (Teffer & Semendeferi, 2012). Emotional development also occurs at this time, often

as a result of brain and cognitive development, allowing for better emotional regulation and resilience (Fuster, 2002). Studies have shown an association between depth and quality of sleep on brain maturation (Kurth et al., 2012), indicating that good sleep health is required during this period of brain development (Grandner, 2019).

Good sleep health in young adults is achieved by meeting recommendations in all dimensions, particularly duration, quality, and timing. Getting 7-9 hours of sleep (Ohayon et al., 2017), feeling satisfied with sleep upon awakening, having high sleep efficiency, maintaining appropriate alertness during waking hours, and sleeping at night, are all indicators of good sleep health (Buysse, 2014). A multitude of studies have shown the prevalence of poor sleep quality in young adults' ranges between 22-87% (Almojali et al., 2017; Gibson et al., 2022; Li et al., 2020; Nikhilesh et al., 2022; Yang et al., 2020). Other studies have evaluated the average sleep duration of young adults, with 28-42% not reaching the recommended 7-9 hours of sleep (Jansen et al., 2021; Metse et al., 2023; Quick et al., 2015) and average sleep duration was found to be between 6.5-7.5 hours per night (Ae Kyung et al., 2021; Aggarwal et al., 2018; Hoopes et al., 2023). This is a concern as obtaining sleep of sufficient duration and quality is very important in such a transitional period.

Young adults are typically 'evening types' and their circadian system aligns with a later timing of waking function and sleep. Evening types have a peak in alertness later in the evening, as well as a preference for going to bed and waking later than the average person. As a consequence, they have difficulty waking up at socially acceptable times (Horne & Ostberg, 1976), which becomes an issue when societal pressures such as typical '9-5' jobs or early university classes require them to wake up earlier then their natural circadian preference. The increasing pressure for sleep across a waking day (homeostatic sleep/wake regulation, which is expanded on further in Section 2.3 of Chapter 2) also builds more slowly in evening types, further promoting later sleep onset (Randler et al., 2017). The social pressure to sleep outside of preferred sleep timing and natural sleep/wake cycles could be a significant factor as to why young adults are not meeting their recommended 7-9 hours of sleep duration.

Good sleep quality for young adults can be characterised by feeling well-rested upon awakening, sleeping within preferred time periods (e.g., late evening), maintaining alertness during the day, and/or having few (less than three) awakenings throughout the night (Krystal & Edinger, 2008; Ohayon et al., 2017). Research suggests reasons for poor sleep health in young adults include increased screen use and bed-time procrastination, longer work commutes, and stimulant use (Luyster et al., 2012; Meredith et al., 2013). These factors can result in young adults placing sleep at a lower priority and/or lead to poor sleep health.

Caffeine is the most extensively consumed psychostimulant across the globe (Addicott et al., 2009). It is consumed predominately for its stimulating properties which occur primarily due to its ability to act as an antagonist for adenosine (A_1 and A_{2a}) receptors in the brain. (Hung et al., 2021). Caffeine consumption creates a perceived feeling of increased alertness by disrupting the mechanisms of homeostatic sleep/wake regulation (Hu et al., 2020). Caffeine in low to moderate doses (≤300 mg/day) has been shown to enhance physical performance and cognitive functioning (Brice & Smith, 2002; van Duinen et al., 2005). According to consensus recommendations, up to 400 mg/day can be safely consumed in healthy adults before experiencing adverse side effects (Akova et al., 2023). However, tolerance can vary significantly between individuals. Daily intake exceeding 400 mg/day has been associated with an increased risk of adverse effects, including nausea, restlessness, anxiety, and insomnia (Berman, 2022). A review summarising the impacts of caffeine on sleep (Clark & Landolt, 2017) has shown that the impacts are dose- and timing-dependent. Higher caffeine intake has been associated with prolonged sleep latency, reduced total sleep time and sleep efficiency, and worsened perceived sleep quality (Clark & Landolt, 2017). These adverse effects on sleep appear heightened when caffeine is consumed within 3-6 hours of bed-time (Drake et al., 2013). Research also suggests the relationship between caffeine and sleep is bi-directional. Caffeine is often consumed to counteract fatigue and sleepiness, but this may amplify sleep issues by causing disruption in sleep structure and the circadian time-keeping system (Hu et al., 2020), which could ultimately effect sleep timing and quality.

Recently, caffeine consumption in young adults has generated research interest worldwide. It has been found that this age group frequently consumes caffeinated products, and often exceeds recommendations for safe intake (Bucher et al., 2019; McIlvain et al., 2011). A study conducted with New Zealand tertiary students revealed that 33% of participants consumed caffeine above the level of adverse effects (3 mg per kilogram of body weight per day) and 14.3% exceeded the recommended safe limit (400 mg) per day (Stachyshyn et al., 2021), with many studies from around the world mirroring these results (Bucher et al., 2019). The main motivators for consumption appear to be for the more desirable effects, such as increased alertness, taste of food and drinks, social aspects, increased focus and concentration, and increased physical performance (Mahoney et al., 2019). The more commonly-known ill effects of caffeine consumption among young adults can include increased heart rate, nausea, and insomnia (Spiller, 1998). Young people often chose to consume caffeine regardless of the ill effects they experience, in desire of the more beneficial ones (Stachyshyn et al., 2021). This raises the question of whether the effect of caffeine on sleep health is understood by young adults, and what the implications of poor sleep health due to caffeine consumption are on their health and well-being.

1.2 Study Justification

Studies examining the effects of caffeine on sleep have been conducted on either large populations or with smaller sample sizes in experimental settings. Population studies have explored participants typical caffeine intake, dosage and timing, and the effects on a subsequent night's sleep (Lohsoonthorn et al., 2013; Vizentin et al., 2023). Large sample sizes are a strength of population studies as they can enhance the statistical accuracy of the results, but often limit the studies to single time point, subjective, easily accessible, and cost-effective measurements for testing. Subjective measures are known to be more inconsistent compared to objective measures, for reasons such as poor recall, challenges with compliance and social desirability bias (Lockley et al., 1999; Moore et al., 2015). In experimental studies, participants are typically given a specific dose of caffeine at a particular time, with a control group receiving a non-caffeinated product (Ho

& Chung, 2013; Marcus et al., 2023). In these studies, the effects are typically measured using both a subjective measure and an objective measure, either actigraphy or polysomnography. The strengths of experimental studies are the use of objective sleep measures, the comparison with a control group and the exactness of caffeine dose(s) (Martin & Hakim, 2011; Natsky et al., 2021). The limitations of experimental designs are that sample sizes are often small due to accessibility and cost, meaning the results may not be generalisable to the general population of young adults. Most studies have only evaluated the effect of caffeine on sleep at one point in time, and temporal associations between caffeine and sleep (Mathew et al., 2022) have only been investigated in adolescents. Furthermore, some population studies on adolescents have failed to find associations between caffeine and sleep (Vizentin et al., 2023), yet experimental research suggests caffeine affects sleep duration (Lodato et al., 2013), quality (Lee & Lin, 2007; Robillard et al., 2015), timing (Ali et al., 2015) and structure (Carrier et al., 2009). Moreover, limited research has been conducted with young adults, despite the large body of research suggesting they are one of the highest caffeine consuming groups.

1.3 Aim, Objectives, and Hypotheses

1.3.1 Aims

- Does poor sleep (e.g., short, or long sleep duration, poor sleep quality, later sleep timing.) predict next-day caffeine consumption in young adults (18-25 years)?
- Does caffeine consumption predict poor sleep that night in young adults (18-25 years)?

1.3.2 Objectives

- Evaluate the relationship between caffeine dosage and objective characteristics of sleep health, including sleep duration, sleep quality and sleep timing.
- Evaluate the relationship between the timing of the last dose of caffeine and objective characteristics of sleep health, including sleep duration, sleep quality and sleep timing.

- Evaluate whether objective characteristics of sleep health, including sleep duration, sleep quality and sleep timing, predict next-day caffeine dosage.

1.3.3 Hypotheses

- As daily caffeine dosage increases, the following night's sleep quality will be poorer, sleep duration will be shorter, and the mid-point timing of sleep will be later.
- As caffeine consumptions occurs closer to bedtime the following night's sleep quality will be poorer, sleep duration will be shorter, and the mid-point timing of sleep will be later.
- Caffeine consumption will be higher the day following a sleep that is short in duration, of poor quality, and/or with a later mid-point of sleep.

1.4 Structure of the Thesis

The thesis consists of four main chapters. Chapter one introduces the topic and outlines the background, study justification, aims, objectives, hypotheses, structure, and researcher contributions of the study. Chapter two is a review of the current literature on caffeine intake and sleep duration, quality, and timing, with a focus on young adults. Chapter three presents the thesis research in manuscript form, consisting of an abstract, introduction, methods, results, discussion, and conclusion. Chapter four consists of final conclusions for the thesis, including recommendations, study limitations, the impact of the research findings and recommendations for future research. There are additional appendices with relevant research documents and cited references at the end of the thesis.

1.5 Researcher Contributions

Researcher	*Contribution*
Sarah Suckling	• Main author of this research. • Completed literature review, data entry, actigraphy scoring and descriptive statistical analyses. Interpreted outputs of linear mixed models. • Completed manuscript, discussion, and conclusion chapters.
Dr Karyn O'Keeffe	• Conducted study design. • Provided supervision with study design and conduct of research. • Provided coaching on and oversight of actigraphy scoring. • Conducted statistical analyses (linear mixed models). Provided guidance in interpretation of statistical analyses. • Assisted with ethics, chapter writing, editing, and revising.
Dr Margo van den Berg	• Conducted study design. • Provided supervision with study design, conduct of research • Provided coaching on and oversight of actigraphy scoring. • Wrote SAS code for linear mixed models. Provided guidance in interpretation of statistical analyses. • Assisted with ethics, chapter writing, editing, and revising.
A/Prof Kay Rutherford-Markwick	• Provided supervision with study design, and conduct of research

	• Assisted with chapter writing, editing, and revising.
Marjial Hermanoche: Dietitian	• Completed data collection and ethics application.

CHAPTER 2 LITERATURE REVIEW

2.1 Introductory paragraph

The following chapter reviews the current literature available surrounding sleep, caffeine, and their inter-relationships. This chapter begins with sleep, and expands on sleep health, how sleep is structured (sleep architecture), the dimensions of sleep and how they are measured, and the function, regulation, and importance of sleep. It then moves onto the consequences of poor sleep health, how sleep is measured, and finally the sleep health of young adults, the focus age group of the present study. The chapter then discusses caffeine, covering what it is, where it is found, the pharmacodynamics and pharmacokinetics of caffeine in the body, and what variables could impact an individual's response to caffeine and why. Finally, the chapter focuses on the relationship between caffeine and sleep, including what current research has been carried out, identifying where the research gaps lie and why the research conducted for the present study is important.

2.2 Sleep Health

Carskadon and Dement (2010) define sleep as "a recurring, reversible neuro-behavioural state of relative perceptual disengagement from and unresponsiveness to the environment. Sleep is typically accompanied (in humans) by postural recumbence, behavioural quiescence, and closed eyes". Good sleep health is vital for maintaining good overall health, well-being, and performance (Samson et al., 2015).

In all mammals, two states of sleep have been determined: non-rapid eye movement (NREM) sleep, which consists of three different stages, and rapid eye movement (REM) sleep (Aeschbach, 2011). Stages of sleep can be determined by the level of brain activity measured by electroencephalogram (EEG), eye movements measured by electrooculogram (EOG) and muscle tone measured by electromyogram (EMG) (Markov & Goldman, 2006). The NREM stages of sleep

are N1, N2, and N3 sleep (Markov & Goldman, 2006). N1 sleep is the lightest stage of sleep and in young adults, is typically entered directly after falling asleep. It is characterised by rolling eye movements and a decrease in muscle tone. The EEG during N1 sleep is a low voltage, mixed frequency signal reflective of desynchronised neuronal firing. N1 sleep has a low arousal threshold, and sleep can be discontinued through light stimuli in the sleeping environment, such as a door closing, or the individual's name being called. N2 sleep is also a light stage of sleep, characterised by a low voltage, mixed frequency EEG signal. The defining features of N2 sleep are spindles and K-complexes that occur intermittently in the EEG. N3 sleep is the deepest stage of sleep, and restoration is considered to occur during this stage. N3 sleep is sometimes referred to as slow wave sleep (SWS) because the stage is characterised by high amplitude, slow wave activity, which is reflective of synchronised neuronal firing. REM sleep is not separated into stages and is characterised by EEG activation and muscle atonia and defined by bursts of rapid eye movements.

2.2.1 Sleep Architecture

Sleep architecture is a term that describes the typical time spent in each stage of sleep (NREM N1-3 sleep and REM sleep) and how the stages are distributed throughout the sleep period (Driller et al., 2023; Hirshkowitz, 2004). A full night's sleep will consist of 4-6 cycles of sleep, which typically consist of four stages and transition from NREM N1 and N2 sleep to N3 sleep to REM sleep. NREM sleep predominates in the first third of the sleep period while REM sleep tends to predominate in the last third of the sleep period (Driller et al., 2023). If any stage or cycle is disrupted by frequent arousals from sleep, then poor sleep quality may occur (Deatherage et al., 2009). Sleep cycles can vary in length; the initial cycle is typically the shortest and ranges from 70-100 minutes, whereas later cycles tend to be 90-120 minutes in length. N1 sleep usually lasts approximately 1-7 minutes after sleep onset. N2 sleep then usually occurs for approximately 10-25 minutes in the first sleep cycle followed by N3 sleep which occurs for approximately 20-40 minutes. Overall, NREM sleep comprises 75-80% (50-60% in N1 and N2 sleep, 15-20% in N3

sleep) of the total sleep period (Carksadon, 2010; Driller et al., 2023). A sleep cycle typically ends with REM sleep, lasting between 10-60 minutes before N1 or N2 sleep is entered again, and usually makes up 20-25% of the total sleep period in adults (Deatherage et al., 2009).

2.2.2 Dimensions of Sleep Health

Sleep health has been defined in a seminal paper as "a multidimensional pattern of sleep-wakefulness, adapted to individual, social, and environmental demands, that promotes physical and mental well-being" (Buysse, 2014). Buysse's model identifies five dimensions that contribute to overall sleep health, which are sleep timing, sleep quality and/or continuity, sleep duration, level of alertness during waking hours and subjective satisfaction with sleep (Buysse, 2014).

2.2.2.1 Sleep Duration

Basal sleep need is the amount of sleep required, free of pre-existing sleep debt, to function and live optimally (Lim & Dinges, 2007). This need can vary from person-to-person due to a variety of factors such as gender, genetics, activity level, illness, and stressors (Watson et al., 2016). While variation exists, the recommended sleep duration for young adults has been established as 7-9 hours per night (Ohayon et al., 2017). Research shows the benefits of meeting recommended sleep durations include decreased sleepiness throughout the day, improved concentration, better weight-management and a decreased risk of developing cardiovascular and metabolic disease (Knutson, 2010). Sleep duration can be measured both subjectively through self-reporting in sleep diaries and/or questionnaires, and objectively through actigraphy and polysomnography (See Section 2.5 for further details on sleep measurement) (Lauderdale et al., 2016).

2.2.2.2 Sleep Quality

Sleep quality is a term that is challenging to define and can be used to describe how satisfied a person is with their sleep (Krystal & Edinger, 2008). One study found that achieving adequate sleep quality was associated with improved subjective well-being (Weinberg et al., 2016). A meta-analysis of cross sectional studies reported overall improvement in sleep quality was associated

with improved mental health, and reduced anxiety and depression (Scott et al., 2021). Sleep quality can be determined by a series of variables including, sleep efficiency (SE), sleep onset latency, wake after sleep onset, and perceived satisfaction with sleep and/or feeling refreshed upon awakening (Sheehan et al., 2020). For young adults, good sleep quality has been defined as a sleep efficiency (percentage of time spent asleep while in bed) of ≥85%, falling asleep in ≤30 minutes, waking up only once during the main sleep period, and spending ≤20 minutes awake after falling asleep (Ohayon et al., 2017).

2.2.2.3 Sleep Timing

Sleep timing refers to the position of sleep within the 24-hour day and is often measured by calculating the mid-point of sleep (the mid-point between sleep onset and the final wake time) (Chaput et al., 2020). Alertness is shown to fluctuate during a 24-hour period (circadian oscillation), such that during the daytime, alertness is high and during the night-time alertness is low (Satterfield & Killgore, 2019), which is why humans tend to sleep during the night-time. Inconsistent or disrupted sleep patterns can lead to a series of increased health risks including metabolic syndrome, diabetes, coronary heart disease and mortality (Buysse, 2014).

2.2.2.4 Chronotypes and Social Jetlag

Chronotypes are individuals' preferred timing for daily activities, including sleep, and are determined by genetics and lifestyle preferences (Roenneberg et al., 2003). Chronotypes are typically defined as morning, intermediate and evening types (Kivelä et al., 2018), which are characterised by the preferred time of day for sleep and other activities. Young adults are typically, but not always, more evening type and prefer to sleep later in the evening (Randler et al., 2017). Social schedules in young adults often interfere with individual sleep preferences, resulting in a sleep debt accrued across working days (Wittmann et al., 2006). This largely affects evening chronotypes as they are typically up late but must wake up at socially acceptable times, resulting in a short sleep duration. Often, this sleep debt results in catch-up sleep at the weekend

(Wittmann et al., 2006). This misalignment between the timing of sleep during the working week and on days off due a conflict with social expectations is called social jet lag. Research shows increased levels of social jetlag are associated with adverse health outcomes, particularly long-term weight gain (Hayes et al., 2022).

2.2.2.5 Other dimensions

The other two dimensions of sleep health include alertness and subjective satisfaction with sleep. Alertness is measured as the ability to maintain attentive wakefulness during the waking day and is often measured through the frequency and number of naps during the day or the propensity to fall asleep (Dement et al., 1982). Satisfaction of sleep is a subjective assessment of "good" or "poor" sleep (Buysse, 2014) and is measured through participants' self-reporting on how satisfied they were with the previous night's sleep. Decreased alertness, frequent naps during the day, and low self-perceived satisfaction are associated with an increased risk of coronary heart disease, impaired neurobehavioural performance, depression, hypertension and mortality (Buysse, 2014)

2.2.3 Sleep Function

Sleep is crucial to maintaining optimal health, well-being, and functioning and is involved in a range of processes including memory consolidation, brain cleansing, immune function, and emotional regulation (Samson et al., 2015). Research shows that, during sleep, there is an increased clearance of neurological waste products, such as β-amyloid, α-synuclein, and tau (Xie et al., 2013), as well as an increased release of anabolic functioning hormones, which promote energy conservation (Schmidt et al., 2017). Both processes strongly support theories for the restorative processes of sleep (Samson et al., 2015). While functions of sleep on immune response are not well researched, evidence suggests that the sleep-wake cycle plays a role in the formation of immunological memory (Besedovsky et al., 2012). Production of pro-inflammatory cytokines and T-cells peak during sleep while other immune cells such as natural killer cells and anti-inflammatory cytokine activity occurs during waking periods (Besedovsky et al., 2012). This is

supported by research showing that prolonged short sleep or disrupted sleep can result in low-grade inflammation and is correlated with diseases that have an inflammatory component such as atherosclerosis or diabetes (Besedovsky et al., 2019).

During sleep, many brain processes occur, such as emotional regulation and memory consolidation, that are vital to learning, functioning and day-to-day living (Tasali et al., 2008). Research suggests that short or poor quality sleep is associated with decreased emotional stability the following day (Vandekerckhove & Wang, 2018). A study carried out with young adults showed that, during sleep, the brain "resets" reactivity to emotional challenges the following day by maintaining functional integrity of the medial prefrontal cortex amygdala circuit, the part of the brain which regulates contextually appropriate emotional responses (Yoo et al., 2007). Sleep enhances emotional regulation by processing emotional experiences during sleep. Negative aspects of emotional experiences are taken away during sleep, allowing people to have a more rational perspective of events in the morning (Cartwright, 2010).

During sleep the consolidation of declarative memories (events and facts) and non-declarative memories (emotion and procedural) is promoted and it is postulated that consolidation is optimised when SWS and REM sleep occur consecutively (Diekelmann et al., 2009). Sleep also appears to play an active role in long-term retention and retrieval of encoded information (Ellenbogen et al., 2006; Jha, 2020). It has also been shown that sleep is essential for learning and motor skills, with multiple studies showing that, compared to being sleep deprived, obtaining sufficient sleep enhances reaction time on the psychomotor vigilance task (a validated measure of response time) (Dinges & Powell, 1985; Samson et al., 2015).

2.3 Sleep Regulation

Sleep is regulated through two interconnected neurobiological mechanisms: the homeostatic sleep drive and the circadian timekeeping system. These systems interact to ensure regular sleep

periods of adequate sleep duration are achieved and ensure sleep periods occur at appropriate times within the 24-hour day/night cycle (Borbély et al., 2016)

2.3.1 Homeostatic Sleep Drive

The homeostatic sleep drive regulates sleep periods and wakefulness by assessing the amount of sleep and wakefulness (Satterfield & Killgore, 2019). It is conceptualised as sleep pressure that builds with the hours of wakefulness across the day (Satterfield & Killgore, 2019). This is a brain-wide process and is likely mediated through adenosine, an extracellular modulatory nucleoside, which slows the neuronal firing rate (Satterfield & Killgore, 2019). Adenosine levels increase as the time spent awake increases, causing an increased pressure for sleep. Both sleep pressure and adenosine dissipate across the sleep period (Satterfield & Killgore, 2019). Therefore, if adequate sleep duration has occurred, no feelings of sleep pressure should be present on awakening.

2.3.2 Circadian time-keeping system

The circadian timekeeping system regulates sleep timing through the daily patterning of sleep and wake, controlled by the circadian rhythm of alertness (Patton & Hastings, 2023). The circadian master clock, which regulates several peripheral clocks in the body including the sleep-wake cycle, is located in the suprachiasmatic nucleus of the hypothalamus and is connected to the external world through the retinohypothalamic tract from the eyes (Aeschbach, 2011). This pathway detects light in the external environment, which the circadian timekeeping system uses to synchronise with the external environment. This synchronisation allows the body to appropriately alternate between daytime alertness and night-time sleepiness over a 24-hour period (sleep/wake cycle) (Satterfield & Killgore, 2019). The timing of exposure to light in a 24-hour period can alter circadian timing at the SCN. This can cause advances and delays in circadian rhythms such as the sleep-wake cycle, so that the sleep period occurs earlier or later in the 24-hour day/night cycle.

2.3.3 Relationship Between Homeostatic Sleep Drive and Circadian Time-keeping System

The homeostatic pressure for sleep that builds during waking hours is countered by the fluctuations in alertness from the circadian timekeeping system. Periods of high alertness typically occur late-morning and in the early evening and periods of low alertness occur in the mid-late afternoon and during the night, with the lowest alertness in the middle of the night. During the night-time, pressure for sleep is high and circadian alertness is low, and therefore sleep onset and maintenance is typically unchallenged (Satterfield & Killgore, 2019). As sleep pressure dissipates, alertness increases, ensuring appropriate levels of alertness when wake up occurs. Disturbances in this neurobehavioural functioning can occur if people go against their natural rhythm, for instance by doing shift work, changing time zones or for reasons such as socialising, insomnia or intake of stimulants, leading to an altered sleep onset (Satterfield & Killgore, 2019)

2.4 Consequences of Poor Sleep Health

Poor sleep health can significantly impair performance (cognitive and physical) alertness, (Charest & Grandner, 2020), emotional stability (Nelson et al., 2022), and physical health and well-being, increasing the risk of disease, poor health and early onset of aging (Jha & Jha, 2020). Each dimension of sleep health has been associated with adverse health consequences if recommendations are not met (Buysse, 2014).

2.4.1 Insufficient Sleep Duration

Research shows that consistently getting less than 7-9 total hours of sleep can significantly impact cognitive performance, particularly working memory, attention span and executive functions including decision making, planning, and processing of information (Charest & Grandner, 2020; Choshen-Hillel et al., 2021; Nakakubo et al., 2017). Studies have shown that consistently limiting sleep duration for consecutive days leads to notable, cumulative impairments in cognitive

performance across all tasks, and that the effects are dose-dependent (i.e. dependent on the amount of sleep obtained) (Belenky et al., 2003; Van Dongen et al., 2003). Alongside cognitive performance, repeated periods of short sleep have been shown to adversely affect physical performance through reduced speed, strength, and reaction time (Taylor & Martin, 2019; Zaim et al., 2012). In addition, insufficient sleep duration can directly increase the risk of diabetes, obesity, cardiovascular disease (CVD), cerebrovascular disease, inflammatory markers, immune dysfunction, mortality and decreased neurological performance (Buysse, 2014; Hanisah et al., 2022).

2.4.2 Insufficient Sleep Quality

Direct consequences of chronic poor quality sleep, best measured by a sleep efficiency of less than 85% and not meeting sleep duration recommendations, include increased risk of CVD, impaired glucose metabolism, and depression (Buysse, 2014). Poor sleep quality is also correlated with daytime sleepiness and impaired concentration (Alapin et al., 2000), increased tiredness and irritability (Nelson et al., 2022), and increased susceptibility to psychological disorders (Edéll-Gustafsson et al., 2002).

2.4.3 Misalignment of Sleep-Timing

Sleeping at times which are out of alignment with the body's preferred timing can increase the risk of diabetes, CVD and obesity (Buysse, 2014). It can also result in daytime sleepiness, placing individuals at risk of unsafe driving behaviours, which in turn increases accident risk (Watling et al., 2020). Abnormal sleep timing can occur because of rapid travel across time zones, shift work, sleep irregularity between weekdays and weekends (social jet lag), or extreme chronotypes attempting to align with socially acceptable times for sleep (Wittmann et al., 2006).

2.5 Sleep Measurement

2.5.1 Objective Sleep Measures

There are multiple methods used to evaluate sleep duration, quality, and timing. Two primary methods exist for measuring these dimensions of sleep objectively: polysomnography (PSG) and actigraphy. Polysomnography is the gold standard for objective sleep measurement. It is typically a sleep laboratory-based tool that measures at a minimum electrooculography (EEG) (eye movement), electroencephalography (EOG) and electromyography (EMG) (Moore et al., 2015; Van De Water et al., 2011). While considered the gold standard method for determining if a person is awake or asleep at any given time, PSG is time intensive, costly and requires specialist expertise to conduct and analyse (Driller et al., 2023; Natsky et al., 2021; Van De Water et al., 2011). An actigraph is a small and often wrist-worn device containing an accelerometer that measures motor activity (actigraphy) over time periods to determine sleep and wake (Chaput et al., 2020). It is a well-regarded and validated tool for the estimation of sleep parameters and can provide a longitudinal assessment of sleep habits across 24-hour periods which are analysed using a validated computer software algorithm (Martin & Hakim, 2011; Moore et al., 2015). Actigraphy can also be used for calculating sleep efficiency during the sleep period as an objective measure of sleep quality. Measurement of sleep onset (time of falling sleep), and sleep offset (time of final waking) can also be used to calculate the mid-point of sleep, an objective measure for sleep timing. While actigraphy can be used in natural sleep environments and is non-invasive, it is limited by inaccurate estimations of sleep onset latency, wakefulness, sleep efficiency and total sleep time (Sadeh, 2011).

2.5.2 Subjective Sleep Measures

Subjective sleep measures, including retrospective questionnaires and prospective sleep diariesare often used in research and frequently alongside an objective measure. While there are currently several validated questionnaires available, the Pittsburgh Sleep Quality Index (PSQI)

(Buysse et al., 1989) and Consensus Sleep Diary (Carney et al., 2012) are focused on in this chapter due to their use in the present study. The PSQI is the most commonly used questionnaire and evaluates seven subjective dimensions of sleep quality to produce an overall score: sleep quality, sleep onset latency, sleep duration, sleep efficiency, sleep disturbances, sleep medication and daytime sleep dysfunction (Buysse et al., 1989). It is limited by participant recall bias and its global sleep score reflects average sleep quality in the past month, making it challenging to capture temporal associations. The Consensus Sleep Diary (Carney et al., 2012) captures daily sleep characteristics within a short time frame of experiencing them, thus increasing accuracy, and allowing for assessment of day-to-day fluctuations in sleep. The disadvantages of the Consensus Sleep Diary include inaccuracies in reporting of total sleep time and sleep efficiency (Dietch & Taylor, 2021). While there are benefits to subjective measures, inconsistencies such as poor participant recall bias, compliance challenges (selective reporting), and social desirability bias can lead to inaccurate reporting of sleep quality. It has been recommended that both objective and subjective measures are used simultaneously when conducting sleep-wake research to limit these inconsistencies (Lockley et al., 1999; Marco et al., 2021; Moore et al., 2015).

2.6 Sleep in Young Adults

2.6.1 Sleep Duration

Young adulthood can be defined as the age range of 18-25 years (Ohayon et al., 2017). An assessment of sleep duration in American adults showed that 30% of young adults (18-25 years) were not achieving adequate sleep duration (>7 hours of sleep per night) (National Center for Chronic Disease Prevention and Health Promotion, 2023). Table 2.1 summarises a range of studies published since 2000, on both large and smaller populations, that have shown similar results. Most young adult populations have average daily sleep durations less than the recommended 7 hours (Ae Kyung et al., 2021; Hoopes et al., 2023). Many of these studies focused on the health (mental and physical) outcomes associated with short sleep, rather than the causes

of short sleep. In addition,, most studies utilised subjective sleep measures such as diaries and questionnaires to record sleep duration, while a few studies used actigraphy or polysomnography. To this author's knowledge, limited sleep research has been focused on young adults in New Zealand.

2.6.2 Sleep Quality

The prevalence of poor sleep quality in young adults worldwide is high, typically ranging from 22-87%, as reflected in

Table 2.2. The main factors affecting sleep quality in this age group are stress, anxiety, smartphone and screen use, as well as use of stimulants and shift work (Priya & Guzman, 2023). This wide prevalence estimate for poor sleep quality is due to the considerable variation in study designs, such as different sample size, control groups, and exclusion criteria (Ohayon et al., 2004). Most research on the sleep of New Zealanders has focused on children (<13 years), adolescents (13-17 years) and all adults (18+ years). The limited research conducted solely with New Zealand young adults has found that 85.9% experienced poor sleep quality, and only 1 in 8 (12.5%) obtained the recommended 7+ hours of sleep at night (Hermanoche, 2023).

Table 2.1: Summary of studies evaluating sleep duration that have included young adults (alphabetical order by author)

Reference	Study Design	Demographic Age, Gender, sample size	Origin	Average Sleep Duration
(Ae Kyung et al., 2021)	Descriptive Research Sleep Questionnaire	19-39 years Male (92) + Female (196) Young Adults n=288	South Korea	6.86 hours
(Aggarwal et al., 2018)	Cross-sectional study Population study + Basic study Actigraphy + PSQI	39 ± 17 years (20-79 years) Female Participants from American Heart Association Go Red for Women Strategically Focused Research n= 323	United States	Population study = 6.8±1.3 hours Basic study= 7.5±1.1 hour
(Chan et al., 2022)	30-Day Daily Longitudinal PSQI	21.7 years ± 4.18 (18-35 years) Male (15) + Female (44) Adults n= 59	Hong Kong	450.56mins ± 59.10 (~7.51 hours)
(Hoopes et al., 2023)	Cross-sectional measures used?	28.9 ± 7.1 years (18- 45 years) Male (22) + Female (41) Generally healthy adults n= 63	NA	417.2 mins / night (~6.95 hours/night)
(Jansen et al., 2021)	Secondary analysis of randomised control trial measures used?	21-30 years Males + Females College Students n= 1444	United States	32% of participants reported <7hr of sleep per night
(Kato et al., 2018)	Cross-sectional measures used?	22.0 ± 2.2 years Males (13) + Females (10) Young Adults n= 23	Japan	369.5 ± 59.4 mins (~ 6.16hours)

Reference	Study Design	Demographic Age, Gender, sample size	Origin	Average Sleep Duration
(Metse et al., 2023)	Population-level Cross-sectional study using the Raine Study data PSG + Self report questionnaire	Young Adults (~22 years) Male + Females Raine Study n= 1234	Western Australia	(n= 952) Reaching adequate duration (7-9hours) = 22.4% (213) Reaching possibly adequate duration (6 hours or 10-11 hours) = 47.8% (455) Inadequate duration (< 6hrs, <11 hours) = 29.8% (284)
(Peltzer & Pengpid, 2016)	Cross-sectional measures used	Mean age = 20.8 ± 2.8 years (17-30 years) Males (50%) and females (50%) Undergraduate University Students n= 800	26 countries across Asia, Africa, and the Americas.	16-17 years = 6.8 hrs 23 years = 7.2hrs 26-30 years = 6.8hrs
(Quick et al., 2015)	Longitudinal Study measures used	18-24 years Male (39%) + Female (61%) Full-time University Students n= 1035	United States	Achieving <7hours per night = **42%**

Search terms "Sleep Duration In young adults" and "prevalence of short sleep-in young adults" between 2000-2024
Excluded: Studies that evaluated the impact of factors other than caffeine on sleep duration and/or manipulated sleep duration.
Note: Some studies summarised in this table included adults (25+ years) but the total age range included young adults (18-25 years).

Table 2.2: Summary of studies evaluating sleep quality that have included young adults (alphabetical order by author)

Reference	Study Design	Demographics Age, gender, sample size	Origin	Prevalence of poor sleep quality (%)
(Almojali et al., 2017)	Cross-sectional PSQI	Medical students Mean age: 21.9 (SD= 1.7) years Male + Female n=332	Saudi Arabia	76
(Camille et al., 2018)	Cross-sectional PSQI	College students Male N=144	United States	64
(Fatima et al., 2016)	Cross-sectional PSQI + Self report	Young adults Mean age: 20.6 (SD= 0.86) years Male + Female n=3778	Italy	Female: 65 Male: 50 Total: 58
(Gibson et al., 2022)	Cross-sectional, retrospective. PSQI	Adults (during lockdown) 20-85 years Male (18%) + female (82%) n=732	New Zealand	54.5
(Hanisah et al., 2022)	Cross-sectional PSQI	University Students NA Females n=112	Malaysia	77
(Hayder et al., 2023)	Cross-sectional PSQI MEQ	University students Mean age: 21.2 (SD= 5.1) years Male + Female (79.5%) n=552	Sharjah/United Arab Emirates	71
(Hermanoche, 2023)	Cross-Sectional PSQI	Young Adults 18-25 years Male + Female n=192	New Zealand	85.2
(Kwame et al., 2022)	Cross- sectional PSQI	University Students Age range: 20-30years Male + Female (73.3%) n=340	Ghana	54
(Lee & Lin, 2007)	Cross-sectional PSQI	College athletes Mean age: 19.3 (SD= 0.6) years Females n=291	Taiwan	44

Reference	Study Design	Demographics Age, gender, sample size	Origin	Prevalence of poor sleep quality (%)
(Lemma et al., 2012)	Cross-sectional PSQI	University Students Mean age: 21 years Male (75%) + Female n=2551	Ethiopia	56
(Li et al., 2020)	Cross-sectional PSQI	University Students Mean age: 19.76 (SD= 1.45) years Male (52.7%) + Female n=6284	China	31
(Li et al., 2023)	Prospective Longitudinal T1- Initial T2- 6 Months post PSQI	Young adults Mean age: 18.8 (SD= 1.2) years Male (37.7%) + Female n=1179	China	Initial: 13 6 Months post: 11
(Mohsin & Yousef Al, 2019)	Cross-sectional PSQI Sleep Beliefs Scale	Medical students Male + Female n=225	Saudi Arabia	57
(Nikhilesh et al., 2022)	Cross-sectional PSQI	Young adults Age range: <30 years Males (77) + Females (233) n=310	India	87
(Schlarb et al., 2017)	Cross-sectional PSQI	University students Mean age: 24 (SD= 3.8) years Male + Female (65%) n=2443	Germany	37
(Tonon et al., 2020)	Cross-sectional PSQI	Military recruits Age: 18 years Male n=236	Brazil	54
(Vargas et al., 2014)	Cross sectional PSQI	College students Mean age: 21.68 years (SD= 3.49) Male + Female (73.2%) n=515	United States	51

Reference	Study Design	Demographics Age, gender, sample size	Origin	Prevalence of poor sleep quality (%)
(Yang et al., 2020)	Cross-sectional PSQI	Returning Workers Mean age: 36.3 (SD= 9.1 years) Male + Female (49.2%) n= 2410	China	22

Search term "prevalence of poor-quality sleep in young adults".
Exclusion: Studies that (a) did not focus on young adults, (b) focused on sleep hygiene rather than sleep quality, (c) evaluated the impact of a particular factor on sleep quality, and (d) used only unvalidated question(naire)s.
PSQI: Pittsburgh Sleep Index Questionnaire; MEQ: Morningness-Eveningness Questionnaire.
Some studies summarised in this table included adults (25+ years) but the total age range included young adults (aged 18-25 years).

2.6.3 Sleep Timing

Sleep timing has been more frequently researched in recent years with studies often utilising objectives measures, such as the mid-point of sleep and sleep onset from PSG or actigraphy (Chaput et al., 2020), and questionnaires (Monk et al., 2003). Young adults typically go to bed later in the evening, with peak evening type occurring during late adolescence and persisting into early adulthood (Randler et al., 2017). A study assessing changes in bedtime over the years for adolescents (15-17 years) showed an average bed-time of 22:18 (SD ± 0:14) on school nights and 22:42 (SD± 0:15) on non-school days (Knutson & Lauderdale, 2009). A cross-sectional study carried out in 1,317 adults (46-66 years) reported an average bedtime ranging between 21:45-23:00 (Duncan et al., 2016). One study carried out in 654 older adults (≥65 years) reported an average habitual bed-time of 23:14 (SD ± 69.9min) (Monk et al., 2011). In comparison, studies in young adults have found average bedtimes of 00:10 (SD ± 1.8hours) (Grummon et al., 2021), 23:59- 00:39 (Lo et al., 2014), and 00:04-00:92, with variation occurring between work days and free days (von Gall et al., 2023). This research suggests that young adults tend to have a much later bedtime than the rest of the population, which aligns with their evening chronotype preferences.

Many studies have investigated the misalignment between the sleep-wake phase and social timing of young adults (social jet lag) (Beauvalet et al., 2017; McMahon et al., 2018; Wittmann et al., 2006). Some studies have suggested that a main cause of social jet lag is bed-time procrastination from wanting to increase time for relaxation, leading to delayed bedtime (Chung et al., 2019; Nauts et al., 2016). Higher bed-time procrastination scores have been associated with both greater social jet lag and shorter sleep durations, with weekend sleep being typically longer than week-day sleep (Xiaoyu et al., 2020). Other studies have also investigated the irregularity of sleep timing between work days and free days and have found that measures of sleep timing, including both mid-point and bedtime, are later on free-days than work days (Lenneis et al., 2021;

Lo et al., 2014). Further, when compared to 40-50 year old's, young adults had significantly higher irregularity in mid-point of sleep (Lenneis et al., 2021).

2.7 Caffeine Sources, Pharmacodynamics, and Metabolism

2.7.1 Where is Caffeine Found?

Caffeine (1,3,7-trimethylxanthine) is one of the most highly consumed psychostimulants in the world (Fulton et al., 2018). Caffeine is naturally occurring and commonly known to be found in coffee, tea, cacao and energy drinks (Spiller, 1998), and known to a lesser extent to be found in chocolate, kola (the basis of cola drinks), and other products such as over-the-counter medications and dietary supplements (Frary et al., 2005). The number of caffeine-containing products is rapidly growing with the addition of caffeine to foods such as jellybeans, marshmallows and chewing gum (Fulton et al., 2018). There has also been an increase in caffeine-containing sports supplements available on the market, which can vary greatly in caffeine quantity, depending on its purpose. With the increase in caffeine-containing products available, there is a concern of whether the quantity of caffeine being consumed by individuals is known, particularly when it is consumed in unsuspected products. Currently the Food and Drug Administration Australia and New Zealand (FDANZ) does not require food or drink products with naturally occurring caffeine content to disclose the exact quantity of caffeine present, but must disclose when it is present (Food Standards Australia and New Zealand, 2023). Product labelling must disclose that caffeine is present if it has been added, or if guarana is present, but not the quantity of caffeine present (Food Standards Australia and New Zealand, 2023).

The caffeine content of products can vary significantly, particularly for beverages such as coffee or tea, which are typically made and ordered to personal preference. For example, coffee orders can range from single to triple shot which creates a variance of 25–214 mg (Desbrow et al., 2007) between coffees ordered. Barista-made coffee can also increase variability through factors such

as the type of beans used, quantity of espresso used (g) or quality of shot produced, all potentially resulting in higher than anticipated caffeine consumption (Desbrow et al., 2012).

In New Zealand some protocols have been put in place to limit excessive caffeine consumption at one time, such as limiting the caffeine content of energy drinks to <32 mg per 100mL. However, there are no laws surrounding the ability to purchase or consume multiple caffeinated products in one day (NZ Beverage Council, 2023). As a result of the variability in, and increased availability of caffeine-containing items, this poses a challenge for people to estimate how much caffeine they are consuming on a day-to-day basis and the impact this may have.

Caffeine is commonly consumed for its ability to enhance focus, boost mood, and help counter feelings of fatigue or drowsiness, particularly following sleep of poor quality or short duration (MacKenzie et al., 2007). Research shows many more beneficial responses such as improved reaction time, increased vigilance, better logical reasoning (Kamimori et al., 2015), and increased performance in strength and endurance training (Norum et al., 2020; Sampaio-Jorge et al., 2021). Caffeine intake has also been shown to increase extracellular serotonin (5-HT) (Okada et al., 1999), the main chemical contributor to feelings of happiness and well-being (Denis & Michael, 2022), making caffeine a desirable product overall for day-to-day consumption. However, some people will experience negative effects from caffeine consumption.

2.7.2 Caffeine Pharmacodynamics

The beneficial responses to caffeine consumption are the main motivators for consumption, but alongside these benefits, less-desirable responses can also occur (Ribeiro et al., 2002; Tennent, 2018). For those who are caffeine sensitive, even a small dose can lead to a variety of adverse reactions including heart burn, insomnia, anxiety, indigestion, headaches, abdominal pain, restlessness, heart palpitations, diarrhoea and/or constipation, and fatigue (Ruiz-Moreno et al., 2020; Spiller, 1998).

The less-desirable responses following caffeine consumption may be less well-known and understood than the desirable responses. Caffeine intake of ≥3 mg per kg of body weight has been associated with adverse effects (Thomson et al., 2014). High caffeine intake can stimulate stress-like effects in the pituitary gland resulting in anxiety, tremors and accelerated heart rate (Spiller, 1998), and for those that are caffeine sensitive, even the smallest dose can result in these severe effects. Caffeine can also impact the gastrointestinal system as it stimulates gastric secretion and gastric and intestinal mobility, as well as having a diuretic effect due to increased renal blood flow and glomerular filtration rate (Spiller, 1998).

Caffeine can impact sleep through its relationship with adenosine. Levels of adenosine increase throughout the day, peaking in the evening. Accumulation of adenosine results in the feeling of sleepiness by stimulating the secretion of GABA and melatonin (sleep-promoting neuromodulators), and inhibiting secretion of acetylcholine, dopamine and norepinephrine (wake-promoting neuromodulators) (Basheer et al., 2004). Therefore, by caffeine binding to adenosine receptors, caffeine intake can result in higher levels of wake promoting neuromodulators and therefore feelings of alertness.

2.7.3 Caffeine Metabolism

Caffeine is part of the methylxanthine group and following consumption has a typical half-life of 2-6 hours in the adult human body (Ferré, 2019). It is primarily metabolised in the liver by the cytochrome P450 1A2 enzyme (Nawrot et al., 2003). The rate of cytochrome P450 1A2 activity controls the amount of time that caffeine stays in the body and can vary significantly between different individuals. The three *CYP1A2* genotypes (AA, AC, and CC) result in varied enzyme activity (Carrillo & Benitez, 1996); people with AA genotype metabolise caffeine “fast” and people with the CC genotype metabolise caffeine “slowly”. The CYP1A2 enzyme is induced by the binding of aromatic hydrocarbons to the Aryl hydrocarbon receptor (AHR) which is a transcription factor protein. The rate of the metabolism of caffeine can be impacted by genetic variation. There are 13 genes thought to be involved with caffeine effects, but variation in either of these genes (CYP1A2

and AHR) are known to result in a different interindividual response to caffeine consumption. Caffeine acts as an antagonist to the adenosine receptors which consist of four genetic subtypes: ADORA1, ADORA2A, ADORA2B, and ADORA3. Increased adenosine in the body leads to an increased production of neurotransmitters that promote alertness, rather than sleepiness, following caffeine consumption (Reichert et al., 2021). Overall, genetic variability within these single nucleotide polymorphisms (*CYP1A2* rs762551; *ADORA2A* rs5751876 and *AHR*; rs4410790) vary the physiological response to caffeine consumption between individuals (Carrillo & Benitez, 1996).

2.7.4 Response to Caffeine Consumption

Levels of physiological responses to caffeine can vary, even from the same dose (Lichtenstein, 2023), and while the smallest amount may elicit no response in one individual, it may elicit a significant negative response in another (Smith, 2002). For this reason, it is important for individuals to be able to estimate with some degree of accuracy the amount of caffeine they are ingesting. There are several reasons why people respond differently to the same dose of caffeine, including genetics, rate of metabolism, and tolerance (habituation).

Like many stimulants, a tolerance to caffeine can build when repeated or prolonged exposure occurs, resulting in habituation, a decreased physiological response post-consumption to the same dose (Spiller, 1998). A study carried out in rats showed that when repeatedly exposed to high doses of caffeine, the concentration of adenosine receptors in the brain increased. As a result of this increase, competition between adenosine and caffeine for adenosine receptors is effectively reduced, and therefore, the level of response elicited by caffeine may also be reduced (Fredholm et al., 1999; Johansson et al., 1993). As caffeine is often consumed daily, if not multiple times a day, habituation is likely to occur and could be another cause for the varied physiological responses between individuals (Beaumont et al., 2017). Habituation can also lead to increased intake of caffeine, as those who habituate must consume a higher quantity to elicit the same effect. However, habituation does not always occur, and some people will maintain the same response

to the same dose of caffeine over a lifetime (Svenningsson et al., 1999). Other factors, such as smoking and gender, can also affect the metabolism of caffeine, adding to the variation in response between individuals (Chung et al., 2000).

2.8 Caffeine Intake in Young Adults

Consumption of caffeine is a long-standing and integral part of many people's day-to-day lives. However, young adults (aged 18-25 years) consume greater amounts of caffeine than the general population (Bertasi et al., 2021; Hermanoche, 2023) and frequently exceed 400 mg (recommended safe level) per day (Bucher et al., 2019). This could be due to a multitude of reasons such as targeted marketing, academic pressure, and/or social factors.

The main sources of caffeine consumed by young adults in New Zealand appear to be coffee, tea and chocolate (Stachyshyn et al., 2021) and worldwide, there has been an increase in consumption of energy drinks in young adults, particularly among males (Bonanni et al., 2022). In general, males typically consume more caffeine than females, possibly because they tend to be less health conscious and also partake in more risk-taking behaviours than females (World Health Organization. Regional Office for Europe, 2018). The main motivators for caffeine consumption in young adults include increasing energy to remedy insufficient sleep, for taste, social factors, or consuming with alcohol for recreational purposes (Malinauskas et al., 2007).

2.8.1 Marketing of Caffeine Products

The marketing of caffeine-containing products, particularly energy drinks and kola beverages, often focuses on the drink's abilities to enhance performance in sports, particularly extreme sports, post-consumption (Bleakley et al., 2022). This targeted marketing, which frequently uses professional sport stars and celebrities, promotes consumption within young adults through enhancing the belief that energy drinks are beneficial to achieving goals (Bleakley et al., 2022).

2.8.2 Consumption in Young Adults

A significant proportion of tertiary students in New Zealand are young adults (Ministry of Education, 2022). A study carried out in New Zealand investigating the caffeine intake of tertiary students (≥16 years) showed the average intake per day was 146.73 mg, with 33% of participants consuming levels above that known to cause adverse effects (3 mg per kilogram bodyweight, per day) and 14.3% consuming above the recommended safe limit (400 mg/day) (Stachyshyn et al., 2021). High caffeine consumption among tertiary students is not limited to New Zealand, with multiple studies from around the world showing similar results (Bucher et al., 2019; Islam et al., 2020). Students stated exams were a major stressor contributing to caffeine consumption alongside other stressors of academic work such as assignment deadlines and attending early morning lectures (Islam et al., 2020). Students said that perceived feelings of increased alertness, concentration, reduced fatigue, and delayed onset of sleepiness post-consumption of caffeine were desirable for academic work by increasing the time and energy available for studying (Bonanni et al., 2022; Stachyshyn et al., 2021)

There may be other factors that drive caffeine consumption in young adults, and in New Zealand, the "coffee culture" is very strong. Many situations, including business meetings and social situations, typically occur "over coffee", particularly for females (Guo, 2020; Stachyshyn et al., 2021). This could suggest that there may be an element of social pressure to drink a caffeinated drink, specifically tea or coffee, during these events, which could be a potential contributor to the high prevalence of caffeine intake.

2.9 Caffeine and Sleep

Caffeine intake is known to have an inverse relationship with sleep duration, to extend sleep onset latency, reduce sleep efficiency, and decrease perceived sleep quality (Hu et al., 2020). As mentioned above, variation in genetics can vary the rate of caffeine metabolism. This means that while the impact on sleep is dose-dependent, the timing and rate of metabolism of caffeine may

also cause the impact on sleep to vary significantly between individuals. As shown in Table 2.3,many studies investigating the impact of caffeine consumption on sleep have had small sample sizes and utilised both an objective and subjective sleep measure.

2.9.1 Effect on Sleep Duration

As Table 2. shows, multiple studies have shown caffeine intake, particularly when closer to bedtime, leads to reduced total sleep duration. One recent study showed sleep duration decreased by 10.4 minutes for every caffeinated beverage consumed that day (Song & Walker, 2023). This suggests that for people who consume at least one caffeinated beverage a day, an hour of sleep debt could accumulate each week. It has beenfound that shorter sleep duration is associated with caffeine consumption when compared to non-caffeine consumption (Drake et al., 2013).

2.9.2 Effect on Sleep Timing

Overall, a small number of studies have assessed the effects of caffeine consumption on sleep timing, as reflected in Table 3. Results show that caffeine consumption has been shown to delay bedtime and increase sleep latency when compared to non-caffeine consuming participants (Drake et al., 2013; Landolt et al., 1995; Robillard et al., 2015; Shilo et al., 2002). Another study found that when a dose of caffeine equivalent to a double shot of espresso was given ~3 hours before participants' habitual bedtime, a 40-minute delay in the circadian melatonin rhythm occurred, promoting a delayed bedtime and delayed timing of the sleep/wake cycle (Burke et al., 2015). Among those few studies evaluating the effects of caffeine consumption on sleep timing, most have evaluated bedtime and sleep latency as sleep timing measures, whereas one study (Mathew et al., 2022) also examined changes in the mid-point of sleep. Mathew et al. (2022) found that as ≥1 caffeine product was consumed, both sleep onset and mid-point were delayed by 17 minutes. Finally, one study showed that as caffeine intake increased, time in bed decreased (Sanchez-Ortuno et al., 2005). This could be a result of delayed bedtime and increased latency

resulting in a shorter time spent in bed, and shorter sleep duration as sleep offset may remain the same.

2.9.3 Sleep Quality

Many studies since the early 2000's have assessed the effect that caffeine ingestion has on sleep quality, as shown in Table 2.. One study has shown that when 100 mg of caffeine was consumed both within 3 hours of bedtime and 1 hour before bedtime, REM sleep was decreased by 3.7 min (Carrier et al., 2009). Higher total daily caffeine doses have also been associated with lower perceived sleep quality, increased restlessness during the night, and feelings of lower alertness upon awakening (Ali et al., 2015; Hindmarch et al., 2000). Another study, where habitual caffeine intake was assessed, found no association between caffeine intake and sleep quality (Watson et al., 2016).

2.9.4 Bi-directional Relationship of Caffeine and Sleep

There is the potential of a bi-directional relationship existing between caffeine intake and sleep (Hu et al., 2020). As caffeine is often consumed as a tool to energise people through the day, there is a potential that more caffeine is consumed after a poor-quality or short sleep, resulting in the following sleep also being of poor quality or short. Mathew et al. (2022) also assessed day-to-day associations of caffeine intake and found that shorter sleep duration and later mid-point of sleep, on average, increased the likelihood of adolescents consuming caffeine the following day. A study carried out in older adults (35-85 years) also showed that a shorter sleep period resulted in a stronger tendency to consume caffeine the following day (Hu et al., 2020). This may be a result of the reliance that some people have of needing caffeine to function after a sleep that is perceived to be poor quality or short in duration.

Table 2.3: Summary of studies evaluating the effect of caffeine dose and timing on sleep duration, quality and timing (alphabetical order by author)

Reference	Study design	Participants Sample Size Age (M ± SD) Gender, Country	Dose	Caffeine Timing	Sleep Duration	Sleep Quality	Sleep Timing
(Ali et al., 2015)	Double-blind randomised, placebo-controlled crossover trial LSEQ Subjective	10 24±4 years Female Athletes New Zealand	Varied intake between participants 0-300 mg/day	1 x Gelatin capsule Containing 6mg/kg caffeine (CAFF) OR placebo (PLA) 45min prior to exercise		↑restless sleep reported in CAFF. CAFF had Longer Sleep Latency than PLA and baseline. Later sleep Onset in CAFF then PLA and baseline. CAFF ↑periods of wakefulness in CAFF than baseline. 0 difference in how participants were feeling upon wakening.	
(Carrier et al., 2009)	Double-blind cross-over Subjective Sleep measure.	**24** (12 aged 20-30, 12 aged 45-60) 20-60years Male (46%) Female (54%)	200 mg OR placebo	100mg capsule OR placebo 3hr before daytime recovery sleep. 100mg capsule OR placebo one hour before recovery sleep.	Shorter sleep duration	Decreased sleep efficiency. ↓N3/SWS ↓N-REM sleep	
(Drake et al., 2013)	Randomized, double blind. Subjective diary measure	**12** 19-48years Male + Female USA	400 mg fixed dose (moderate)	0hr, 3hr & 6hr prior to habitual bedtime.	Adverse effects on sleep latency, and TST.		
(Hindmarch et al., 2000)	Randomized cross-over. PSQI + Actigraph	**30** 19-36years Male + Female UK	1.Water 2.Tea 37.5 mg 3.Tea 75 mg 4.Coffee 75 mg 5.Coffee 150 mg	Same dose was given at 0900, 1300, 1700, 2100	Higher dose = shorter sleep time.	Higher dose= ↓Perceived sleep quality	

Reference	Study design	Participants Sample Size Age (M ± SD) Gender, Country	Dose	Caffeine Timing	Sleep Duration	Sleep Quality	Sleep Timing
(Ho & Chung, 2013)	Double blind control group Subjective + Actigraph	10 21.4 years Males (6) + Females (4) NA Hong Kong	Group 1: 14 days caffeine free. Group 2: 14 days consuming coffee	Consumed usual coffee intake and an additional coffee within 6 hours of bedtime.		No significant changes in sleep quality were found.	
(Lee et al., 2014)	Cross-sectional	262 21 ± 2.40years Male (155) + Female (118) Korea	Continued regular day-to-day intake.	Unassigned: following usual caffeine intake pattern.		Sleep quality decreased as total caffeine intake increased.	
(Lodato et al., 2013)	Cross-sectional PSG	1522 13 years NA	Continued regular day-to-day intake.	Unassigned: following usual caffeine intake pattern.	Higher caffeine intake resulted was reported with shorter duration.		
(Lohsoonthorn et al., 2013)	Cross-sectional PSQI + food diary	2854 20.3 ± 1.3 years Males + Females (67%) Thailand	Continued regular day-to-day intake.	Unassigned: following usual caffeine intake pattern.		Significant association between poor sleep quality and caffeine intake	
(Lunsford-Avery et al., 2022)	Cross-sectional Used single-channel EEG device + Daily diary reporting caffeine intake. Objective + Subjective	98 11-17 years Female =49 (50%) Male=49 (50%) USA	Continued regular day-to-day intake.	Unassigned: following usual caffeine intake pattern.	Increased total caffeine intake associated with reduced TST		
(Marcus et al., 2023)	Prospective, randomised, case-crossover trial	100 18+ years Male (49%) + Female (51%) USA	Randomly assigned day-to-day to consume or to abstain from caffeine intake over a 14-day period.	Unassigned: following usual caffeine intake pattern.	Shorter sleep duration on caffeine consumed days compared to non-caffeine consumed days.		

Reference	Study design	Participants Sample Size Age (M ± SD) Gender, Country	Dose	Caffeine Timing	Sleep Duration	Sleep Quality	Sleep Timing
(Robillard et al., 2015)	Cross-sectional PSG	46 22 (young adults) 23.5 ± 1.9years 24 (middle aged) 51.7 ± 11.5years NA	200 mg & 400 mg	3 hours and 1 hour before bedtime.	Decreased sleep duration	Decreased sleep efficiency & Increased sleep latency	
(Sanchez-Ortuno et al., 2005)	Cross-sectional Subjective	1498 51 ± 3.2 years Males: 64% France	Continued regular day-to-day intake.	Unassigned: following usual caffeine intake pattern.	When caffeine intake exceeds 8 cups, sleep duration and time in bed decreased..		
(Shilo et al., 2002)	Double blind control group Subjective + Actigraph	6 31 ± 12 years Males (3) + Females (3) US	Day 1: either caffeinated or decaffeinated beverage & alternate beverage 7 days later.		Decreased sleep duration.	Decreased perceived sleep quality & increased sleep latency.	
(Song & Walker, 2023)	Real world, micro-longitudinal Daily survey Subjective	19 30.8 ± 2.3 years Males USA	Continued regular day-to-day intake.	Unassigned: following usual caffeine intake pattern.	The greater the caffeine intake, the shorter the sleep duration		
(Vizentin et al., 2023)	Cross-sectional Subjective	71,533 14.6 ± 1.6 Males: 50% Females: 50%	Continued regular day-to-day intake.	Unassigned: following usual caffeine intake pattern.	No significant difference in sleep duration		
(Watson et al., 2016)	Cross-Sectional Used PSQI and C-FFQ Subjective	80 38.9 ± 19.3 years Males= 26 (32.5%) Females= 54 (67.5%) Australia	Continued regular day-to-day intake.	Unassigned: following usual caffeine intake pattern.	Longer time spent in bed was correlated with lower caffeine intake.	No significant correlation was found between caffeine and sleep quality	

Reference	Study design	Participants Sample Size Age (M ± SD) Gender, Country	Dose	Caffeine Timing	Sleep Duration	Sleep Quality	Sleep Timing
(Weibel et al., 2021)	Double-blind, randomised, crossover. (PSG+LSEQ) Objective + Subjective	20 18-35 years Male	150 mg Caffeine OR placebo (mannitol)	3x daily 45min, 255min, and 475min POST awakening	No significant differences found between placebo or caffeine in both subjective and objective sleep measures.		
(Mathew et al., 2022)	Cross-sectional Daily diary + Actigraphy Subjective + Objective	589 15.4 ± 0.5 years Male (277) + Female (312) USA	Continued regular day-to-day intake	Unassigned: following usual caffeine intake pattern.	No significant association with sleep duration	No significant association with sleep efficiency or subjective sleep quality. ≥ 1 caffeinated beverage consumed sleep onset was delayed by 17min.	≥ 1 caffeinated beverage consumed midpoint of sleep was delayed by 17 min.

Search term "Effects of caffeine dose on sleep quality/sleep duration/sleep-timing/mid-point of sleep/bedtime" from 2000-2024.
Exclusion criteria: Studies where a comorbidity is being assessed, or sleep was being manipulated.
NA: Demographic information not available in the study

2.10 Summary of the Literature

Sleep is an essential process for day-to-day functioning, health, and well-being (Samson et al., 2015). Sleep health is best determined and measured by multiple dimensions, all of which need to be adequate for good sleep health to occur (Buysse, 2014). Insufficient sleep duration, poor sleep quality, and misalignment of sleep timing have been associated with adverse outcomes including, decreased performance (Belenky et al., 2003; Grandner, 2019), increased risk of adverse health outcomes (Buysse, 2014), and decreased mental health and emotional stability (Buysse, 2014; Nelson et al., 2022).

Young adults have a high prevalence of poor sleep health, with a plethora of research showing young adults frequently fail to achieve their recommended sleep duration (Ae Kyung et al., 2021; Hoopes et al., 2023), have poor sleep quality (Hermanoche, 2023; Kwame et al., 2022), and have later sleep-timing compared to other age groups (Grummon et al., 2021; Lo et al., 2014). Common factors affecting sleep health in young adults include screen use, bedtime procrastination, social jetlag, and stimulant use (Priya & Guzman, 2023).

Caffeine is a population stimulant used worldwide, mostly consumed for its perceived ability to improve cognition, performance, and alertness post consumption (MacKenzie et al., 2007). Responses to caffeine can vary, and typically become more adverse as the dosage increases. While it is commonly known in the scientific community that caffeine can affect sleep, the effects may not be well-known and understood by young adults. Caffeine consumption has been associated with shortened sleep duration, later bedtime and increased sleep onset latency, and decreased sleep quality. Caffeine intake in young adults is high, frequently exceeding safe levels (Bertasi et al., 2021; Bucher et al., 2019), raising concern of how this caffeine intake is affecting the sleep health of young adults. To gain a better understanding of the relationship between caffeine and

sleep health, the effects of caffeine on sleep health and how sleep health predicts caffeine intake the following day needs to be investigated.

CHAPTER 3 RESEARCH STUDY MANUSCRIPT

3.1 Abstract

Poor sleep health is common in young adults for a variety of reasons, including screen use, bed-time procrastination, and stimulant use. Caffeine, the most commonly consumed psychostimulant, is well known for its adverse effects on sleep health, including reduced sleep quality, prolonged sleep latency, and reduced time spent in REM sleep. A large body of research has shown that good sleep health is essential for optimal health (mental and physical) and waking performance. Young adults are one of the largest consumers of caffeinated products, particularly energy drinks, but limited research has been carried out on the impacts of this caffeine intake on the sleep health of young adults, especially in New Zealand. Studies done in young adults overseas have found high caffeine intake to be associated with shorter sleep duration (Carrier et al., 2009) and decreased sleep quality (Ali et al., 2015) . Studies have also looked at how sleep health can affect caffeine intake the following day.

A bidirectional relationship between caffeine intake and sleep health has been found, characterised by a cycle of reliance on caffeine to function during waking hours, leading to poor sleep health. This study aimed to determine whether caffeine consumption negatively impacts sleep health and whether sleep health dimensions (duration, quality, timing) impact the following day's caffeine dosage, in young New Zealand adults (aged 18-25 years). Fifty one young adults were asked to wear an Actigraph GT3X and complete a sleep diary for 7 days. Diaries assessed subjective sleep and daily caffeine intake. Separate mixed linear models were used to determine whether self-reported caffeine intake and timing were predictors of the following night's

actigraphic sleep duration, efficiency, and timing within and between participants (n=355 days). Lagged models evaluated whether actigraphic sleep duration, quality and timing affected the following day's total caffeine intake (n=304 days). A significant positive within-person (B = 0.002; p = 0.018) and conversely negative between-person association (B = -0.002; p = 0.026) was found between total daily caffeine intake and subsequent night time sleep duration. A significant positive within-person and a conversely negative between-person association was found between both daily (Within-person: B=0.001, p= 0.02; Between-person: B= -0.001, p= 0.02) and night time (Within-person: B= 0.02, p= 0.02; Between-person: B=-0.002, p=0.03) sleep duration and next day caffeine dose. Young adults should be made aware of the impact that caffeine can have on sleep health, and the consequences of poor sleep health.

Keywords: sleep duration; sleep timing; sleep efficiency; sleep quality; caffeine; young adult; actigraphy; diary

Within-person: B=,p=; Between-person: B=,p=)

3.2 Introduction

Sleep is an essential function for day to day living and supports human health, well-being and performance (Samson et al., 2015). Modern day pressures have caused challenges for prioritising sleep as it is easily reduced to fit lifestyles. Sleep of good duration, quality and timing optimises a multitude of processes, including memory consolidation (Walker, 2009), cognition (Diekelmann, 2014), performance, emotional regulation (Cartwright, 2010) and immune function (Imeri & Opp, 2009). A growing body of research shows the effects of poor sleep health on both cognitive and physical function, resulting in effects such as reduced alertness and vigilance (Belenky et al., 2003), and increased emotional sensitivity and stress responsivity (Nelson et al., 2022). These effects could cause significant barriers to optimal functioning during day-to-day life, at a personal, social and societal level (Grandner, 2019).

For optimal sleep health it is recommended that young adults sleep between 7-9 hours per night (Hirshkowitz et al., 2015) aligned with their natural preferred sleep timing . Good sleep health is also achieved by having good sleep quality, feeling refreshed upon awakening, and maintaining appropriate levels of alertness during the day (Buysse, 2014). Young adults (18-25years) frequently report poor quality (Almojali et al., 2017; Fatima et al., 2016) and short sleep (<7 hours) (Ae Kyung et al., 2021; Quick et al., 2015). Young adults are typically evening type, with a natural preference for going to bed later and waking up later than the average person (Randler et al., 2017). However, societal pressures tend to require young adults to get out of bed earlier than preferred, in which can result innot reaching the recommended 7-9 hours of sleep.

Between the ages of 18-25, large developmental changes occur in the brain which are associated with better decision making, enhanced emotional regulation, and improved critical thinking (Fuster, 2002). Research has shown that sleep has a vital role in all of these processes (Kurth et al., 2012), with good sleep health optimising cognitive function, and therefore, it is important for good sleep health to be maintained during young adulthood (Grandner, 2019). There are multiple factors which can potentially cause reduced sleep health in young adults, including increased academic and social pressures, increased bedtime procrastination, stimulant use, and lifestyle preferences that do not prioritise sleep (Luyster et al., 2012; Meredith et al., 2013).

Caffeine is the most highly consumed psychostimulant in the world (Addicott et al., 2009), with the largest amounts of caffeine coming from coffee and tea. Caffeine consumption is popular for its perceived feelings of increased alertness, facilitated by its ability to act as an antagonist for adenosine (A_1 and A_2) receptors in the brain (Basheer et al., 2004), which affects sleep homeostasis. Adverse effects from caffeine intake such as nausea, restlessness, and insomnia have been associated with a daily intake exceeding the recommended safe limit of 400 mg/day (Berman, 2022) but those who are caffeine sensitive can experience these effects from even the smallest dose (Smith, 2002). Consumption of caffeine has been linked to delayed onset of sleep, decreased overall sleep duration, lower sleep efficiency, and a perceived decline in sleep quality

(Clark & Landolt, 2017). This relationship appears bidirectional, with caffeine intake impacting sleep health, and poor sleep health affecting caffeine intake the following day (Hu et al., 2020).

Young adults worldwide have been identified as high consumers of caffeine, frequently exceeding the recommended intake (Bucher et al., 2019; McIlvain et al., 2011). Motivators for consuming caffeine include increased alertness, the taste of caffeinated products, social aspects, and increased concentration and physical performance (Mahoney et al., 2019). Many young adults associate consuming caffeine with these desirable responses (Stachyshyn et al., 2021), but others may experience only undesirable responses, such as nausea, jitteriness, and insomnia (Spiller, 1998). Investigation into the effects of caffeine consumption on sleep health is necessary given the prevalence of high intake among young adults and the potential adverse implications for health and well-being.

Previous studies in sleep health have found caffeine consumption can reduce sleep duration (Carrier et al., 2009; Hindmarch et al., 2000; Robillard et al., 2015), reduce perceived sleep quality (Shilo et al., 2002) and increase sleep latency (Robillard et al., 2015). Results from the limited number of studies done with young adults have reported equivocal results, with some population studies finding no effects and experimental studies showing caffeine consumption has significant effects on sleep. These contrasting results could be due to the use of subjective sleep measures which may be less reliance and single time point assessment of recent sleep characteristics.

Day-to-day (temporal) bi-directional associations are important to evaluate because of the cyclical nature of caffeine consumption and poor sleep. To the authors' knowledge, there is no research investigating temporal associations between caffeine consumption and sleep in young adults. However, studies in adolescents (15-17 years) have shown that caffeine consumption can delay sleep-timing (Mathew et al., 2022), shorten sleep duration (Lodato et al., 2013) and that people with greater variability in midpoint of sleep and sleep duration were more likely to consume caffeine the following day (Mathew et al., 2022).

The present study aimed to determine the temporal associations between caffeine consumption and sleep health in young New Zealand adults. Specifically, this study aimed to (1) evaluate the relationship between self-reported caffeine dose and timing on objective characteristics of sleep health, including sleep duration, sleep quality and sleep timing, and (2) evaluate whether objective characteristics of sleep health, including sleep duration, sleep quality and sleep timing, predict next-day caffeine consumption.

3.3 Materials and Methods

3.3.1 Participants

Data for this study were collected as part of a larger study investigating sleep health and caffeine consumption (completed in 2023) in New Zealand young adults. Participants were recruited through social media channels and newsletters, as well as poster advertisements displayed on the Massey University Albany campus. Participants were a convenience sample of 315 participants based in New Zealand who responded to advertisements and completed the Pittsburgh Sleep Quality Index (PSQI) (Buysse et al., 1989) and a validated caffeine consumption questionnaire (CaffCo) (Rowe et al., 2020). A sub-sample of participants residing in the Auckland region (n=52) were invited to participate in a subsequent study, and those who agreed (n=52) wore an actigraph and completed a sleep diary for 7 days. Inclusion criteria included being aged between 18-25 years old, being fluent in reading and writing English, did not have a current problem with sleep, consuming low to moderate amounts of alcohol, being in good general health with no history of heart, neurological and/or psychiatric illness based on health screening, and not engaged in shift work. Our exclusion criteria was to be excluded if response to frequency of consumption is ‘daily’ AND response to amount consumed in one sitting is ‘2-4 drinks OR To be excluded if response to amount consumed in one sitting is ‘5-6 drinks’ or ‘More than 6 drinks’ (with any frequency). The study was approved by the Massey University Human Ethics Committee: Southern A (SOA 21/11) and the author was approved to be added to the study.

3.3.2 Sleep Measures

Subjective Sleep: Participants completed a diary based on the Consensus Sleep Diary-E (Carney et al., 2012) in the evening before bed and in the morning on waking, in which they recorded caffeine consumption, including the type of product(s) consumed during the day and the time of last consumption, alcohol consumption (number of standard drinks and any medications and/or supplements. Participants also reported on their sleep, including time in bed, the start time of attempting sleep, perceived time they took to fall asleep, the number and duration of awakenings, the time of final awakening and total sleep duration. Sleep quality was evaluated on a Likert scale (response options: "very poor", "poor", "fair", "good", "very good"). They were also asked how rested or refreshed they felt on waking and could answer on the following Likert scale: "Not at all rested", "Slightly rested", "Somewhat rested", "Well-rested", "Very well-rested". Participants were able to provide additional comments regarding causes of sleep disruption (i.e. illness or children in bed).

Actigraphic Sleep: Sleep/wake activity was recorded in 60-second epochs with an Actigraph™ GT3X accelerometer (*Actigraph, Pensacola, FL, USA)*, worn on their non-dominant wrist for 7 days. The actigraphy data was downloaded using ActiLife software (Version 6.1.2, ActiGraph) and scored by a single researcher, using the Cole-Kripke algorithm (Cole et al., 1992) to determine sleep periods. Sleep intervals for analysis were determined manually by a decrease in activity levels and corroboration with diary information. The start of the sleep interval for analysis was manually determined by the level of movement and the sleep diary entry for "time tried to go to sleep" (marked as the 'in-bed' time). The end of the sleep interval for analysis was manually determined by the level of movement and the sleep diary entry for "time out of bed" (marked as the 'out-bed' time). If discrepancies occurred between the diary and actigraphy data, the actigraphy data was prioritised. If during a sleep period significant movement in the actigraphy data exceeded 10 minutes at one time and/or the diary indicated a period of time out of bed, the

sleep interval was marked as ended and a second sleep interval was scored once the movement had diminished to attempting sleep levels. Day time intervals of sleep were scored only if a nap was reported in the diary. The nap was scored based on the duration noted in the diary and where it aligned with low movement in the actigraphy recording. Any sleep interval that occurred ≥60 minutes after the end of night-time sleep intervals was deemed a nap.

3.3.3 Caffeine Consumption Measures:

In the diary, participants were asked to record consumption of any of the following caffeinated products: coffee, instant or café (cups), Black tea (cups), Green tea (cups), Kola drinks (e.g. coca cola) (mL), energy drinks (e.g. Lift Plus) (mL); and how many of each product they consumed in total per day. Sports supplements, such as pre-workout supplements, were also included in the product list and these were estimated by scoop. Participants were asked to note the time of their final consumption of any caffeinated product each day. Daily caffeine consumption for each participant was calculated by assigning a caffeine content to each product; one teaspoon instant = 8 mg; one espresso shot =120 mg; one cup of green tea = 31 mg; and one cup of black tea= 57 mg. Caffeine quantity of pre-packaged sources such as kola, energy drinks and sports supplements were assigned based on manufacturer labelling. The sum of caffeine content from all sources for each day was used to determine total daily caffeine dose in milligrams (mg).

Demographics: Relevant demographic information about the participants, including their age, gender, ethnicity, highest education level, occupation, employment status, smoking status and BMI were derived from the Caffco questionnaire.

3.3.4 Data Management

One participant was excluded due to being on sertraline, which can impact sleep health. Sleep and caffeine consumption was extracted using the ActiLife software and diary data and merged

together by date and participant ID (n=355 (51 participants x 7 days minus 2 excluded diary days)). To assess the associations between caffeine consumption and subsequent sleep, that day's diary entry for caffeine consumption and actigraphic sleep that night were aligned on the same date in the merged database. To assess the effects of sleep duration, quality, and timing on the following day's caffeine dose (total mg consumed), the sleep data were lagged by one day. Lagging data resulted in the loss of one row of sleep and caffeine data from the data set, leaving a reduced sample size for analysis (n=305 (51 participants x 6 days)).

A power calculation based on the findings of Mathew et al. (2022) determined that 95 observations were needed to detect a significant within-person association between caffeine dose and the mid-point of sleep ($p<0.05$; 80% statistical power). This was met with 355 observations being analysed.

3.3.4.1 Actigraphic Sleep Measures

Sleep onset, sleep offset, sleep duration and sleep efficiency were determined by the actigraphy algorithm based on the manually scored sleep interval. Sleep onset was defined as the first minute that the algorithm scored sleep. Seven (13.5%) participants reported napping on 61 diary days and therefore, sleep duration and efficiency was calculated for both night-time and total sleep per day (designated, daily sleep). A 'day' was defined as starting at the onset of night time sleep (as noted in the diary) and ending at the onset of the next night's sleep. Total sleep time was calculated from the total minutes the algorithm scored as sleep in each interval. Night time sleep duration was calculated as the sum of total sleep time from all night time sleep periods, as noted in the diary. Total daily sleep duration was calculated from the sum of total sleep time from all night-time sleep periods and total sleep time from all daytime naps that occurred before the start of the next night-time sleep period. Sleep efficiency was calculated by the scoring algorithm from the total number of minutes of sleep in the scored interval divided by the time in bed (i.e., the duration between in-bed and out-bed time). Night time sleep efficiency was calculated from all night time sleep periods. Daily sleep efficiency was calculated from all night time and day time

naps. The mid-point of sleep was used as a measure of sleep timing and was calculated from the mid-point between sleep onset and final wake up time of night-time sleep. For analyses, the mid-point of sleep was centred around midnight and represented as decimal hours.

3.3.5 Covariates

Participants were asked to report demographic information, including age, gender, highest qualification (education), ethnicity, occupation, employment status and smoking status. Ethnicity was categorically prioritised based on the Health Information Standard Organisation (HISO) Ethnicity Data Protocols (Ministry Of Health, 2017), following the level 1 prioritisation codes: 1. Māori, 2. Pacific Peoples (includes Fijian, Samoan, Tongan etc), 3. Asian (includes Indian, Chinese, Korean, Japanese etc), 4. Other Ethnicity, and 5. European (including NZ European). The highest level of education was categorised as "Bachelor's degree", "Postgraduate Degree", "Completed High School", "Diploma/Certificate", or "Did Not Answer". Body Mass Index (BMI) was determined through self-reported weight divided by self-reported height squared, and represented by a numerical value.

3.3.6 Statistical Analyses

Descriptive analyses of demographic, sleep and caffeine data were completed using IBM SPSS Statistics software (version 29.0.1.0 (171)). The final timing of caffeine consumption was calculated as the time interval (hours) between the final caffeinated product consumed (from the diary) and actigraphic sleep onset.

Mixed linear models were carried out using SAS 9.4 software (SAS Institute, Cary, NC, USA) to determine temporal associations between a) caffeine intake (dose and timing) and the subsequent night's sleep (duration, efficiency, and timing), and b) between sleep (duration and efficiency) and next day caffeine intake. Whereas the general linear model (GLM) uses an estimation method (ordinary least squares) that requires complete data, the linear mixed model employs a likelihood-based estimation method, which uses all available data. A major advantage of this method

is that it can handle unbalanced and/or missing data (Wolfinger & Chang, 1998). All caffeine and sleep variables were calculated as within person and between person variances from the mean. Within person variances were centred at the person's cross-day mean and calculated for each day as the deviation from the person's cross-day mean. Positive within-person values indicated that the value for that variable was higher than the person's average across all days. Between person variances were centred at the group's cross-day mean and calculated for each day as the deviation from the group's cross-day mean.. Positive between-person values indicated that a participant's value for that variable was higher than the group mean.

To evaluate associations between caffeine intake and subsequent sleep on five sleep outcome measures: (1) night-time sleep duration, (2) daily sleep duration, (3) night-time sleep efficiency, (4) daily sleep efficiency and (5) mid-point of sleep, two sets of linear mixed models were used. The first set of models included caffeine dose (within- and between-person) as predictors, and the second set of models included the time interval between the final caffeine dose and sleep onset (within- and between-person) as predictors. Each model included 355 observations from 51 participants (minus two diary days).

Lagged data were used in the mixed linear models which assessed within- and between-person associations between each of sleep duration (night time and daily), efficiency (night time and daily), and next day's total caffeine intake (mg). There were 305 observations included from 52 participants.

All models used an autoregressive covariance structure. Participant ID was included as a random effect to account for individual differences. The DDFM=BETWITHIN option was used to estimate the degrees of freedom. All models included the covariates age, gender, education, BMI, and ethnicity. Model assumptions were checked visually, and the distribution of residuals were tested with the Kolmogorov-Smirnov test of normality, with an appropriate transformation applied for non-normal residual distributions. Where outliers were identified in a model, the model was re-

run excluding these. If exclusion of outliers changed the findings, then the model reported is with outliers removed. If the findings did not change, the model reported includes any outliers.

3.4 Results

3.4.1 Descriptive Statistics

Table 3.1 describes the demographic information of all 52 participants. The majority of participants were female (87%) and the mean age of participants was 22.06 (SD ± 2.04). Just over half were European (53.8%) and 40% were Asian.

Participants had an average BMI of 22.82 (SD ± 2.94). The majority (71%) of participants were in the healthy BMI range of 18-24kg/m^2. The majority of participants (88.5%) did not smoke and were students (73.1%). There was an equal distribution of participants partaking in either paid (46.2%) or unpaid (50%) employment. The highest level of education reported was a Bachelor's degree, which was obtained by 63.5% of participants.

Table 3.1: Participant demographics

Variable	n (%)	M ± SD	Median (range)	n
Age		22.06 ± 2.043	22.00 (18-25)	52
Gender				
Female	43 (87%)			
Male	9 (17.3%)			
Ethnicity				
Asian	21 (40%)			
European	23(53.8%)			
Other	3(5.7%%)			
Body mass index		22.82 ± 2.94	22.45 (17.58-29.72)	42 [a]
Smoking status				52
Yes	0			
No	46 (88.5%)			
Occasionally	2 (3.85%			
Did not answer	4 (7.7%)			

Variable	n (%)	M ± SD	Median (range)	n
Occupation				52
Student	38 (73.1%)			
Full time worker	11 (21.2%)			
Part time worker	1 (1.9%)			
Did not answer	2 (3.8%)			
Employment				52
Unpaid employment	26 (50%)			
Paid employment	24 (46.2%)			
Did not answer	2 (3.8%)			
Education: Highest qualification				52
Bachelor's Degree	33 (63.5%)			
Postgraduate Degree	5 (9.6%)			
Completed Highschool	11 (21.2%)			
Diploma/Certificate	1 (1.9%)			
Did not answer	2 (3.8%)			

n, number; %, proportion of sample, M, mean; SD, Standard deviation; Numerical data are presented as both M ± SD and median (range), categorical data are presented as n (%)

[a] 10 participants did not provide height and/or weight information to calculate body mass index.

The descriptive statistics for sleep and caffeine consumption are shown in Table 3.2. The average sleep duration from the actigraphy data for this population was 7.31 hours (SD ± 1.28) for night time sleep, and 7.51 hours (SD ± 1.26) for total daily sleep. The time of sleep onset ranged widely between 17:15- 05:01, with the average being 23:43. Out-bed time (sleep offset) also ranged widely (03:00-15:01) averaging at 07:56 (SD ± 1.33).

For this population, total caffeine intake ranged from 0-1050 mg per day, with the average daily intake being 243.7 mg (SD ± 184.2). The average daily caffeine intake is under the safe limit (3 mg per kilogram bodyweight per day), but on 7.88% of diary days participants exceeded the safe limit of caffeine intake per day (400 mg), and on 30% of days, participants reported that no caffeine was consumed. The time of final caffeine intake also varied greatly between 07:30-23:30, averaging at 14:13 (SD± 3:56).

Table 3.2: Descriptive statistics for sleep and caffeine consumption

Variable	M ± SD.	Median (range)	n
Actigraphic sleep characteristics			
Sleep duration - Night time sleep (h)	7.31 ± 1.28	7.45 (1.45-11.75)	
Sleep duration -Total daily sleep (h)	7.51 ± 1.26	7:58 (1.45-11.75)	
Sleep efficiency - Night-time sleep (%)	88.16 ±6.42	89.16 (35-98)	355
Sleep efficiency - Total daily sleep (%)	87.82± 6.33	89.00 (35.00-98.00)	355
Sleep onset of night time sleep (hh:mm)	23:43 ± 1:35	23:31 (17:15-05:01)	355
Sleep offset of night time sleep (hh:mm)	07:56 ± 1:33	7:49 (03:00-15:01)	355
Mid-point of night time sleep (hh:mm)	03:50 ± 01:25	03:38 (0:43-9:43)	355
Caffeine Consumption			
Total daily caffeine dose (mg) [a]	243.7 ± 184.2	155 (0.00-1050.00)	217[1]

Time of final caffeine intake (hh:mm) [b]	14:13 ± 3:56	14:00 (07:30-23:30)
Time between final caffeine dose and sleep onset (hours) [b]	9.28 ± 4.07	9.33 (0.00-17.49)

n, number of days of diary data; M, mean; SD, Standard deviation; h, hours, hh:mm, clock time. Numerical data are presented as both M ± SD and median (range).

[a] Five diary days did not include caffeine quantity data, [b] 31 diary days did not include the final timing of caffeine consumption.

[1]138 missing observation for this data, and of these 108 cases are for observations with 0 mg caffeine intake.

3.4.1 Temporal Associations between Caffeine Consumption and Sleep

3.4.1.1 Total daily caffeine intake as a predictor of that night's sleep

Table 3.3 shows the results of mixed linear models with total daily caffeine intake (dose) as a predictor of subsequent sleep. There was a significant positive within-person association between caffeine dose and night time sleep duration. On days where a person's caffeine intake was higher than their average, sleep duration on the subsequent night was longer. For every additional 100 mg of caffeine consumed, sleep duration increased by 12 for that participant.

Additionally, there was a significant negative between-person association between caffeine dose and night time sleep duration. On days where participants' caffeine intake was higher than the group's cross-day average, sleep duration on the subsequent night was shorter. For every additional 100 mg of caffeine consumed, sleep duration decreased by 10 minutes.

There were no within- or between-person associations between caffeine dose and daily sleep duration, nighttime or daily sleep efficiency or mid-point of sleep.

3.4.1.2 The timing of final caffeine consumption as a predictor of that night's sleep.

Table 3.4 shows the results of mixed linear models with the time interval between final caffeine intake and sleep onset as a predictor for subsequent sleep. No significant relationship was found between the time of final caffeine intake, either within- or between-person, and nighttime and daily sleep duration, night time and daily sleep efficiency or mid-point of sleep.

Table 3.3: Total daily caffeine dose predicting subsequent night's sleep

Model Predictor	Model outcome									
	Total Daily Sleep Duration (Hours)[a]		Night-Time Sleep Duration (Hours)[a]		Total Daily Sleep Efficiency (%)[a, b]		Night-time sleep Efficiency (%)[a, b]		Mid-point of Sleep (Hours)[a]	
	B	(SE)	B	(SE)	B	(SE)	B	(SE)	B	(SE)
Total daily caffeine dose (mg)										
Intercept	7.66	(2.05)	6.96	(2.31)	-0.13	(0.59)	-1.86	(0.60)	9.57	(2.71)
Within-Person	0.0014	(0.0009)	0.0022	(0.0009)**	-0.00003	(0.0002)	0.00003	(0.0002)	0.0002	(0.0010)
Between-Person	-0.0011	(0.0007)	-0.0017	(0.0008)**	0.00005	(0.0002)	0.00005	(0.0002)	-0.0002	(0.0009)

Each column for model outcome represents a separate mixed linear model, adjusted for age, gender, ethnicity, education, and body mass index.
B: fixed effect parameter estimate, SE: standard error, Sleep timing measure (mid-point of sleep) was centred around midnight (0:00). [a] Outliers removed, [b] Transformation applied, *p < 0.05, **p <0.01, ***p< 0,001

Table 3.4: Time of last caffeine dose predicting subsequent night's sleep

Model Predictor	Model outcome									
	Total Daily Sleep Duration (Hours)[a]		NightTime Sleep Duration (Hours)[a]		Daily Sleep Efficiency (%)[a, b]		NightTime Sleep Efficiency (%)[a, b]		Mid-point of Sleep (Hours)[a]	
	B	(SE)	B	(SE)	B	(SE)	B	(SE)	B	(SE)
Time between last caffeine dose and sleep onset (hours)										
Intercept	7.06	(2.08)	6.58	(2.48)	-1.18	(0.56)	-1.69	(0.65)	9.02	(2.69)
Within-Person	0.03	(0.05)	-0.0071	(0.06)	-0.01	(0.01)	-0.01	(0.01)	0.05	(0.06)
Between-Person	-0.05	(0.04)	-0.01	(0.05)	0.00051	(0.01)	0.0064	(0.01)	0.02	(0.05)

Each column for model outcome represents a separate mixed linear model, adjusted for age, gender, ethnicity, education, and body mass index.
B: fixed effect parameter estimate, SE: standard error, Sleep timing measure (mid-point of sleep) was centred around midnight (0:00). [a] Outliers removed, [b] Transformation applied, *p < 0.05, **p <0.01, ***p< 0,001

3.4.1.3 Sleep as a predictor of next day caffeine intake.

Table 3.5 presents the results of mixed linear models with sleep characteristics as predictors of the following day's total caffeine intake (dose). There was a significant positive within-person association between both night time and daily sleep duration and next day caffeine dose. On days where a person's nighttime and daily sleep were longer than their average, they consumed a higher dose of caffeine the next day. There was also a significant negative between-person association between both night time and daily sleep duration and next day caffeine dose. On days where participants' night time and daily sleep were higher than the group's cross-day average, less caffeine was consumed the next day. There were no within- or between-person associations between night time and daily sleep efficiency, or mid-point of sleep, and next day caffeine dose.

Table 3.5: Sleep predicting next day caffeine consumption.

Model predictor	Model outcome: Total daily caffeine dose (mg)					
			Within-Person		Between-Person	
	Intercept	(SE)	B	(SE)	B	(SE)
Sleep duration						
Night time sleep duration (hours)[b]	-3.34	(19.64)	2.98	(1.27)*	-3.06	(1.22)*
Total daily sleep duration (hours)[b]	-3.52	(20.21)	2.99	(1.46)*	-2.95	(1.43)*
Sleep efficiency						
Night time sleep efficiency (%)[b]	-5.74	(21.50)	24.92	(27.95)	-20.33	(26.94)
Total daily sleep efficiency (%)[b]	-6.91	(21.27)	25.13	(28.50)	-21.92	(27.44)
Sleep timing						
Mid-point of sleep (hours)[b]	-6.78	(23.27)	0.13	(1.42)	-0.26	(1.36)

Each row for model predictor represents a separate mixed linear model, adjusted for age, gender, ethnicity, education, and body mass index.
B: fixed effect parameter estimate, SE: standard error, Sleep timing measure (mid-point of sleep) was centered around midnight (0:00). [a] Outliers removed, [b] Transformation applied, *p < 0.05, **p <0.01, ***p< 0,001

3.5 Discussion

This study is the first among young adults to use both objective (actigraphy) and subjective measures (diary data) to evaluate whether self-reported caffeine dose and the self-reported time of consumption of the last caffeinated product is associated with actigraphic characteristics of sleep health, including sleep duration, sleep quality and sleep timing. This study also investigated whether sleep duration, sleep quality or sleep timing, was associated with the following day's caffeine intake. When examining within-person variances, it was found that as individual people consumed more caffeine than their average across the 7-days, they slept for longer (within person variances). However, across the whole sample when people consumed more caffeine they slept for a shorter period (between person variances). The current study showed that lower sleep duration at night for all participants (between person variances) was associated with higher caffeine intake the following day, but as sleep duration exceeded an individual's nightly average (within-person variances), they consumed more caffeine the following day. Average daily caffeine intake of the participants (243.7 mg) in the current study was lower than the recommended daily intake (400 mg). However, intake varied significantly across the days (SD=184.2 mg), with the highest intake reaching 1050mg.

Most previous studies have looked at associations across a sample level (between person variances). There are two different types are studies assessing caffeine consumption and sleep characteristics in either a population sample or in a laboratory setting. Those done in population settings have found significant associations between increased caffeine intake and decreased sleep quality (Lee et al., 2014), and sleep duration (Marcus et al., 2023; Song & Walker, 2023).

Marcus et al. (2023) measured the effects of caffeine on several outcome factors including sleep duration and found that on days where caffeine was consumed, sleep was shorter than on days where caffeine was not consumed. This study listed limitations of a small sample size, did not control for caffeine withdrawal symptoms, and was not blinded to control for other causal factors that could have affected sleep and other measured outcomes.

Watson et al. (2016) investigated how sleep outcomes impact the following days caffeine intake. They found longer time spent in bed was associated with less caffeine intake the following day, which supports the suggestion that the relationship between caffeine and sleep is bidirectional. Watson et al. (2016) used a validated questionnaire for estimating caffeine quantities and its impact on sleep variables. Reported limitations of this study included a population sample size that may not be generalisable to people who consume higher volumes of caffeine, such as shift workers. They also used self-report sleep measures which are shown to have some inaccuracies compared to objective measures such as PSG or actigraphy. Our study has the advantage of having both objective sleep measures aligned with self-report of sleep to limit inconsistencies in reporting.

While the above studies align with the findings of the current study, findings in young adults are not always consistent and some studies have shown no association between caffeine and sleep measures. One large population study done in adolescents, an age group very close to young adults, found no association between caffeine consumption and sleep duration (Vizentin et al., 2023). This study reported having the advantage of assessing a very large sample size (n= 71,533), but the limitations of not controlling for other confounding factors that could affect sleep, and consisted of only Brazilian adolescents, limiting the generalisability of the findings.

Another study completed on adolescents found those who reported shorter sleep duration and higher screen time, had significantly higher caffeine intake (Lodato et al., 2013). A large strength of this study is large population-based sample size (n=2787). Limitations of this study **i**nclude use of the FFQ, which has predetermined foods lists that may not have representative of their population group and relies on participants recall. Another limitation was the use of self-reported sleep duration as the sleep measure and an objective sleep measure was not possible with the large sample size.

Significant findings of experimental studies have been much more unequivocal, making it very clear the relationship between sleep characteristics (duration, quality, and timing) and caffeine consumption is dose dependant.

Carrier et al. (2009) compared the effects of 100 mg doses of caffeine on daytime recovery sleep between younger (20-30 years) and middle aged (45-60 years) adults. They found caffeine decreased sleep duration, efficiency, REM, and SWS in daytime recovery sleeps for both age groups. This study reported that the age-related effects of caffeine on sleep may have been underestimated as participants were selected based on their consumption of 1-3 cups of caffeine containing beverages a day. This did not control for the fact that older adults who were sensitive to caffeine may have stopped consuming caffeine to limit the adverse effects. Strengths of their study include all participants complete a controlled sleep with a placebo secondary to the caffeine dosage, and sleeps were measured in a laboratory setting.

Weibel assessed used PSG to measure the impact of daily caffeine dosage (3x 150 mg) on sleep in young adult men. They found caffeine to have no impact on sleep duration, or quality when compared to placebo, but REM was reduced in caffeine consumption compared to placebo. Strengths of this study include using the gold standard of sleep

measurement (PSG) alongside a subjective sleep measure and validated questionnaire (PSQI). A thorough exclusion criteria was used to limit any external factors that could affect sleep outcomes, and to reduce variance in the data that can occur from contraception and the menstrual cycle only male participants were used. Limitations of this study were reported as having reduced generalisability due to being an all-male and limited age ranged sample size. The sample size was also limited (n=20), however, according to their power calculation the sample size was adequate. Finally, genetic variability was not assessed which could vary the effects of caffeine consumption.

Outcomes of previous research are unequivocal, and there could be several reasons for that. For example, some people may already know the effect that caffeine has on their sleep so choose to avoid caffeine to limit the adverse. Another possible reason, as mentioned in chapter 2, is that some people do not experience any adverse effects from caffeine consumption, so no association between caffeine and sleep outcomes would be found. This could be the reason no significant associations are found between caffeine and some sleep outcomes such as quality and timing), in both this study and previous studies. Another reason could be that have many studies assessing young adults have had population groups of university students, most likely due to the high volume of young adults attending university. Typically, university students do not follow traditional '9-5' scheduled days, which can result in less regulated sleep patterns and could create challenges to investigating the effects of caffeine on sleep.

In most previous studies, they have looked at associations between the whole sample (between person variances) and our study is unique in that it also looks at within person variances. This has the advantage of understanding how baseline sleep needs might vary at the individual level by looking at day-to-day variations. This allows us to consider in some respects the individual sleep behaviour in our analyses.

Only two current studies exist assessing temporal associations between caffeine consumption and sleep outcomes (Lunsford-Avery et al., 2022; Mathew et al., 2022) both in young adult populations. Lunsford-Avery et al. (2022) assessed both the impact of caffeine intake and timing on sleep outcomes (sleep duration, sleep-onset latency, sleep efficiency, wake after sleep onset and time spent in sleep stages), as well as the impact of sleep variables on the following days caffeine intake. They assessed averages of the sample (between person variances) and not individual variances (within person). They had a variety of significant findings including, when caffeine was consumed in the evening sleep efficiency was decreased and sleep onset latency increased. Similar to our findings, they also found increased caffeine intake was associated with shorter sleep duration. Strengths of this study include the use of the objective sleep measure in the home environment, and the study of daily caffeine consumption to establish the direction of effects, however, this study also reported several limitations. They did not ask for what type of caffeinated product consumed in the diary question, making reporting of caffeine intake potentially inaccurate. For sleep measurements they used an unvalidated, single-channel consumer grade EEG device, and calculated sleep measures with an automated algorithm. Our study had the advantage of using both a validated diary (consensus sleep diary) and sleep measure (GT3X Actigraphy watch) meaning the inconsistencies of our sleep measurements were limited.

Mathew et al. (2022) had a similar study design to us, investigated both between person and within person variances, but in adolescents. They found when adolescents consumed ≥1 caffeinated beverage they had later sleep onset the following night and wake up time the following morning compared to when caffeine was not consumed. They also found increased variability in sleep duration and midpoint of sleep increased the odds of a caffeinated beverage being consumed the following day. A strength of this study is the

assessment of a large (n=458) and diverse sample group of adolescents, from several areas in the USA. Limitations of this study include only being able to assess whether caffeine was consumed or not, through quantifying caffeine intake by zero or ≥1 caffeine beverage. Timing of caffeine and product caffeine dosages were not assessed, limiting the impact of the study's findings. Our study has the advantage of looking at specific dose based on the diary reporting exact caffeinated products consumed across the day.

Our findings, while unexpected, could be due to several factors. Firstly, we did not measure a baseline sleep need for participants, making it impossible to report whether participants were gaining adequate sleep which can affect caffeine intake. Belenky (2003) found it took more than 3 nights of 8 hours in bed to recover from one week of accumulated sleep debt. If a person is experiencing sleep restriction, they might have been recovering from sleep need and will often consume more caffeine counteract sleepiness during recovery (Skeldon et al., 2017). Napping in the day can often be a sign of sleep restriction, and 13.5% of our participants reporting a nap on 61 of the diary days, this is a sign sleep restriction may have been occurring in our sample, which could have affected our results.

People may also have been experiencing sleep inertia, a temporary decline in mood and performance upon awakening (Hilditch & McHill, 2019). Sleep inertia could result in people reaching for caffeine in the morning to counteract the heightened sleepiness upon awakening. In future studies this could be controlled for by participants gathering diary data or questionnaire information of their typical sleep need. With this information future studies can control for it in analyses.

Secondly, we did not know as for scheduled and unscheduled days. Sleep health, particularly sleep duration is known to vary between unscheduled and scheduled days, with people often having more time available to sleep and therefore increasing duration. By

knowing whether days are scheduled or unscheduled this could be controlled for in future studies. Thirdly, our study consisted of a large percentage of students (73%) who typically have significantly less sleep regularity than full-time workers, particularly when students are juggling studying with part-time work. Lastly, our questionnaire did not ask for external factors which are known to impact sleep quality, such as daily personal stress or exam stress (Åkerstedt et al., 2012), and therefore, we do not know if the data from the present study is an accurate representation of the typical sleep of these participants, nor if the quality of sleep was good. Our models were also not controlled for external factors that can affect sleep for example, iron deficiency or mental health. While our study did have the benefit of capturing day to day variances in caffeine intake and did best to capture dosage accurately, it is possible that diary bias and missing data could mean caffeine intake might not be as accurate as if another method of dietary collection could be more accurate.

This study had many strengths including the use of the consensus sleep diary. Which is a standardised measure use in sleep research to capture various aspects of sleep. This was used alongside the actigraphy, a validated objective sleep measure. As mentioned in chapter 2, use of simultaneous objective and subjective sleep measures has been shown to increase accuracy of recording (Lockley et al., 1999; Moore et al., 2015).

Limitations of this study include self-report for caffeine intake. Self-report can have inaccuracies for reasons such as selection bias, participant recall. As mentioned above we didn't have baseline sleep needs or scheduled or unscheduled days which would need to be considered for future studies and well as whether or not other factors effecting sleep needed to be controlled for in future studies.

3.6 Conclusion

The present study demonstrates that higher caffeine intake can reduce total sleep duration in young adults when considering the sample average, but that within participants, associations between caffeine intake and sleep may be reflective of use of caffeine to recover from a sleep debt. On average, shorter sleep duration predicted higher caffeine intake the following day but showed the converse relationship at the individual level. This study was useful in investigating the bidirectional relationships between caffeine intake and sleep in young adults, and increased knowledge which could support an aim of increasing health, well-being and performance in young adults (Buysse, 2014; Sletten et al., 2023). Overall, these findings suggest young adults should limit their caffeine intake to best benefit their sleep duration, and further research is required in this field to further investigate the relationships between caffeine intake and sleep quality and timing in young adults. Further investigation into caffeine and sleep duration with more extensive diaries and controlled models could be beneficial for solidifying the effects of caffeine and how it varies between person.

CHAPTER 4 CONCLUSION

4.1 Summary of Findings:

This is the first study to look at the temporal associations between caffeine intake and objective sleep measures in New Zealand young adults (aged 18-25 years).

Objective One was to evaluate the relationship between caffeine dosage and sleep duration, quality, and timing. The results both support and contradict the hypotheses. It was predicted that increased caffeine dosage would be associated with decreased sleep duration, sleep quality and delayed sleep timing. It was found that between person, as people consumed more caffeine, they had shorter sleep. Contradictory to this, when looking at within person variances, as people consumed more than their average across the week, their sleep duration was longer. We found no association between caffeine dosage and sleep quality or timing.

Objective two was to assess whether the timing of the final caffeine intake impacted sleep duration, quality, or timing. The present study found no significant association between caffeine timing and any sleep characteristics. This contradicts our hypotheses, and previous findings from other researchers (Carrier et al., 2009; Hindmarch et al., 2000; Lee & Lin, 2007; Shilo et al., 2002) which suggest that the later caffeine is consumed in the day, the subsequent night sleep was shorter, worse in quality, and more time was spent trying to fall asleep.

Objective three was to assess whether characteristics of a night's sleep were associated with the following day's caffeine dose. Similarly, the findings of the present study both support and contradict our hypotheses. It was predicted that as sleep outcomes worsened (i.e., with shorter sleep, poorer sleep efficiency and later sleep timing), the following day's caffeine

intake would be higher. It was found that, between participants, the longer a person slept, the less caffeine they consumed the following day, which agreed with our hypothesis. However, contradictory to our hypothesis, when examining within person variances, we found that as a person slept longer than their average, they consumed more caffeine the following day. We found no association between sleep timing and sleep quality on caffeine intake the following day.

Together, these findings suggest that while, in general, sleeping longer predicts shorter sleep duration the following day, this is individualised and that several factors may impact the desire to reach for caffeine upon awakening. We also found that the average sleep onset was 23:43 ± 1:35, suggesting our participants already followed late bedtime schedules, potentially affecting both timing and duration. This is reflective of young adults' evening chronotype, suggesting an alternative method may be required to evaluate how caffeine affects sleep duration and timing. No significant association was found between timing of final caffeine intake and sleep objectives which was very unexpected given previous findings in this field. Overall, this study supports the suggestion that there is a bi-directional between day-to-day caffeine dosage and sleep duration.

4.2 Strengths:

Our study had a series of strengths. We used a subjective sleep measure (consensus sleep diary) and aligned it with the actigraphy data to capture sleep outcomes. Using objective or subjective measures alone has been recognised to result in inconsistencies in reporting (Dietch & Taylor, 2021; Sadeh, 2011). Evidence suggests using both measures reduces inconsistencies recording of sleep outcomes (Lockley et al., 1999; Moore et al., 2015). The actigraphy data was manual scored, as opposed to automatic scoring available with the

software. Manual scoring allowed for sleep periods to be scored with the sleep diary information, increasing the accuracy of nap and sleep period scoring.

We are also the first study to report on objective measures of New Zealand young adults' sleep health. While similar studies have been done with adolescents, little research has been done on temporal associations of caffeine and duration, quality, and timing, in young adults in this field. This is the first study to investigated day-to-day associations between caffeine consumption and sleep characteristics in young adults over a one-week monitoring period. Previous studies have looked into the effects of caffeine dosage and sleep over a single day (Vizentin et al., 2023) or looked at the effects of caffeine on single sleep outcomes rather than a variety (Drake et al., 2013; Ho & Chung, 2013). Our study is more extensive through investigating multiple sleep variables over a 7-day monitoring period, allowing for a more thorough assessment of the variability of both sleep and caffeine consumption.

Some experimental studies have assessed at the effects of precise dosing and timing on sleep (Carrier et al., 2009; Drake et al., 2013) and have evaluated the effects of consuming one's caffeine intake with an additional coffee added (Ho & Chung, 2013), but no studies have assessed the effects of temporal associations over a period of time.

4.3 Limitations:

This study had some limitations that may have affected the results. These include:

The study only assessed 7-days of sleep and dietary intake, which may not represent fluctuations in sleep/wake patterns that can occur in young adults (Lenneis et al., 2021). Sleep and dietary patterns tend to vary week to week, not just day-to-day, (von Gall et al., 2023) so the findings from one week of data may not be sufficient to detect bi-directional associations between caffeine and sleep.

It was not known if the days were scheduled or unscheduled days. Young adults, much like other adults, frequently days away from study or work (e.g., weekends) to recover from any sleep debt that they have accumulated on study/work days (Roenneberg et al., 2003). This may have affected the results because we do not know if we captured sufficient scheduled and/or free days to accurately reflect the effects of caffeine on sleep health.

The Consensus Sleep Diary does not capture the time in the day naps occurred. Instead, it captures the total duration of naps. This created challenges for actigraphy scoring, requiring the scorer to estimate when a nap likely occurred based on a combination of diary data and activity levels. The accuracy of the scoring of naps may, therefore, have been reduced. Due to the constraints regarding software availability, the actigraphy data was not double scored.

There was an uneven distribution of participants from different ethnic groups in the sample. Our sample group was 53.8% European and 40% so is not representative of the general population. Cultural differences in sleep (Rao et al., 1999) and caffeine intake (Denden et al., 2016) may exist, which could mean our results are not generalisable to the New Zealand population.

Our sample size also included a lot of highly educated young adults (73.1% were had a bachelor's degree or higher), who could already be aware of the impacts of caffeine on sleep and chose to limit their intake to earlier in the day rather than closer to bedtime. In addition, the general young adult population in New Zealand is comprised of approximately 40% who have completed a Bachelor's degree or higher (OECD, 2019). Therefore, as above, the findings may not be generalisable to the general population.

Baseline sleep requirements were not captured, so sleep debt could not be calculated. One hypothesis for why people might be sleeping longer and also consuming more caffeine is

that they are recovering from a sleep debt - i.e., needing more sleep and feeling sleepy that day.

4.4 Research impact:

The findings of this study support evidence that caffeine consumption is a contributor to poor sleep duration in New Zealand young adults. Poor sleep health has been associated with decreased performance (physical and cognitive) (Choshen-Hillel et al., 2021; Taylor & Martin, 2019) as well as decreased health and well-being (Buysse, 2014; Edéll-Gustafsson et al., 2002). Caffeine is typically consumed for the desired outcome of increasing concentration, performance, and alertness (MacKenzie et al., 2007). Young adults may not know this caffeine could be contradictory, through hindering performance and focus through its impact on sleep duration (Charest & Grandner, 2020; Choshen-Hillel et al., 2021). For young adults to make an informed decision about their caffeine consumption requires an understanding of both the benefits and consequences of caffeine intake. Caffeinated products are typically marketed based on their benefits such as improving focus, energy levels and alertness but are not required to provide information on their adverse effects (Bessada et al., 2018; Bleakley et al., 2022). It is apparent that, worldwide, caffeine intake in young adults needs to be reduced (Bucher et al., 2019; Islam et al., 2020) and there is a need for young adults to understand the adverse effects of high caffeine consumption (De Sanctis et al., 2017).

While further research should be done to investigate the effects of caffeine on additional sleep quality and timing before this is a supported theory, this study may suggest that caffeine intake may only affect objective sleep duration. Our findings suggest further research into what other factors could be affecting sleep quality and timing, such as screen time, physical activity, or dietary behaviours, would be beneficial to improve young adults

sleep health. The consequences of poor sleep duration are significant enough to still require a reduction in caffeine intake (De Sanctis et al., 2017). This study also suggests that the relationship between sleep health and caffeine is bidirectional. This could create a cyclic relationship on reliance on caffeine in young adults to get through the day after a poor sleep, and the increased caffeine intake affecting the subsequent night's sleep.

4.5 Recommendations:

Overall recommendations would be to aim to reduce caffeine intake in young adults. While the mean intake of our sample group sat within a safe limit, diary entries on some days indicated that these limits were exceeded, and one participant managed 1050 mg in one day. This shows that some young adults are choosing to consume excessive amounts of caffeine. This could be due to a lack of awareness and promotion of the adverse effects of caffeine (Bessada et al., 2018) and the increasing number of caffeinated products available on the market. There are several proposed strategies to address this, including:

- Increasing awareness of the both the consequences of poor sleep health in young adults and the associations between caffeine consumption and sleep, particularly at such a transitional age, may reduce the caffeine intake in this age group and promote better sleep health. Young adults can be a challenging group to educate, as they often still partake in impulsive and risk-taking behaviour. Preventative health promotion in young adults and adolescents has been shown to be successful in establishing healthy habits early on in life (Inserm Collective Expertise Centre, 2001). Dietary habits, including caffeine consumption, and sleep education should be mandatory in secondary school curriculum. Educating people at an age where habitual caffeine consumption typically begins could be beneficial for creating better lifelong caffeine habits, which may consequently improve sleep health in young adults.

- Young adults have been shown to be impulsive, careless, and habitual consumers (Mokhlis, 2009) suggesting that other barriers to purchasing caffeine products should also be put in place. Dietitians could suggest that new laws are put in place that limit the caffeine content of caffeine-containing products, such as instant coffee, tea, ready to go drinks, and medications, in the same way they have with energy drinks. FDANZ could also institute a food tax on caffeine products to limit companies from adding unnecessary caffeine to products, therefore limiting caffeinated products available for young adults to purchase. Furthermore, laws could be established where exact amounts of caffeine present in a product needs to be stated on packaging and nutrition panels, so young adults, and the wider general population of consumers can be confident in how much they are choosing to consume.

4.6 Future research

Further work is required in this this field as this study suggests caffeine does affect sleep duration, and a bidirectional relationship between caffeine intake and sleep duration exists. However, sleep is complex and requires more investigation to determine if caffeine affects other variables of sleep health as well.

4.6.1 Future studies could:

- Include both the dose and timing of caffeine together as predictors of sleep objectives in mixed models, to assess associations. This will aim to have a more accurate representation than timing or dosage alone, and rather whether the later timing and dosage cause an effect.

- Investigate the typical timing of all caffeine intake by gathering information of caffeine timing. This would allow assessment of whether the people are waking up sleepy and reaching for caffeine upon awakening and/or more throughout the day.
- Include a more representative sample of young adults. Future studies could investigate confounding factors that could be affecting their sleep or caffeine habits. Examples could include demographics, education level, physical activity, and/or dietary behaviours. This will help to assess what other factors could be determining the habitual caffeine intake of individuals, and their resulting sleep health.

Further development of the daily diary could help with gathering further information to expand research in this field. Developments could include:

- Include one or more diary questions asking if there are personal circumstances going that participants perceive is affecting their sleep health (e.g. stress, exams etc) and capturing typical sleep health characteristics prior to the study monitoring period. This will help to gain a better understanding of the participants' baseline sleep needs in general, as well as if there were other factors affecting their sleep that could have impacted the results.
- Include a question in the diary asking if there were factors that impacted their choices relating to caffeine intake each day (e.g. felt more tired, socialising etc). As caffeine intake in our participants typically fluctuated each day, it could be beneficial to understand what causes intake to vary. Studies could also calculate each participant's average dose of caffeine consumed during the monitoring period. This may help to determine whether it is only some individuals who consume significant amounts of caffeine, or all young adults. It will also help determine if there a particular quantity or limit that results in caffeine effecting sleep.

- Include more detailed questions to capture the time and duration of daily naps to increase the accuracy of actigraphy scoring.

Include which caffeine product was consumed at the final intake and what days of the week each day of monitoring occurs on. This will help to build a more accurate picture of the impact of caffeine on sleep as it is more specific and helps to incorporate sleep regularity.

Finally, while has shown that caffeine is a contributor to poor sleep health in young adults, the present study raises the question of additional factors that may affect sleep health in young adults. For example, lifestyle preferences such as high alcohol consumption (Park et al., 2015), high stress lifestyles (Kim & Dimsdale, 2007), or shift work (McDowall et al., 2017)can have negative impacts on sleep health. It is possible that as many young adults choose to further their education they face academic stress and more competition and pressure to succeed (Tavolacci et al., 2013). The promotion of constant productiveness may cause young adults to stop prioritising their sleep, particularly in university students, who may choose to forgo sleep to further academic achievements (Rodgers et al., 2016). Moreover, it is not clear that young adults are aware of the importance of sleep is, particularly for their life stage, and that poor sleep health in young adulthood may have long-term impacts for later life.

APPENDIX A **INFO SHEET PART 2**

MASSEY UNIVERSITY

COLLEGE OF HEALTH

TE KURA HAUORA TANGATA

The Effects of Caffeine Consumption on Sleep Quality in New Zealand Young Adults

Information sheet (Part 2)

We invite you to participate in part 2 of the study which involves wearing a sleep/wake activity monitor and completing a sleep diary for 7 days. This is also being conducted by researchers at the School of Sport, Exercise and Nutrition, and the School of Health Sciences at Massey University.

Who will participate?

To participate, you need to be:

- Currently living in Auckland
- Between the ages of 18-25 years old
- Fluent in reading and writing in English
- In good general health with no current sleep problems or history of heart, neurological or psychiatric illness.
- Not working as a shift-worker

What will you need to do?

You will need to complete and pass a health screening questionnaire, which will take about 2-5 minutes of your time. You will need to wear an activity monitor ('Actigraph') on your wrist for a period of one week (24 hours a day for 7 consecutive days), including showering (they are water resistant). This device is similar to a Fitbit and will record your physical activity and sleep/wake data. You will also need to fill in a sleep diary each morning when you wake and each evening before you get into bed. You will be asked to record your previous night's sleep and activities that you completed during the day that might have affected your sleep, including caffeine intake. Completing this diary will take approximately 5-7 minutes each day.

To thank you for your time and participation, you will be offered a $20 koha (gift voucher) after completion of the one-week data collection period and return of the actigraphy watch.

How will your data be looked after?
Your data will only be used for research purposes and will be stored securely on password-protected computers in password-protected files, only available to the research team. In order to maintain confidentiality, a coding system will be used where each participant is given a unique identifier. This code will be used to link your questionnaire with your sleep/wake activity data and consent form. This means that although you will not be anonymous to the research team, all data will be anonymised.

Information collected from the health questionnaire is only used for the purpose of screening. The research team will only keep your responses from this screening questionnaire for the duration of the study. If your screening questionnaire indicates that you do not meet the study criteria listed above, your screening questionnaire will be immediately destroyed.

What are my rights?
After having read and understood the study information, you will be asked to complete a consent form. You have the right to receive a summary of your sleep-related metric information upon request. You have the right to withdraw from the study up until return of the actigraphy watch.

Project Contacts
If you have any questions regarding this project, please contact the student researcher and/or one of the supervisors.

Student Researcher
Marjial Hermanoche (School of Sport, Exercise, and Nutrition)
Email: caffcosleepstudy@gmail.com
Mob: [redacted]

Supervisors
A/Prof Kay Rutherfurd-Markwick (School of Health Sciences)
Email: K.J.Rutherfurd@massey.ac.nz
Phone: +64 (09) 213 6646

Prof Ajmol Ali (School of Sport, Exercise and Nutrition)
Email: A.Ali@massey.ac.nz
Phone: +64 (09) 213 6414

Prof Carol Wham (School of Sport, Exercise and Nutrition)
Email: C.A.Wham@massey.ac.nz
Phone: +64 (09) 213 6644

Dr Karyn O'Keeffe (School of Health Sciences)
Email: K.M.OKeeffe@massey.ac.nz
Phone: +64 (04) 979 3260

APPENDIX B COMMITTEE APPROVAL STATEMENT

This project has been reviewed and approved by the Massey University Human Ethics Committee: Southern A, Application 21/11. If you have any concerns about the conduct of this research, please contact Dr Negar Partow, Chair, Massey University Human Ethics Committee: Southern A, telephone 04 801 5799 x 63363, email humanethicsoutha@massey.ac.nz.

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

Date: 27 April 2021

Dear Marjial Hermanoche

Re: Ethics Notification - **SOA 21/11 - The Effects of Caffeine Consumption on Sleep Quality in Healthy New Zealand Young Adults (aged 18-25 years old).**

Thank you for the above application that was considered by the Massey University Human Ethics Committee: **Human Ethics Southern A Committee** at their meeting held on **Tuesday, 27 April, 2021**.

Approval is for three years. If this project has not been completed within three years from the date of this letter, reapproval must be requested.

If the nature, content, location, procedures or personnel of your approved application change, please advise the Secretary of the Committee.

Yours sincerely

Professor Craig Johnson
Chair, Human Ethics Chairs' Committee and Director (Research Ethics)

Consensus Sleep Diary

APPENDIX C CONSENSUS SLEEP DIARY

Consensus Sleep Diary-E (Please Complete Upon Awakening). **Participant ID#: ____________________**

	Example							
Today's Date	04/02/2021							
1. What time did you get into bed?	10:15 pm							
2. What time did you try to go to sleep?	11:30 pm							
3. How long did it take you to fall asleep?	55 min							
4. How many times did you wake up, not counting your final awakening?	6 times							
5. In total, how long did these awakenings last?	2 hours 5 min							
6a. What time was your final awakening?	6:35 am							
6b. After your final awakening, how long did you spend in bed trying to sleep?	45 min							
6c. Did you wake up earlier than you planned?	☒Yes ☐No	☐Yes ☐No	☐Yes ☐No	☐Yes ☐No	☐Yes ☐No	☐Yes ☐No	☐Yes ☐No	☐Yes ☐No
6d. If yes, how much earlier?	1 hour							
7. What time did you get out of bed for the day?	7:20 am							
8. In total, how long did you sleep?	4 hours 10 min							
9. How would you rate the quality of your sleep?	☐Very poor ☒Poor ☐Fair ☐Good ☐Very good	☐Very poor ☐Poor ☐Fair ☐Good ☐Very good	☐Very poor ☐Poor ☐Fair ☐Good ☐Very good	☐Very poor ☐Poor ☐Fair ☐Good ☐Very good	☐Very poor ☐Poor ☐Fair ☐Good ☐Very good	☐Very poor ☐Poor ☐Fair ☐Good ☐Very good	☐Very poor ☐Poor ☐Fair ☐Good ☐Very good	☐Very poor ☐Poor ☐Fair ☐Good ☐Very good
10. How rested or refreshed did you feel when you woke up for the day?	☐Not at all rested ☒Slightly rested ☐Somewhat rested ☐Well-rested ☐Very well-rested	☐Not at all rested ☐Slightly rested ☐Somewhat rested ☐Well-rested ☐Very well-rested	☐Not at all rested ☐Slightly rested ☐Somewhat rested ☐Well-rested ☐Very well-rested	☐Not at all rested ☐Slightly rested ☐Somewhat rested ☐Well-rested ☐Very well-rested	☐Not at all rested ☐Slightly rested ☐Somewhat rested ☐Well-rested ☐Very well-rested	☐Not at all rested ☐Slightly rested ☐Somewhat rested ☐Well-rested ☐Very well-rested	☐Not at all rested ☐Slightly rested ☐Somewhat rested ☐Well-rested ☐Very well-rested	☐Not at all rested ☐Slightly rested ☐Somewhat rested ☐Well-rested ☐Very well-rested

Sleep Diary - Complete in the EVENING **Participant ID#: _____**

	Example							
Today's Date	04/02/2021							
11a. How many times did you nap or doze? 11b. In total, how long did you nap or doze?	2 times 1 hour 10 min							
12a. How many drinks containing alcohol did you have? 12b. What time was your last drink?	3 drinks 9:20 pm							
13a. How many/ much of the following caffeinated products did you have today? • Coffee (instant): ___ cups • Coffee (café): ___ cups • Black tea: ___ cups • Green tea: ___ cups • Cola flavoured drinks (e.g., coca cola): ___ drinks___ (mL) • Energy drinks (e.g., Lift plus) ___ drinks___ (mL) 13b. What time was your last drink?	- Coffee (instant, 2 tsp), 1 cup - Red Bull, 473mL can 3:00 pm	Caffeinated product(s), describe type and amount:	Caffeinated product(s), describe type and amount:	Caffeinated product(s), describe type and amount:	Caffeinated product(s), describe type and amount:	Caffeinated product(s), describe type and amount:	Caffeinated product(s), describe type and amount:	Caffeinated product(s), describe type and amount:
14. Did you take any over-the-counter or prescription medication(s) to help you sleep? If so, list medication(s), dose, and time taken	☒Yes ☐No Medication(s): Relaxo-Herb Dose: 50mg Time(s) taken: 11pm	☐Yes ☐No Medication(s): Dose: Time(s) taken:	☐Yes ☐No Medication(s): Dose: Time(s) taken	☐Yes ☐No Medication(s): Dose: Time(s) taken	☐Yes ☐No Medication(s): Dose: Time(s) taken	☐Yes ☐No Medication(s): Dose: Time(s) taken	☐Yes ☐No Medication(s): Dose: Time(s) taken	☐Yes ☐No Medication(s): Dose: Time(s) taken
15. Comments (if applicable)	I have a cold							

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