Examining societal and intraindividual determinants of sleep-wake timing and social jetlag

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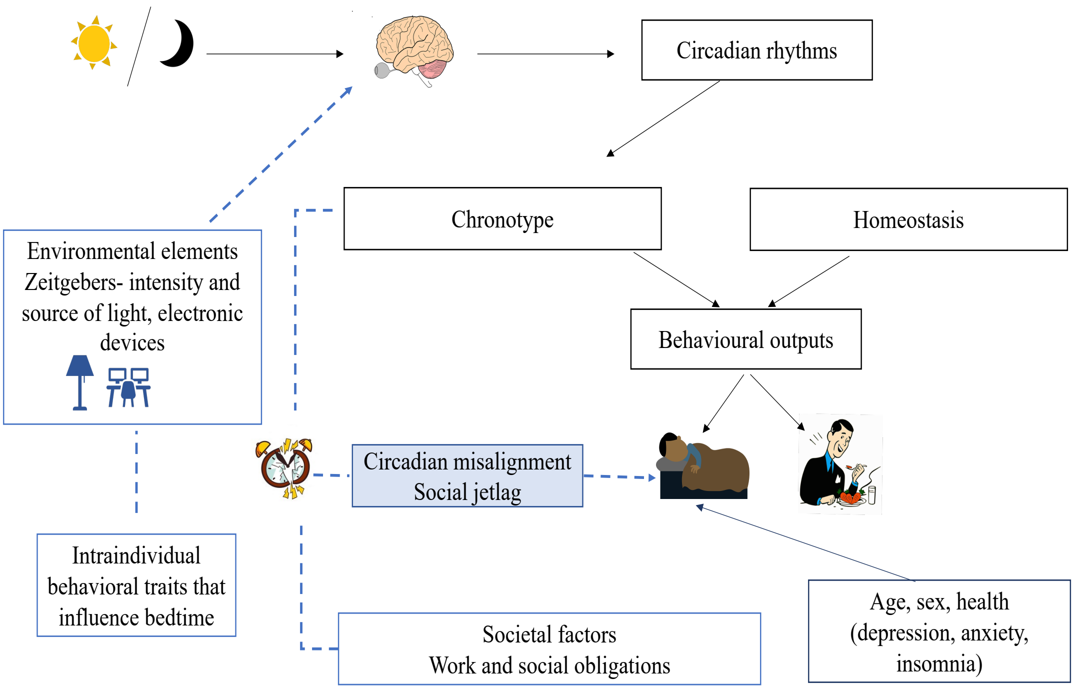
Research summary

The primary objective of this research was to examine societal and intraindividual behavioural determinants of sleep-wake timings and social jetlag. Occupational demands and timings may influence bedtime and waketime. Behavioural factors could additionally influence sleep-wake timings via bedtime decisions. The impact of workday sleep-wake timings on social jetlag was explored in this research. The association between social jetlag and the temporal consideration and discounting of future consequences and dysfunctional beliefs about sleep were also explored. The evidence from the current research suggest that societal factors have a strong influence on social jetlag. Later workday sleep-wake timings during the pandemic resulted in a significant reduction in social jetlag. There was no evidence of an association between social jetlag, chronotype and intraindividual traits. Work-free day midsleep (chronotype) was a significant determinant of social jetlag. Social jetlag and chronotype demonstrated differential relationships with other societal and demographic factors. Differential relationships between social jetlag, chronotype and other key sleep parameters such as sleep quality and insomnia were also observed. Current research suggests social jetlag may be a distinct sleep phenomenon with strong associations with sleep-wake timings. Modifications to work schedules may be one option for reducing social jetlag. However, this was at the expense of late sleep-wake timings, and the long-term chronobiological implications of the changes observed during the pandemic are yet to be fully understood. Alternatively, a reduction in social jetlag may be feasible via phase advancing of late chronotypes. Social jetlag is ubiquitous in modern society and presents a significant public health concern. Current research identifies challenges to translation of circadian science into policies. Public education on sleep regularity and circadian misalignment could facilitate a discussion between scientists and the general public and may facilitate a chronobiologically sound solution to the widespread problem of social jetlag in modern society.

Theoretical framework for current research



Societal and behavioural determinants of sleep-wake timings, circadian misalignment and social jetlag Social cues (work obligations) and intraindividual traits (bedtime behaviours) may interact with environmental elements (light exposure) to effect biology (circadian rhythms and homeostasis) that ultimately impact on the entrainment of the internal rhythms and sleep-wake cycle. Both photic and non-photic cues may share a complex relationship in the entrainment of the human circadian system in modern industrialized societies.

Chapter 1. Introduction

Social jetlag: misalignment between internal rhythms and external social time

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1.1 Introduction

The earth's daily 24-hour rotation results in environmental changes such as temperature and dark-light cycles. To adapt to these changes and to facilitate food sourcing and survival, living organisms on earth have an internal biological clock that generates near 24-hour period rhythms, known as circadian rhythms. These internally generated rhythms are considered an integral part of an organism's biology for coordinating not only external activities such as hunting for food, but for facilitating the internal organs to coordinate absorption of nutrients and to function within a complex system of molecular framework. Absence of internal timekeeping for such a synchronization is believed to result in biological chaos (Forster & Kreitzman, 2017).

These internal timekeepers however do not run at exactly 24 hours to match with the external environment's rotation (Foster & Roenneberg, 2008). To minimise the offset between internal and external time, the internal clocks receive environmental time cues (zeitgebers) such as light and temperature from the external environment to time the internal mechanisms of the body to produce meaningful behaviours for the organism's survival. In humans, sleep-wake cycles and feeding cycles are the most observable behavioural manifestations of circadian rhythms. The day-night variations in these activities suggest a temporal nature that is synchronized to the light-dark cycles of the natural environment (Foster & Kreitzman, 2017).

The synchrony between the external light-dark cycles and the internal rhythms would have been particularly important from an evolutionary point of view, when hunter-gatherers needed to maintain high levels of arousal and orientation to their environment to forage and hunt for food safely during the day and also to stay away from predatory animals after dark (Siegel, 2005; Worthman, 2008). Modern day humans in industrialized societies no longer hunt for food, however, sleep is still considered important for overall health and well-being and it is recommended that adults should get 7–9 hours of sleep, which increases to 8–10 hours for adolescents (Hirshkowitzetal et al.,2015). Sleep surveys from around the world however indicate a worldwide problem of insufficient sleep duration (Carskadon et al., 2006; Kronholm et al., 2008; Stranges et al.,2012).

Besides sleep duration, disruptions to sleep-wake rhythms and sleep timings are of increasing concern in recent times. Industrialization and the effects of modern life (such as prolonged indoor evening light exposure and use of light emitting technology) are reported to be significant factors in the desynchrony between internal and external rhythms (Lunn et al., 2017). Socially imposed timings, such as work or school start timings, are also reported to impact on the internal rhythms with cascading effects on sleep-wake behaviours. Social jetlag, the sleep phenomenon that is a result of the variability in sleep-wake timings between work and work-free days (Wittman et al., 2006), is an example of the undesirable consequence of the misalignment between the external environment and the internal biological clocks. Approximately 88% of the nearly 300,000 participants in a German database (The Munich Chronotype Questionnaire; see Roenneberg et al., 2019) recorded at least 1 hour of social jetlag. This indicates how ubiquitous social jetlag is in modern society.

Circadian misalignment and social jetlag are associated with significant adverse health and behavioural outcomes such as obesity, diabetes, psychiatric disorders, cardiometabolic disorders, substance use and daytime sleepiness (Haynie et al., 2017; Henderson et al., 2019; Ito et al., 2017; Islam et al., 2020; Kelly et al., 2019; Larcher et al., 2016; Levandovski et al., 2011; Suikki et al., 2021; Sudy et al., 2019; Wong et al., 2015). The undesirable impact that social jetlag has on key health and behavioural parameters makes the widespread and chronic nature of social jetlag a significant public health concern. It is thus important to examine significant risks for social jetlag and examine ways to reduce or eliminate it.

Realigning internal and external timings and narrowing the gap between work and work-free days sleep-wake timings may facilitate reduction or elimination of social jetlag. Internal sleep-wake cycles are determined both by a homeostatic drive for sleep and the circadian propensity for rest-activity that is synchronized to the external environment (Borberly 1982). Several factors are associated with sleep-wake timings, and the gap between work and workfree days and social jetlag. For example, the impact of biological and environmental factors on the internal circadian propensity for sleep is widely discussed (for example, age/sex, homeostasis, melatonin, modern-day light-dark cycles; Cipolla-Neto & do Amaral, 2018; Lunn et al., 2017; Stothard et al., 2017).

Additionally, social factors may act as zeitgebers (Mistlberger & Skene, 2004). Socially imposed timings, such as work or school start timings, may influence bedtime and waketime. Intraindividual behavioural factors have been associated with delayed bedtime and insufficient sleep (Kroese et al., 2014). Behavioural factors could be additional zeitgebers that impact on social jetlag, via bedtime decisions. Thus, socially imposed timings (via forced waketime), and behavioural traits (via behaviours that delay bedtime) may be significant risk factors for a cycle of late sleep-wake timings, circadian misalignment and social jetlag. This current research examines societal and intraindividual determinants of sleep-wake timing and social jetlag.

1.2 Circadian rhythms

Circadian rhythms are recurring cycles with a near 24-hour period that are manifested in a host of molecular, physiological, and behavioural outputs and are the product of a biological internal clock system (Jagannath et al., 2017). As illustrated in figure 1.1 (redrawn from Foster & Kreitzman, 2017), the earth's daily rotation and seasonal cycles result in cyclic changes in environmental conditions such as temperature, light and availability of food. An organism's internal oscillators running independent of these environmental changes would not manifest in adaptive time-specific behaviours if it is not coordinated with the environmental conditions (for example, sourcing for food when there is light and it is safe to do so). The environmental cues are received for synchronizing or entrainment by an internal body clock which facilitates the synchronization of the internal rhythms to the external environmental rhythms.

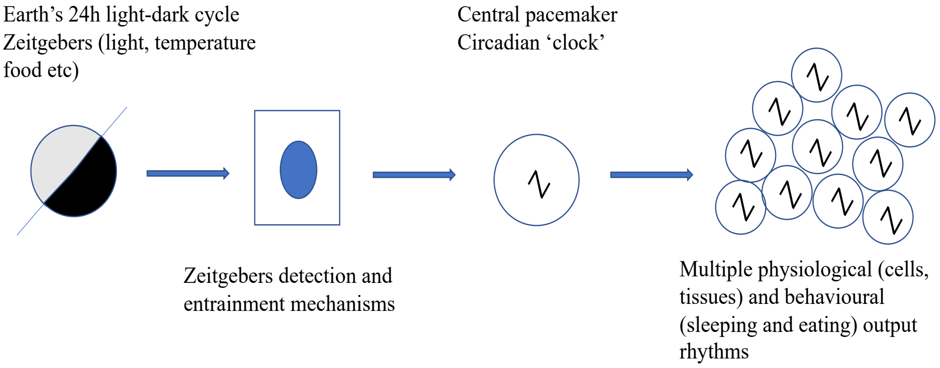


Figure 1.1 24-hour light-dark rotations and the circadian system
Earth's 24-hour daily rotation generates light-dark and temperature rhythms. The external rhythms are synchronized with the internal processes by the central pacemaker (SCN) which sets the internal rhythms and passes on signals to peripheral clocks for a coordinated systems-wide organization of physiological and behavioural outputs (sleeping, sourcing for food etc) that are adaptive to the environment. Figure redrawn from Foster and Kreitzman, 2017.

A synchronous circadian clock optimally regulates bodily functioning and sleep-wake cycles with reference to an organism's environment; conversely, desynchronous circadian rhythms could potentially lead to a number of health complications (Roenneberg & Merrow, 2016). This reflects the highly distributed nature of the circadian system and the pervasive nature of its influence on physiology and behaviour. In humans, the suprachiasmatic nuclei (SCN) pass on the information about the environment to peripheral clocks which result in useful physiological and behavioural outputs (for example, feeding and sleep-wake cycles).

1.3 Homeostatic and circadian regulation of sleep-wake cycles

Sleep-wake behaviour, the central focus of this thesis, is an observable output of the circadian rhythms. In this section, the sleep-wake cycle and the two-process model of sleep regulation is discussed. Sleep is a complex neurophysiological state and as conceptualized in the two-process model, sleep-wake behaviour is an interaction between the internal circadian system (process C) and the homeostatic process (process S) (Figure 1.2; Borbely et al., 2016). The homeostatic drive for sleep is the build-up of pressure for sleep throughout the day. The pressure gets stronger through the day as the time lapse from the last sleep episode increases to initiate sleep and becomes weaker during sleep to initiate awakening (Borbely et al.,2016).

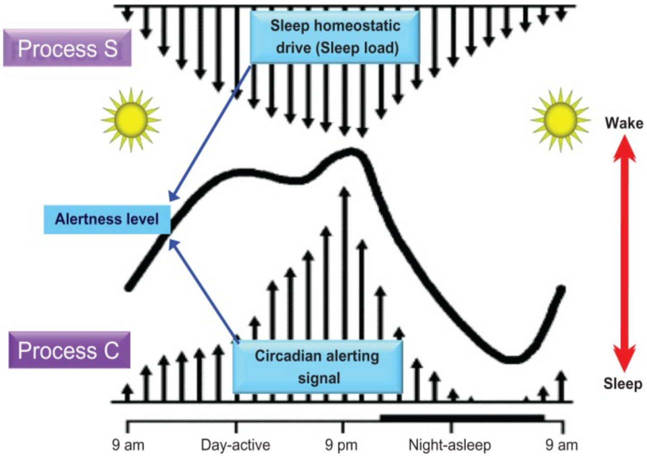


Figure 1.2 Two processes govern the daily expression of sleep–wake cycles in humans. Process S represents the homeostatic sleep pressure that accumulates and increases in intensity throughout the day. Process C is the circadian process for wakefulness that maintains alertness during the day, counteracting Process S. Sleep onset is facilitated when sleep propensity reaches its peak in time with the start of the decline in the circadian propensity for alertness. Image from Vosko et al., 2010 with original image credited to Kryger MH, Roth T, Dement WC, eds., 2005.

As shown in figure 1.2 (figure from Vosko et al., 2010) the homeostatic process works with the opposing oscillator, process C, according to the model proposed by Borberly (1982). The homeostatic pressure for sleep-wake cycle is believed to share a significant and functional relationship with the biological propensity for sleep-wake rhythms. The homeostatic drive and circadian rhythms work together to determine sleep time through inhibition of wake promotion, and to determine wake time through the inhibition of sleep propensity. The circadian propensity for wake (process C) increases as the homeostatic drive for sleep increases (process S), pushing and pulling sleep-wake propensity in opposite directions to keep the drive for sleep low during periods optimal for wake, and the drive for wake low during conditions optimal for sleep. Sleep onset is facilitated when the drive for sleep is maximum and the circadian drive for wake reaches a highest point for the day and starts to decrease. Conversely, at the end of a sleep episode, the drive for sleep is low while the circadian propensity for wakefulness increases to facilitate waking.

The circadian oscillation for wake gets stronger through the day, during the wake promotion period, (in contrast to the increasing homeostatic sleepiness) reaching a maximum just before habitual bedtime (Dober, 2018). The wake maintenance signals slowly decline with the onset of nocturnal melatonin (see section 1.4.3) which is considered a biological marker and phase of circadian entrainment (Dijk & Archer, 2009). The start of the decline of the circadian propensity for wake coincides with the maximum strength of the homeostatic drive for sleep just before habitual bedtime. The internal circadian system processes changes in the environment, such as changes in light and temperatures, to synchronize, adapt and align the body’s rest and activity levels with the appropriate and conducive external conditions. Thus, the propensity for sleep is ideally timed for when it is dark, and with the onset of the endogenous melatonin and low body temperature. The propensity for wakefulness starts increasing when melatonin decreases, and body temperature rises (Arendt & Skene, 2005).

Once sleep is initiated, there are several stages to the sleep cycle. The cycle starts with light sleep progressing into slow-wave sleep activity (SWA) during the Non-Rapid Eye Movement stage (NREM); this is the stage when the muscles in the body relax and most physiological functions (such as heart rate and respiration) and brain activity (confirmed via EEG studies) are observed to slow down (Foster & Kreitzman, 2017; Worthman, 2008). This stage is the marker for process S (Borbély & Achermann, 1999). There are 1-4 stages of NREM sleep. At stage 4, the sleep cycle moves into the Rapid Eye Movement (REM) stage, and after the REM stage moves back to stages 1-4 of NREM (Foster & Wulff , 2005).

The REM stage is associated with dreaming and muscles are immobilized as a protective mechanism to prevent mirroring of movements from dreams that could result in dangerous movements and falls during sleep (Worthman, 2008). Each sleep cycle, moving through NREM and REM lasts about 70-90 minutes. Five such cycles, ending with REM, are expected in an average night uninterrupted by sleep disturbances or the alarm clock (Foster & Wulff, 2005).

From an evolutionary standpoint, a synchronous circadian clock and well-timed sleep could have served to protect animals from danger by keeping them away from predators at the time of maximum risk of predation in any given environmental niche (Siegel, 2005). From a biological perspective, sleep is a time for the body and mind to re-establish homeostasis disrupted by wakefulness and to remove built-up toxins (Lucey & Holtzman, 2015). Sleep-wake behaviour expressions vary among species, depending on their habitat, diet, status in the food chain, and body mass/brain sizes (Siegel, 2005). Therefore, the temporal architecture of sleep in the animal kingdom may serve an important purpose in promoting survival by synchronizing internal sleep-wake rhythms with the environmental light-dark cycle. The internal biological processes and the external environmental elements are synchronized via a process known as entrainment which is the focus of the next section.

1.4 The master circadian clock in humans

The suprachiasmatic nuclei (SCN) of the anterior hypothalamus is regarded as the central clock in humans responsible for generating behavioural rhythms as experiments have demonstrated that bilateral lesions to the SCN eliminated drinking and activity rhythms in rats (Stephan & Zucker, 1972). The SCN is considered the master circadian clock, which signals to other peripheral clocks widely distributed in vital organs such as the liver and the heart (Scheer et al., 2009). At a molecular level, the pervasiveness of the clock in the transcriptome is shown through 40% of all genes displaying daily rhythms in expression in at least one tissue (in animal studies; Zhang et al., 2014).

From a system point of view, the SCN is regarded as a key player in regulating most internal circadian rhythms. Figure 1.3A (figure from Patton & Hastings, 2018) shows the location of the SCN in a mouse brain. Figure 1.3B shows the neuronal activity of the SCN displaying circadian patterns, confirming the role the SCN plays in the internal rhythms. Figure 1.3C shows the SCN on a human brain. Other sites with independent clocks and rhythms, such as the olfactory bulb that remained unaffected by SCN lesions, have also been identified (Granados-Fuentes et al., 2004). However, the SCN is still primarily responsible for regulating sleep-wake cycles (Sack et al., 2000), with animal studies demonstrating complete arrhythmicity of sleep-wake cycles following SCN lesions (Liu et al., 2012). In humans, the SCN regulates sleep-wake cycles by synchronizing the internal systems with the external light-dark cycles of the natural environment in a sophisticated temporal operation known as entrainment.

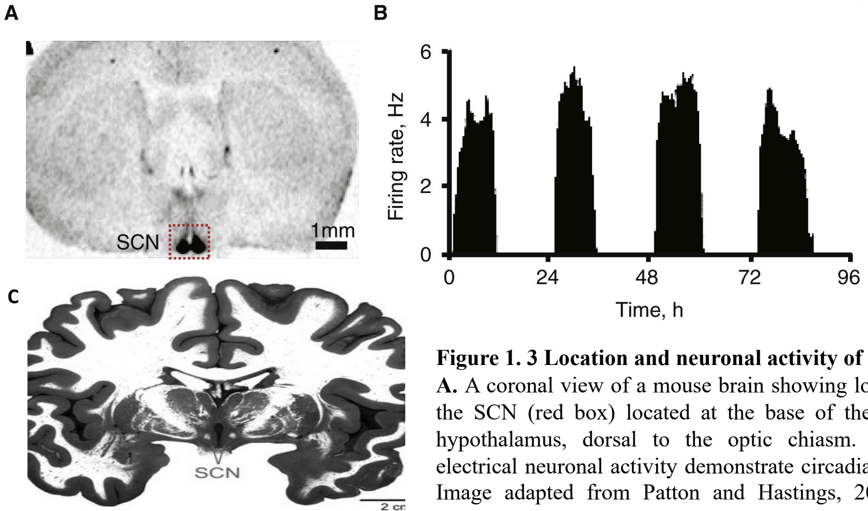


Figure 1. 3 Location and neuronal activity of the SCN **A.** A coronal view of a mouse brain showing location of the SCN (red box) located at the base of the anterior hypothalamus, dorsal to the optic chiasm. **B.** SCN electrical neuronal activity demonstrate circadian cycles. Image adapted from Patton and Hastings, 2018 with original image credited to Hastings and Herzog, 2004. **C.** A coronal view of a human brain showing location of the SCN. Image adapted from Hofman, 2007.

1.4.1 Entrainment

In 1729, Jean Jacques d'Ortous de Mairan, an astronomer, published a simple experiment that demonstrated the endogenous nature of circadian rhythms in nature. The mimosa plant's leaves droop at dusk and rise in daylight. de Mairan placed the plant in a cupboard to observe if the plant's behaviour would be altered in the absence of the sun. He observed that the plant still opened and closed at various times of the day. In the absence of light, the plant still demonstrated the behaviour of opening and closing its leaves, suggesting an internal representation of day and night persisting in constant dark condition. These internal representations when persisting in constant condition, independent of the constant changes in the environment, are said to be free-running (Evans & Silver, 2015).

Although organisms demonstrate self-sustaining endogenous internal rhythms, free-running internal clocks do not run at precisely 24 hours, while the environmental solar cycle is by definition exactly 24 hours (Foster & Roenneberg, 2008). Thus, of central importance to the useful functioning of the circadian system is the synchronization of the internal clock system to appropriate time cues in the environment. This synchronization is known as entrainment. Without entrainment, internal and external time would become desynchronized. Without entrainment, the usefulness of the clock in predicting rhythmic changes in the environment would be lost, and behavioural outputs may be out of sync with the rhythmic changes of the external environment.

1.4.2 Photic entrainment: Light and the human phase response curve

In order to avoid the situation of behavioural outputs been out of sync (free-running) with the external environment, the internal clock system is reset by time cues (“zeitgebers”) in the environment. The dominant zeitgeber for the resetting of the clock is light (Hughes, 2015). The change or shifts in an organism’s free-running rhythm in response to light is dependent on the time (photoperiod) of light exposure, and this dependent relationship is explained via phase response curves (Pittendrigh & Dan, 1976). In other words, whether free-running rhythms advance, to earlier timings, or delay, to later timings, is dependent on the time of light exposure

An organism’s next day activities advance to an earlier timing when exposed to light in the late night (early morning). Exposure to light in the early night results in a delay in the next day activities rhythms. Merrow et al., 2005 demonstrated the effects of light on the entrainment process via an example of the spore formation activity of Neurospora Crassa (Figure 1.4) which runs less than 24 hours in constant light and temperature condition (A). While ambient temperature (colder or warmer; B+C) and light at subjective day (D) alters the rhythm of spore formation only slightly, exposure to light at night produced large shifts (E). Exposure to both light-dark cycles entrained the rhythms to a 24-hour cycle (Merrow et al., 2005).

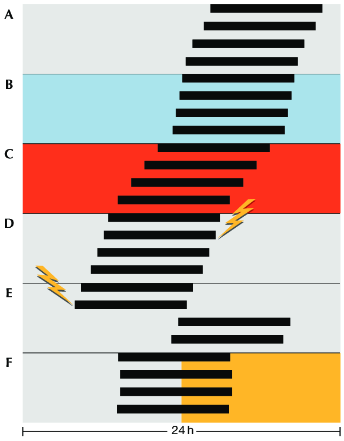


Figure 1.4 The effect of light on entrained and free-running rhythms
The 24-hour activity of spore formation in Neurospora Crassa demonstrating entrainment **A.** In constant darkness and temperature (25 °C), activity is observed to be slightly shorter than 24 hours. **B.** When is is colder (20 °C) activity lengthens and **C.** shortens when it is warmer (30 °C). **D.** Light exposure at daytime does not produce significant changes to rhythms but **E.** a significant shift to later timings is observed when light is introduced at night. **F.** Natural 24-hour light-dark cycles entrain the spore formation activity to a period of exactly 24 hours. Image and text adapted from Merrow et al., 2005.

The phase response to light is similar across species, and in humans there is some evidence of phase response to light throughout the day (Duffy & Wright, 2005). The human circadian system is believed to be very sensitive to light, both in terms of timing and in terms of the intensity of the light. Phillips et al. (2019) tested the effects of varying light intensity in the evening on melatonin onset, which is a measurable circadian output and a phase marker (discussed in the next section). They found that light intensity of <30 lux resulted in 50% suppression of melatonin. They further found that light intensity of 50 lux resulted in delayed melatonin onset by more than an hour. This is significant as humans may be exposed to daily light intensities of 30 or more lux, especially in the evenings before bedtime. This will be revisited in later sections under discussion of the impact of modern day living on sleep-wake rhythms. Before that, the next important point to discuss in the photic entrainment of the human circadian system is the photosensitive pathway in the brain and the role of melatonin in entrainment.

1.4.3 Photosensitive entrainment pathway, melanopsin and melatonin

Light interacting with the SCN is a key component in the entrainment process for circadian rhythms (Chellappa et al., 2011; Wright et al., 2013). Figure 1.5 (figure from Patton & Hastings, 2018) shows the photosensitive entrainment system across species. In mammals, light which is the dominant cue is received through the retina and coordinated through the SCN in the entrainment process. The photoreceptive system for photic effects on the circadian system is not the classical visual system of rods and cones, but rather involves a small proportion of retinal ganglion cells containing the photopigment melanopsin (Hughes et al., 2015; Figure 1.6). Melanopsin is maximally sensitive to visible short-wavelength light, in the blue end of the visible spectrum. Such light leads to depolarization of the retinal ganglion cells, whose axons travel in the retinohypothalamic tract and project directly to the SCN in a glutamatergic pathway (West et al., 2010). The SCN itself projects afferent axons within and around the hypothalamus and thalamus, regions that in turn may propagate the SCN-derived neuronal time stamp through the rest of the brain (Saper et al., 2005).

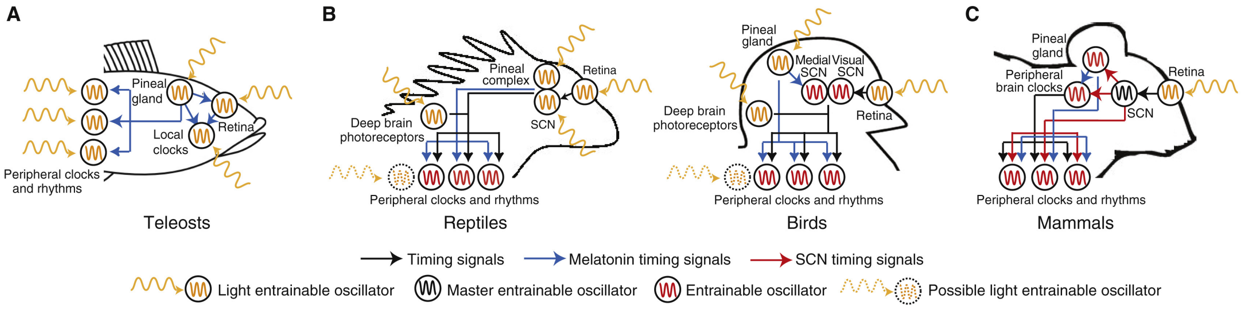


Figure 1.5 The photosensitive entrainment system across species
Clocks and the entrainment process in **A**. fish and **B.** reptiles and birds. **C.** The SCN based mammalian entrainment system with entrainment via the retina and coordination of the process through the SCN to peripheral clocks. Figure from Patton and Hastings, 2018.

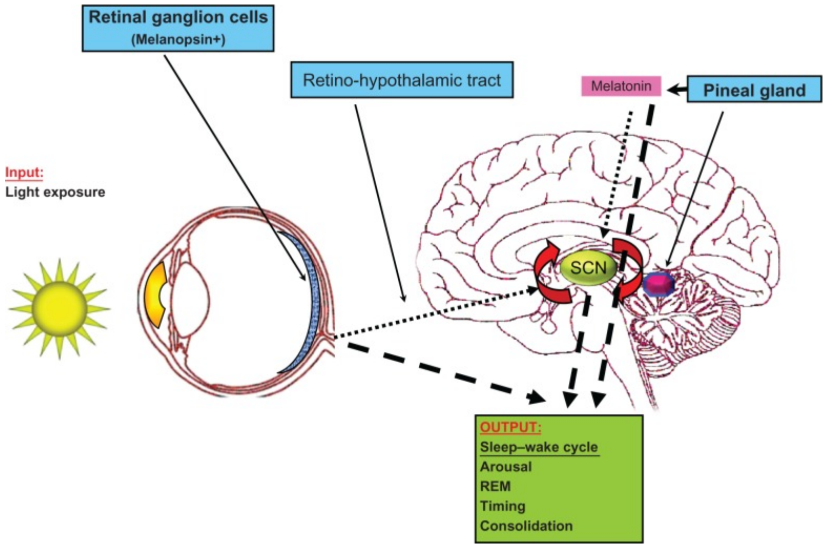


Figure 1.6 The retino-hypothalamic pathway of the entrainment process
Retinal ganglion cells, containing the photopigment melanopsin, are the photosensitive receptors of light cues from the environment which are projected onto the SCN via the retino-hypothalamic tract. The SCN projects unto other brain regions. One such region is the pineal gland where melatonin production displays a diurnal rhythm; increasing at night or in dim light conditions, and reducing during the day. Figure from Vosko et al., 2010.

One such indirect projection, via the sympathetic ganglion chain, is onto the pineal gland near the dorsal thalamus, which synthesizes melatonin in the absence of light and may act as a systemic signaller of day length and circadian phase, as well as feeding back to the SCN (Saper et al., 2005). Figure 1.6 (figure from Vosko et al., 2010) shows the location of the pineal gland. Melatonin is present across species, and in mammals the pineal gland synthesizes melatonin with endocrinal functions, and it has been noted that melatonin has roles in several pathologies (Cipolla-Neto & do Amaral, 2018). Melatonin production in the pineal gland is timed to the photoperiod information received from the SCN, such that melatonin decreases in the presence of light and increases in darkness (Canteras et al., 2011).

Light at night blocks melatonin production, but this process is counteracted by an inbuilt protective mechanism that blocks projection of light information to the pineal gland in a process known as photoinhibition (Cipolla-Neto et al., 1999). However, the inhibitory process appears to be dependent on the range of colour and intensity of the light source (Akiyama et al., 2017, Gooley et al., 2011, Lockley et al., 2003); it appears to be specifically effective for blue range from 460 to 480nm and at light intensity of 60-130 lux (<200lux; Cipolla-Neto & do Amaral, 2018). Recall the study by Phillips et al (2019) above. They found significant melatonin suppression at light levels as low as <30 lux, and they further reported significant interindividual variations in response to same levels of light.

Taken together, current research highlights that the human photic entrainment system is highly sensitive to light and that indoor evening light may have significant impact on phase markers for internal rhythms. It appears that the impact on phase markers may be significant even at lower intensity levels. This has important implications in understanding the impact of 24/7 light (and reduced natural light exposure) on sleep-wake cycles in modern times.

Additionally, melatonin is recognized as a chronobiotic – a therapeutic agent that resets out of sync clocks and synchronizes biological oscillations (Arendt & Skene, 2005; Cipolla-Neto & do Amaral, 2018). Figure 1.7 (figure from Arendt & Skene, 2005) shows the free-running pattern of endogenous melatonin secretion with no exogenous melatonin treatment or placebo. Exogenous melatonin, from day 12 at a fixed clock time, phase advances slowly and eventually entrainment occurs.

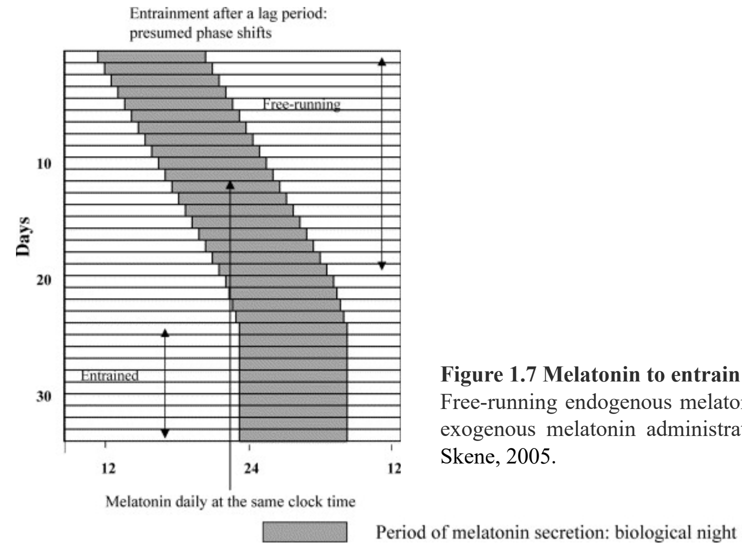


Figure 1.7 Melatonin to entrain free-running rhythms
Free-running endogenous melatonin rythmns eventually entrains after daily exogenous melatonin administration from 12 day. Image from Arendt & Skene, 2005.

The diurnal patterns, night-time increase and daytime suppression, of melatonin points to the important role that the hormone might play in the entrainment of the internal rhythms to synchronize and adapt activities to the external light-dark cycle. The timing of melatonin onset is regarded as a biomarker for the circadian phase (Arendt & Skene, 2005). The correlation between suppression of melatonin at night by light and increase in alertness levels might hint at the important role melatonin plays in balancing the circadian drive for alertness and the homeostatic drive for sleep (Foster & Krietzman, 2017). However, Foster and Keitzman (2017) caution against assuming a causal relationship between melatonin and sleep-wake timings. They highlight that circadian sleep-wake rhythms were still observed in circumstances where endogenous melatonin was absent, such as in pinealectomy. Nonetheless, as shown by Arendt and Skene (2005), melatonin may be useful in entraining free-running rhythms.

Light and the photic input pathway are important for entraining the internal clocks to set rhythms, and which in turn regulate the behaviours and functioning of an organism (Hughes et al., 2015; Wright et al., 2013). Entrainment is an important process in the synchronization and optimal functioning of the sleep-wake cycle. The importance of light cues from the environment for synchronizing circadian rhythm is highlighted in studies involving completely blind individuals, where the absence of light demonstrated a lack of circadian entrainment manifesting in free-running, non-24-hour circadian rhythms (Sack et al., 2000).

On the other hand, excess or incorrectly timed light can disrupt circadian processes as well; Granados-Fuentes et al. (2004) found that prolonged light exposure caused arrhythmicity in feeding and locomotion activities in rats. In humans, as zeitgebers may differ in strength depending on circumstances and living conditions, entrainment might be a highly individualized and unique experience. As such, factors influencing exposure to light, such as the duration and timing of light exposure and the strength of the light source, are of central importance to the synchronization of the circadian clock (Chellappa et al., 2011), and may explain why sleep-wake cycles in modern times may be very different from preindustrial or rural societies.

1.4.4 Nonphotic entrainment: social and intraindividual traits as zeitgebers

In the preceding sections, light as an important zeitgeber, and the neurobiological pathway through which light entrains the internal circadian system were discussed. Although light is a potent source of entrainment, the mammalian circadian system has been identified to respond to other zeitgebers too (Mistleberger & Skene, 2004). Aschoff et al. (1972) for example, demonstrated the effect of social cues on the entrainment process. In an experiment where participants were in constant darkness condition, regular meal timings and sleep-wake timings appeared to have an entraining effect on the rhythms of temperature and urinary cortisol. Similarly, in another classic experiment, acoustic cues with instructions for sleep start and sleep end were found to be effective synchronizers for temperature (Wever, 1989).

Exercise has been identified as a potential zeitgeber as well. Baehr et al. (2003) demonstrated that exercise before bedtime phase delayed dim-light melatonin onset in both young and older adults. In another experiment, timed exercise in the early and middle parts of the day was shown to phase advance sleep onset (Yamanaka et al., 2010). This appears to be remarkably similar to the phase response of rhythms to timed light exposure discussed in section 1.4.2. Yamanaka et al. (2010), controlled the light exposure of the participants at less than 10 lux, and were able to distinguish the non-photic effects of exercise on entraining rhythms. More recently, Youngstedt et al. (2019) also demonstrated that physical activity in the mornings and afternoons resulted in phase advances while evening activities resulted in phase delays.

There are also suggestions that meal timings could be zeitgebers and some earlier studies have shown that shifts in meal timings or food intake over the course of a 24-hour period may influence metabolites such as leptin (Fogteloo et al., 2004; Schoeller et al, 1997). More recently, periods of fasting, such as during the Ramadan period, have been shown to associate with phase changes in melatonin and cortisol, and in serum levels of leptin, ghrelin and melatonin (Al-Rawi et al., 2020). This suggests a potential effect of meal timings on hormonal secretion and time-of-day effects on metabolites.

While the evidence for the potential effects of non-photic stimuli on the phase response curve, in addition to or independently of light, is emerging, surprisingly little is known of the effect of intraindividual behavioural traits in setting or resetting internal rhythms. A reason for this could be the difficulty in assessing and articulating links between constructs such as self-regulation, time orientation and biomarkers while accounting for confounding variables in the interaction. It has been suggested that the effects non-photic zeitgebers in phase setting of the internal circadian clocks could be through sleep-wake cycles (Elmore et al., 1994; Mistlberger & Skene, 2005).

Work and school start timings, for example, could be zeitgebers by dictating sleep start and sleep end timings on workdays. However, as there is a break from the demands of work and school on work-free days, and sleep-wake timings on workdays are not sustained through the week, it is not clear if work demands could have enough strength to entrain the clocks for phase shifting effects to be observed. This may be further complicated by exposure to light at night and by the use of electronic devices. The difference in sleep-wake timings between work and work-free days, the effect of chronotype on this difference and social jetlag will be discussed in more detail in section 1.6. Here, in the context of non-photic cues on the setting of rhythms and clocks, it may be important to consider the role of intraindividual behavioural traits.

The use of electronic devices, for example, is a risk for exposure to the blue end of the light spectrum which is associated with delayed melatonin secretion and delayed sleep onset (Arendt & Skene, 2005; Chellappa et al., 2011; Cipolla-Neto & do Amaral, 2018; Lunn et al., 2017; West et al., 2010). The use of electronic devices is associated with delayed bedtimes (Chung et al., 2020). The use of electronic devices before bedtime and light at night could in turn be influenced by intraindividual traits as such time orientation and dysfunctional beliefs. There is indication in the current literature that intraindividual traits such as self-regulation is linked to bedtime procrastination (Kroese et al., 2014). Consideration of future consequences of present behaviour has been linked to health behaviours such as exercise, diet and smoking (Adam, 2012; Joireman et al., 2012; Piko and Brassai, 2009). It could be the case that behavioural traits influence sleep-wake timings via poor bedtime decisions which in turn may impact on the setting of the clocks via light exposure.

Based on the discussions above on the importance of light on setting the internal clocks and the photic entrainment process, social cues (occupational demands) and intraindividual traits (self-regulation, time orientations, beliefs) may interact with environmental elements (daylight exposure and light at night) to effect biology (circadian rhythms and homeostasis) that ultimately impact on the setting of the internal rhythms. Both photic and non-photic cues may share a complex relationship in the entrainment of the human circadian system in modern industrialized societies. Light exposure at night in industrialized societies and implications of modern lifestyles on sleep-wake timings is discussed next.

1.5 Impact of industrialization on circadian rhythms and entrainment

Research on the impact of light suggests that exposure to high-intensity short-wavelength light, specifically to the blue end of the light spectrum, could delay melatonin secretion in humans and impinge on the entrainment of the circadian system (Chellappa et al., 2011; Lunn et al., 2017; West et al., 2010). Urban populations work later into the night and sleep later than those in rural areas (Ohida et al., 2001). Indoor electric light in cities facilitates leisure and work activities independent of natural light. The difference in light exposure, such as less natural daylight and more indoor light exposure, between city and rural areas (Roenneberg & Merrow, 2007) could be the key ingredient for the difference observed in rural and urban sleep patterns.

The impact of our daily environment on our sleep-wake behaviours is further illustrated by studies examining circadian adaptation to light exposure (Stothard et al., 2017; Wright et al., 2013). Wright et al. (2013) highlighted that the modern lifestyle of inadequate exposure to sunlight and increased evening light exposure is associated with delayed circadian clocks and sleep times. Further, Stothard et al. (2017) demonstrated that a weekend camping trip and a shift from an urban environment (electric lighting) to a wild environment (natural light-dark cycle) helped to reset the circadian clock to earlier timings. Thus, research supports the high sensitivity and adaptability of human circadian clocks to environmental light cues and the importance of light exposure on sleep-wake timings.

It may be the case that urbanization, societal norms and modern technology-assisted living are possible explanation for some of the sleep issues faced in the industrialized world (Lunn et al., 2017). This hypothesis and the importance of the environment's impact on sleep are illustrated by bioanthropological research on preindustrialized societies. Preindustrialized societies, such as the Hadza clan in Northern Tanzania, the Tsimane in Bolivia and the Toba/Qom societies in the Argentinean Chaco, are hunter-gatherers. These societies subsist primarily (or partly) by hunting and foraging for food without the aid of modern equipment. They live on the outskirts of small towns or in isolated villages (Pontzer 2012; Valeggia et al., 2010). The Hadza men hunt game while women forage plants and their diet consist of mostly fruits, tubers, game meat and honey (Marlowe, 2010). The hunter-gather lifestyles of these societies are similar to that of the Pleistocene ancestors of modern-day humans (Pontzer, 2012), making them an ideal comparison model to study the impact of industrialization on human biology and health.

Additionally, as individuals in these societies are exposed to natural sunlight, experience seasonal temperatures without the use of electricity, and are not subjected to or have reduced exposure to artificial light and heat emitting devices (Yetish et al., 2015), their sleep-wake patterns provide insights into how humans slept before the invention of artificial lights or technological devices. de la Iglesia et al. (2015) worked with one group in Toba/Qom community who had access to electric lights, and another group who relied solely on natural light. They found that the group with access to electric lights had later sleep onset and shorter sleep durations than the group without artificial light. In another study, Yetish et al. (2015) examined the sleep-wake behaviour and light exposure of the Hadza, the Kalahari San and the Tsimane communities. They found the individuals in these societies had strongest light exposure in the morning and lower levels of light at night from natural sources like fire. This study highlighted that the Hadza, the Kalahari and the Tsimane all had lower rates of sleep disorders or sleep disturbances than the rates reported in modern societies.

In the absence of evening light and electronic devices, preindustralized societies and agrarian or rural communities were found to have sleep that is closely synchronized to dawn, the natural dark-light cycles and seasonal variations (Roenneberg et al, 2007; Skeldon et al., 2017). Besides use of artificial sources of light at night and use of light emitting electronic devices, waketime activities have also been highlighted as potential interference to good sleep (Evans et al., 2011). This could perhaps be explained by harvesting and other farming activities which may be natural-light dependent. For example, in a Pennsylvanian Amish community, with little or no contact with electronic devices, and high daytime physical activities levels, sleep-wake timings were earlier (Evans et al., 2011). This is remarkably different to the sleep-wake practices of industrialized societies and provides evidence that daytime social and occupational commitments and availability of leisure activities may influence sleep-wake timings.

Studies on preindustrialized hunter-gatherers and rural communities indicate more robust patterns of sleep-wake behaviours and generally better health outcomes in these communities than in industrialized societies (de la Iglesia et al., 2015; Pontzer 2012; Yetish et al., 2015). The differences in lifestyle (physical activity levels) and environmental influences (light) could be critical factors accounting for the better sleep schedules and absence or lower incidents of sleep disorders observed in preindustrial and rural communities.

Preindustrialized and rural communities primarily engage in work within natural daylight hours, have higher levels of physical exertion required for hunting and farming activities, minimal or no access to electronic devices, and rely on fresh wholefoods. On the other hand, modern-day city lifestyle involves sedentary office work, exposure to evening artificial light and round the clock availability of processed food. Such daytime activities and light exposure may weaken the time cues (zeitgebers) from the environment and may disrupt the process of synchronization between the internal biological rhythms and the external environment.

1.6 Chronotype: variations in entrainment and sleep-wake rhythms

Chronotype refers to the specific entrainment and/or activity-rest preference of an individual in a given 24-hour day (Adan et al., 2012). Depending on the instrument used, the measure may also be denoted as circadian topology or diurnal preference (Tonetti et al., 2013). Chronotype may manifest as actual (pr preferred) sleep-wake timings under idealized conditions (Tonetti et al., 2013). Early risers who are preferentially active in the mornings are said to have a morning chronotype and are often dubbed as larks, and late risers with more nocturnal activities have late chronotypes and are popularly dubbed owls.

Historically, chronotype was first examined in the 1900s, with early conceptions of chronotype as a dichotomous personality trait (Roenneberg et al., 2015). In 1976, the Morningness and Eveningness Questionnaire (MEQ) was published by Horne and Ostberg, which asks participants their preferred sleep and wake time if they had no timed obligations. The MEQ assessed alertness levels upon waking up in the morning. The more recent Munich Chronotype Questionnaire (MCTQ; Roenneberg et al., 2003), on the other hand, assesses chronotype through the actual, rather than the preferred, sleep-wake time of participants (Roenneberg et al., 2015). Both the MEQ and MCTQ produce a continuous measure for assessment of chronotype, reflecting that there is a distribution of chronotype in any given population. Figure 1.8 shows the distribution of chronotypes from the MCTQ database as of 2017.

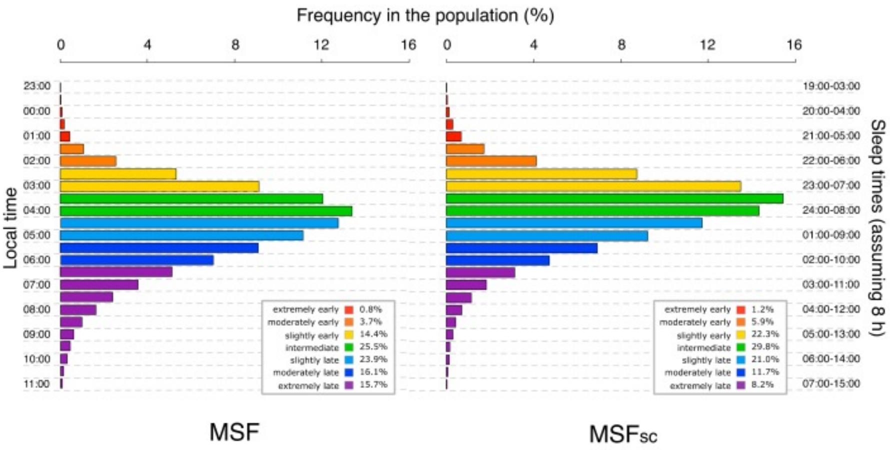


Figure 1.8 Distribution of chronotype
Distributions of midsleep on free days (MSF) (left panel) and midsleep on free days sleep corrected (MSF_{sc}) (right panel) in the Munich ChronoType Questionnaire (MCTQ) database (as of July 2017). Image from, Roenneberg et al., 2019

Although historically chronotype was considered a psychological trait, with increasing knowledge of the temporal nature of the biological organization of internal rhythms, Roenneberg and his team proposed conceptualizing chronotype as a biological construct (Roenneberg et al., 2019). As a physiological process, chronotype can be understood as an entrained circadian cycle, with early chronotypes showing an earlier phase of entrainment and late chronotypes showing a delayed phase. Although the entrainment phase may be difficult to directly measure due to the complexity of the entrainment process, the biological (such as plasma melatonin) and behavioural outputs (such as sleep-wake timings) that are determined by the entrainment process may be useful indicators and measurements of chronotype (Roenneberg et al., 2019).

Chronotype is assessed via sleep-wake timings reported in the MCTQ. Sleep timings are reported separately for workdays and work-free days. This feature of the MCTQ distinguishes between sleep-wake behaviours on workdays when sleep is dictated by alarm clocks and sleep timings on work-free days when sleep is unconstrained by social obligations. Sleep-wake timings on work-free days, specifically midsleep timings on work-free day (midpoint of sleep duration on a given night), is used as an indicator of the true phase of circadian entrainment for sleep-wake. On work-free days, the circadian system might not be under pressure to adapt to social timings (Roenneberg et al, 2019). On workdays, on the other hand, internal rhythms are forced to adapt to the timings imposed by occupational obligations.

Individuals with late sleep-wake timings, known as late chronotypes, struggle to sleep earlier on workdays to compensate for having to wake up earlier to go to work the next day. This may result in sleep loss on workdays. Roenneberg and team found the compensation strategy for most people is to sleep in on work-free days rather than go to bed earlier on workdays. They proposed applying a sleep correction to the midsleep timings on work-free days to account for the confounding effects of workday sleep loss (Roenneberg et al., 2007).

The wide variation in distribution of chronotype in any given population may be due to several factors such as genetics and variations in entrainment as discussed in the previous sections. As discussed previously, sleep-wake behaviours have evolved remarkably from preindustrial and rural/ agrarian populations, as a result of light exposure and other factors specific to modern industrialized lifestyle. Studies show chronotypes are earlier in rural societies (Carvalho et al., 2014). Current distribution of chronotypes can thus be seen as manifestations of the adaption to modern lifestyles and zeitgeber strength.

This was illustrated in the studies cited earlier (Stothard et al., 2017; Wright et al., 2013) which showed that moving away from an urban environment into a wild environment advanced the clock, resulting in earlier sleep-wake timings. A recent experimental study (Facer-Childs et al., 2019) followed a clinical trial protocol with an experimental and control group to test out an intervention to advance sleep timings. A group of participants were instructed to keep to regular sleep-wake timings on work and work-free days (with no more than 15-30 minutes variations), limit light exposure at night and have meals at regular times every day for three weeks (intervention group). The results of this study showed that late chronotypes could advance their clocks by 2 hours when they were exposed, and entrained, to regular zeitgebers such as light, food intake and sleep timings. These remarkable observations illustrate how adaptable the internal circadian systems are to the external environment.

1.6.1 Social jetlag

Social jetlag, a sleep phenomenon first observed and named by Roenneberg and his team in 2006, (Wittman et al; 2006) is the result of an internal circadian clock that is misaligned with socially imposed timings. Social jetlag manifests as a desynchrony between internal biological time and external time. While analyzing the sleep-wake timings on work and work-free days on the MCTQ, Roenneberg and his team observed the participants were displaying an effect similar to travel jetlag.

When traveling to another country or a different time zone, the internal rhythms need time to adjust to the new light-dark cycle and is out of sync with the new external environment’s cues. It usually takes a day for each time zone crossed for the internal organs to adapt (Roenneberg et al., 2019). The body’s internal physiology and behavioural outputs such as sleep and meal timings may be timed to the departure time zone rather than the destination time zone. This effect is known as jetlag, aptly named as it is a condition precipitated by jet travel.

The sleep-wake timings of the participants in the MCTQ database resembled traveling to a different time zone over work-free days and returning on workdays (Roenneberg et al., 2007; Roenneberg et al., 2019; Wittman et al., 2006). While jetlag is transitory (the internal rhythms catch up with the external environmental rhythms and stabilize), social jetlag is chronic (Korman et al, 2020) and the constant changes in sleep-wake timings across work and work-free days make it hard for the circadian clock to adapt, synchronize and stabilize. In social jetlag, the circadian clock is in a state of constant flux moving back and forth between work and work-free days sleep-wake timings.

As mentioned in previous sections, altered zeitgebers and strength of the zeitgebers in modern society has precipitated changes to the entrainment process and delayed sleep-wake cycles. Although sleep might have shifted considerably later in modern societies, school and work timings are earlier in the day requiring an early wake-up timing. This has created a situation where the preferred sleep-wake timings or the biological propensity for sleep is at odds with sleep timings that are required by occupational demands.

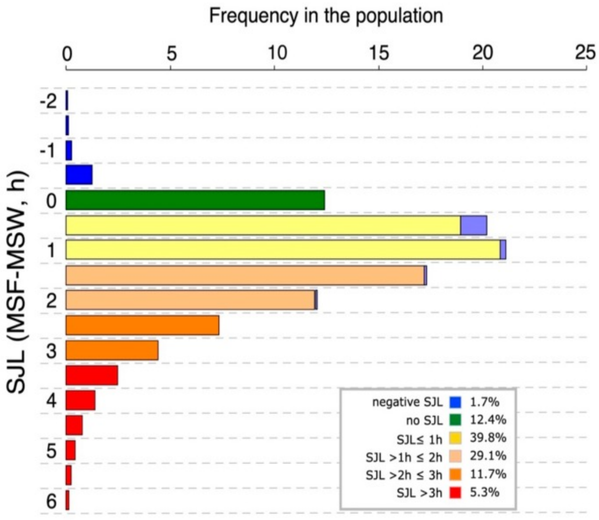


Figure 1.9 Distribution of social jetlag
Distributions of social jetlag (SJL) in the MCTQ database (as of July 2017). The distribution graphs shows that nearly 88% (of about 300,000) of the participants presented with social jetlag, indicating how widespread it is in industrialized societies. Only 12% reported no social jetlag. A smaller percentage (<2%) presented with negative social jetlag, with about 40% presenting with 1-3hours of social jetlag. Image from Roenneberg et al., 2019.

1.6.2 Social jetlag and midsleep timings

Figure 1.9 (Roenneberg et al., 2019) shows the distribution of social jetlag in the MCTQ database. Colour coded legend shows the percentage of the participants who presented with or without social jetlag. Early chronotypes may also present with social jetlag when forced to stay up later on weekends for evening social obligations. They may be unable to sleep in due to their biological propensity for waking early (Foster & Kreitzman 2017; Roenneberg et al., 2007; Roenneberg et al., 2019) which pushes their midsleep timings on work-free days to be earlier than midsleep timings on workdays resulting in a negative social jetlag value.

On the distribution graph, the early chronotypes' social jetlag is represented as dark blue bars. To represent the distribution as the absolute values of social jetlag in the population, Roenneberg et al., 2019, presented negative social jetlag as an extension (light blue) of the respective social jetlag groups. The distribution graph shows that nearly 88% (of about 300,000) of the participants presented with social jetlag, indicating how widespread it is in industrialized societies. Only 12% reported no social jetlag. A smaller percentage (<2%) presented with negative social jetlag, with about 40% presenting with 1-3hours of social jetlag.

Social jetlag is calculated as the difference between work and work-free day midsleep timings (Wittman et al., 2006). Midsleep is the midpoint of sleep duration for a given night. For example, if work-free day sleep onset time is 24:00 with a sleep duration of 8 hours (sleep offset is at 08:00), the midpoint of sleep is 04:00. On a workday if the sleep onset is 24:00 with a sleep duration of 7 hours (sleep offset is at 07:00), the midpoint of sleep is 03:30. The resulting difference of 30 minutes (04:00-03:30) is social jetlag. In the above example, sleep onset was kept constant for a simple illustration. Figure 1.10 (Roenneberg et al., 2019) below shows a situation where sleep duration (as a result of irregular sleep onset and offset) is varied on both work and work-free days, as may be expected in the real world.

Social jetlag is generally associated with late chronotypes (Roenneberg et al., 2019; Wittman et al., 2006). Referring back to figure 1.10, the green dots of late chronotypes tend to be further away from the red dots. Late chronotype, with a late onset of sleep may find it difficult to fall asleep earlier on workdays to compensate for waking up earlier for work obligations (Wittman et al., 2006). As the wake propensity tends to be later than required for work, an alarm clock is often required for forced waking. The alarm clock interferes with the full sleep cycle, forcing the body to wake up when it is not ready to be awake, resulting in incomplete sleep (Foster & Kreitzman, 2017; Roenneberg et al., 2019). This consequently results in sleep loss.

To make-up for the sleep debt, late chronotypes do not go to bed earlier but compensate by sleeping in later on work-free day (Roenneberg et al., 2019), increasing sleep duration on work-free day and pushing the green dot further away from the red dot. The later the chronotype and the wider the gap between workday and work-free days sleep-wake timings, the higher the social jetlag.

Work and school start time and family responsibilities may account for daily variations in sleep onset and offset timings. Even on work-free days, family or other social obligations may place demands on sleep. As mentioned earlier, sleep-wake timings on work-free days are used as the phase of entrainment as it believed to reflect true sleep behaviour free from the pressures of occupational demands. For this purpose, participants who use an alarm clock for waking up on work-free days are excluded from the assessment of social jetlag, as their phase of entrainment cannot be accurately assessed.

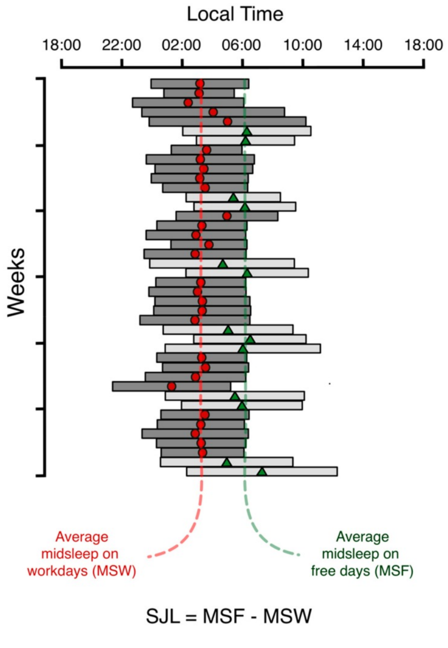


Figure 1.10 Gap in workday and work-free day midsleep timings
In late chronotypes, who accumulate sleep debt during workdays, the midsleep timings on work-free days (green dots and light grey bars) are generally later than midsleep on workdays (red dots and dark grey bars). This results in social jetlag. The later the chronotype or wider the gap between the green and red dots, the higher the social jetlag. Image from Roenneberg et al., 2019.

1.6.3 Developmental and sex-based variations in social jetlag and chronotype

As social jetlag is a consequent of chronotype, factors influencing chronotype may be significant factors impacting social jetlag too. As mentioned in section 1.4, adaptation to light-dark cycles is a significant factor determining phase of entrainment. Additionally, age and sex are factors accounting for variations observed in chronotype, and by extension in social jetlag.

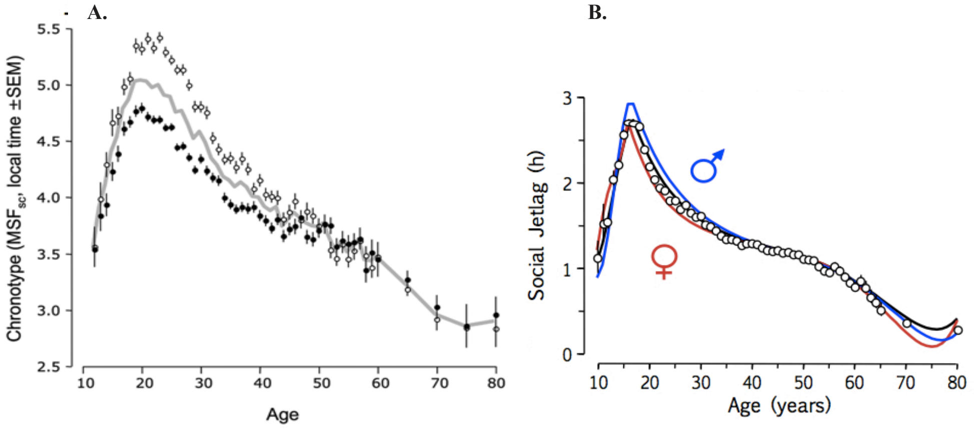


Figure 1.11 Social jetlag and chronotype by age and sex
Both images show the developmental course of chronotype and social jetlag. **A.** Teens and young adulthood is associated with later chronotype, with earlier timings associated with older adults. Men (open circles) generally have later chronotypes than women (closed circles) **B.** Similarly, social jetlag is generally higher in the younger ages and in males (blue). Images from Roenneberg and Merrow, 2007 and Roenneberg et al., 2012 respectively.

Chronotype is reported to follow a marked developmental time course across the life span, with teens and young adulthood associated with late chronotype (Borisenkov et al., 2010; Carskadon, 2011). Chronotype peaks in the early 20s (see grey line representing average chronotype for the entire population on Figure 1.11A; image from Roenneberg & Merrow, 2007) and moves toward early chronotype with increasing age. Additionally, there are gender-based variations in chronotype, with men (black circles on Figure 1.11A) generally having later chronotypes than women, most markedly during adolescence (Fischer et al., 2017). Similarly, social jetlag follows a developmental trajectory (figure 1.11B; image from Roenneberg et al., 2012), with social jetlag highest in the younger age groups, peaking in early adulthood and declining with age. Most notably, older adults present with lower social jetlag, possibly because of lower occupational demands than younger adults.

1.6.4 Adverse health outcomes associated with chronotype and social jetlag

Adverse health outcomes are associated with chronotype and social jetlag. This section presents a brief overview of the most recent studies that investigated the associations between social jetlag, chronotype, circadian misalignment and health or behavioural outcomes.

Sleep-wake alterations are commonly reported in neurological disorders (Malhotra, 2018). Specifically, circadian dysregulation is associated with Alzheimer's disease (Ju et al., 2014). Neurobiological evidence suggests that SCN dysfunction with implications on melatonin expression, and sensitivity to light for entrainment could be the link for disordered sleep in Alzheimer's disease (Van Erum et al., 2018). A study investigating melatonin expression in Alzheimer's patients found that dim-light melatonin onset (delayed by 55 minutes) and melatonin secretion were significantly delayed in patients with Alzheimer's disease compared to healthy controls (Manni et al., 2019). This study however did not find any significant difference in chronotype or sleep duration between healthy controls and patients.

Shorter sleep duration has been associated with an increased risk for Alzheimer's disease (Andrews et al., 2021). Interestingly, having an early chronotype has been linked to an increased risk for Alzheimer's disease (Cullel et al., 2021; Huang et al., 2020). Another study however did not report a causal link between sleep traits and risk for Alzheimer's disease (Anderson et al., 2021). In contrast to the effect of chronotype for Alzheimer's risk, Cullel et al (2021) found that late chronotype was associated with an early onset of Parkinson's disease and suggested early chronotypes may have protective effect against early onset of the disease.

Patients with epilepsy were found to have significantly higher social jetlag than healthy controls, and patients with general epilepsy presented with late chronotype and higher social jetlag than patients with focal epilepsy (Choi et al., 2016). However, another study found that patients with focal epilepsy more often identified as early chronotypes compared to healthy controls, although the circadian phase measured via dim-light melatonin onset indicated an intermediate chronotype with no significant difference when compared to healthy controls (Manni et al., 2015).The authors of that study speculate that the lifestyle choice induced by the disease such as having a regular sleep schedule and early bedtime may have influenced patients to lean towards early chronotypes and to identify as early types (Manni et al., 2015).

In a large prospective study, healthy sleep (defined as early chronotype, sleep duration of between 7-8 hours, no insomnia symptoms, no snoring and no daytime sleepiness) associated with reduced risks for coronary heart diseases and stroke (Fan et al., 2020). Wong et al., 2015 found late chronotype and social jetlag associated with lower high-density lipoprotein cholesterol (HDL) levels. This study was with an older sample and only a small percentage of participants presented as late chronotypes and had a mean social jetlag of 44 minutes. The authors caution that the result may be an underestimation of the true cardiometabolic risk in the general population. However, the effects of chronotype and social jetlag persisted even after they adjusted for participant health behaviours such as smoking and physical activity, suggesting a significant result.

Heart rate variability or the time interval between successive heartbeats is an indicator of cardiovascular control, with low heart rate variability indicating higher risk for cardiovascular diseases. In a recent study, Sudy et al. (2019) demonstrated that social jetlag affected heart rate variability during sleep. Most significantly, lower heart rate variability function was more pronounced during the first few hours of sleep on workdays than on work-free days in participants with higher social jetlag. Participants with lower social jetlag did not display differences in heart rate variability between work and work-free days. This study highlights that sleep variability between work and work-free days is a significant risk for dysfunction in autonomic regulations associated with cardiovascular diseases.

The association between blood pressure and social jetlag and chronotype is somewhat varied. In the Wong et al. (2015) study cited above, neither chronotype nor social jetlag were associated with blood pressure. Makarem et al. (2020) found better sleep regularity was associated with lower odds of hypertension but social jetlag itself did not present significant associations with blood pressure measures. Hausler et al., (2020) reported no significant associations between hypertension and sleep duration variability.

Another study found extreme chronotypes (either morning or late) were associated with higher odds of hypertension, and odds for hypertension increased with increasing sleep variability (Johnson et al., 2020). The Johnson et al. (2020) study was with older participants (average age 63 years old) and 85% of them had hypertension. Another study did not find an association between chronotype and hypertension (Sansom et al., 2021). This study however did find an interesting combined effect of chronotype and obstructive sleep apnoea; amongst those with sleep apnoea, early chronotypes compared to late chronotypes were more likely to be at higher risk for hypertension.

Research has shown varied relationships between obesity and social jetlag. Studies have found an association between body mass index, an indicator for obesity, and social jetlag in children as young as 8-11 years old (Higgins et al., 2021; Stoner et al., 2018). However, another study on adolescents did not observe similar associations (de Zwart et al., 2018). In adults, McMahon et al. (2019) showed that early chronotypes with less than 6 hours of sleep duration were more likely to have higher body fat ratio and waist to hip ratio than intermediate type chronotype.

Both social jetlag and chronotype have been associated with glycaemic control (HbA1c) and diabetes. Recently, Kelly et al. (2022) reported that patients with type 2 diabetes reported higher social jetlag than healthy controls but reported no differences in sleep timing variability between the two groups. In the same study, they reported that sleep timing variability was inversely correlated with HbA1c. In another study, Kelly et al. (2020) reported that late chronotype was associated with HbA1c but only in patients with more than 90 minutes of social jetlag. Rusu et al. (2019), further showed that patients with type 1 diabetes who had social jetlag of more than 1 hour presented with significantly higher HbA1c levels.

A recent review of mental health and social jetlag in adolescents and young adults found an association between clinical depression and social jetlag (Henderson et al., 2019). Tamura et al., (2021) showed that social jetlag of more than 1 hour was associated with risk for irritable mood in adolescents. In adults who were non-shift workers, more than 1 hour of social jetlag was associated with higher depression symptoms (Islam et al., 2020). In one study using a clinical sample, patients with major depression did not report higher social jetlag than controls even when medication use was accounted for (Knapen et al., 2018).

Similarly, chronotype has been associated with mood and depression. A sex-wise analysis in one study showed that late chronotype was associated with an increased risk for depression but only in men (Kim et al., 2020). A further within-sex analysis revealed that women with late chronotype presented with a higher risk for depression than women who were intermediate or early chronotype. In a non-clinical sample examining the relationship between personality traits, mood, anxiety symptoms and chronotype, late chronotype was associated with depression and psychopathy (Akram et al., 2019). The authors suggest that the link between late chronotype and psychopathic traits may be due to late chronotypes' struggles with emotional regulation.

Social jetlag and chronotype have also been associated with substance use and behavioural outcomes. For example, Taylor et al., 2020 assessed the effect of chronotype on alcohol use in a sample of undergraduate students. They reported late chronotypes presented with significantly more symptoms meeting the criteria for a substance use disorder. Haynie et al., 2018 used a cross-lagged analysis to examine the bidirectional association between alcohol use and sleep duration and sleep timings in adolescents. They found that social jetlag predicted alcohol use, and alcohol use predicted subsequent short sleep duration and late chronotype. This study highlights longitudinal predictive impact that chronotype and social jetlag may have on behaviours.

Evidence from the above studies suggest links between chronotype, social jetlag and major non-communicable diseases and disorders. Circadian misalignment and desynchronized internal rhythms may have deleterious effects on biomarkers associated with these diseases. Surprisingly, a recent Lancet review (Yusuf et al., 2020) of modifiable risk factors for cardiovascular diseases across several countries did not include sleep parameters as potential risk factors. It may be the case that the role of sleep variability and social jetlag is still not apparent or widely recognized. The effect of chronotype and social jetlag on health and behavioural outcomes may be varied, but current evidence suggests unequivocal links that imply the importance of transdiagnostic assessments and treatment of circadian misalignment in major diseases and disorders.

1.7 Current research overview and objectives

The evidence from the current literature on social jetlag thus far suggests that the synchrony between the internal and external clocks and the harmonious functioning of the circadian cycle of sleep-wake is dependent upon a number of risk factors. Biological, demographic, environmental and health factors may present as risk factors for social jetlag. Refer to figure 1.12. Black arrows represent the entrainment pathway of internal rhythms in humans, synchronized with the daily natural light-dark cycles. Interaction between entrained circadian processes and homeostasis determine behavioural outputs such as sleeping and feeding. Dashed blue arrows on the figure represent factors that interrupt this process.

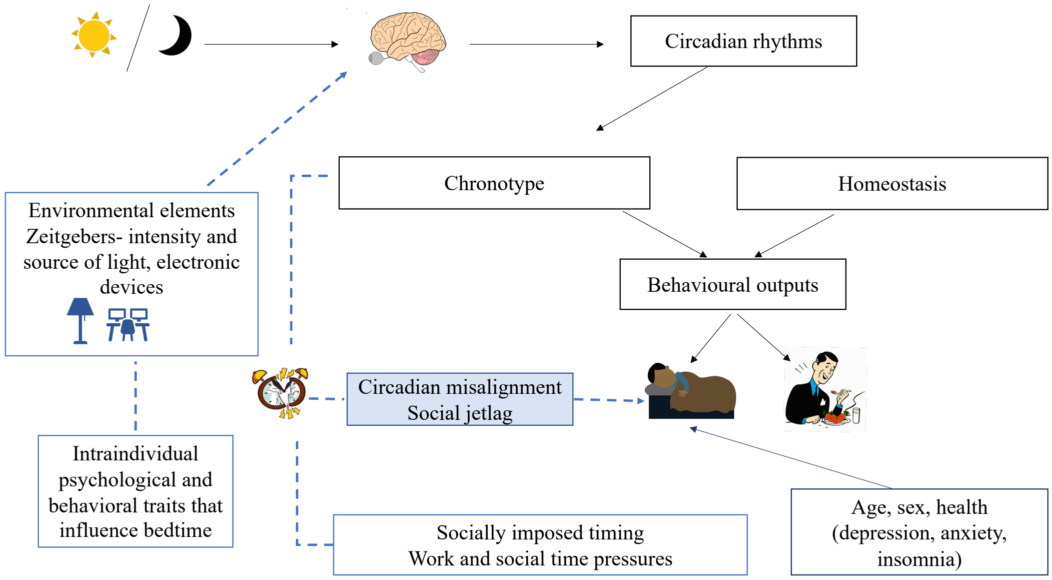


Figure 1.12 Societal and intraindividual behavioural determinants of sleep-wake timings, circadian misalignment and social jetlag
Black arrows represent the photic entrainment pathway in humans, and the interaction between homeostasis and circadian processes determining behavioural outputs such as sleeping and eating. Dashed blue arrows represent factors that interrupt this process. Social cues (work obligations) and intraindividual traits (bedtime behaviours) may interact with environmental elements (light exposure) to effect biology (circadian rhythms and homeostasis) that ultimately impact on the entrainment of the internal rhythms and sleep-wake cycle. Both photic and non-photic cues may share a complex relationship in the entrainment of the human circadian system in modern industrialized societies.

One of the primary objectives of this research was to examine the effects of socially imposed timings and intraindividual traits on sleep-wake timings and the subsequent impact on social jetlag. Under normal circumstances, i.e., prepandemic times, sleep-wake timings on workdays were dictated by socially imposed work or school start times. There may have been limited opportunities for flexibility in choosing sleep end timings on workdays. The manipulation of time twice a year, from standard time to daylight saving time and back to standard time, is another socially imposed timing. A second primary objective of this research is to describe the relationship between chronotype and social jetlag during the pandemic. The current research further aimed to describe the association between demographic factors, mental health and social jetlag.

1.7.1 Summary of chapters

Chapter 2 explores social jetlag's association with sleep quality. Sleep quality is an important construct most often studied in sleep research. In this research, specifically, the relationship between social jetlag, chronotype and sleep quality is examined in a mediation model.

Chapter 3 explores the preferences for the biannual clock changes in Ireland, and the preferences for standard time or daylights savings time should clock changes be abolished. This study aimed to understand the chronobiological underpinnings, if any, of such preferences. For example, individuals with late chronotypes may prefer longer daylight in the evenings for outdoor leisure activities. The study thus hypothesized that later chronotype and higher social jetlag may associate with a preference for daylight saving time.

In chapter 4, the changes to sleep-wake timings in Ireland during the pandemic are described. The COVID-19 pandemic, and the social and travel restrictions imposed to mitigate the spread of the virus, created a natural experiment to study the impact of workday pressures on sleep-wake behaviours. The premise for this study was that sleep-wake timings on workdays may become later under the work-from-home orders as a result of a flexible self-determined work start time and/or as a result of absent commute time to a physical office space. In Ireland, workers designated as essential workers, such as those working in public transportation, health services, and grocery stores, were required to continue to attend their usual place of work while everyone else switched to working from home. The study was thus able to assess the impact of work status, work-from home and essential workers, on sleep-wake timings. A survey intended for the clock change study was due for implementation at the end of March 2020 when the clocks switched to daylight saving time. The social and travel restrictions were imposed in Ireland at around the same time. The initial survey was then extended to include a cross-sectional assessment of sleep-wake timings before (retrospective reporting) and during the pandemic.

In chapter 5, using reference samples obtained before the pandemic, the relationship between social jetlag and chronotype before the pandemic and the changes in the relationship during the pandemic are described. Social jetlag shares a close relationship with chronotype, age and sex. In this research, the impact of other factors on social jetlag is also explored. Factors such as working hours, caregiver responsibilities and urban/rural locations are explored. The association between social jetlag, insomnia and mental health distress is also explored.

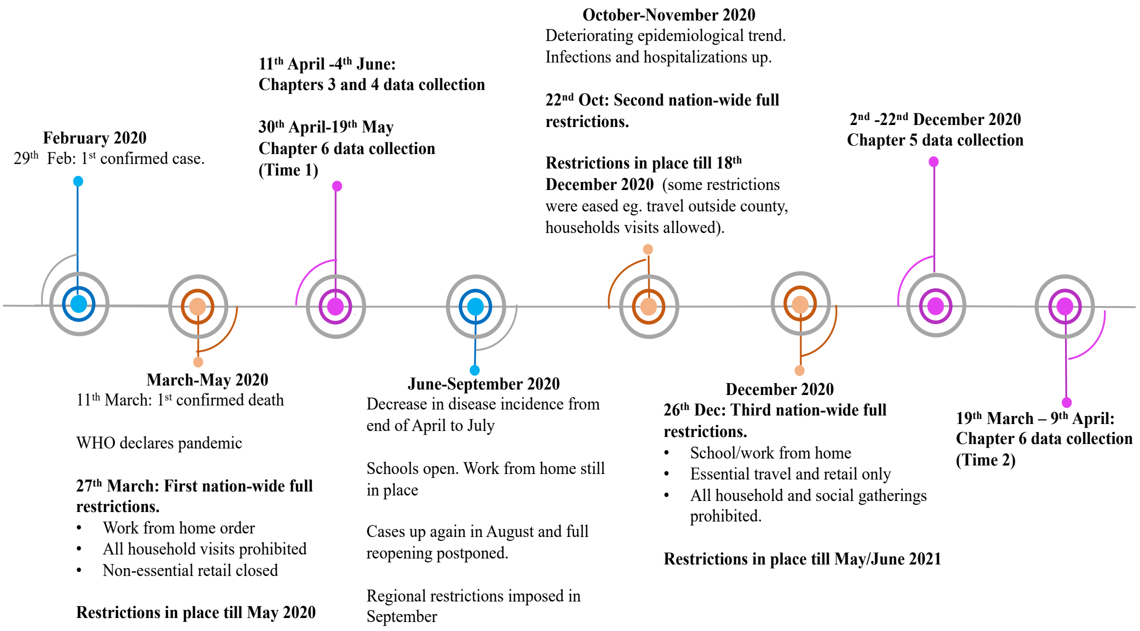
Chapter 6 further explores the relationship between sleep and mental health discussed in chapter 5. This chapter discusses the longitudinal effects that insomnia symptoms and depression symptom have on themselves and on each other at two points during the pandemic. Furthermore, the effect of COVID-19 specific anxiety on this relationship is also explored.

Chapter 7 explores the associations between intraindividual behavioural traits and social jetlag. The traits included in this study are temporal discounting and consideration of future consequences and dysfunctional beliefs. These traits were selected as prior studies indicate links between these traits in other health behaviours. In terms of sleep-wake behaviours, it may be the case that present time orientation and discounting of future consequences result in behaviours that trigger a cycle of delayed bedtime, late chronotypes and social jetlag. The study hypothesized that present time orientation, discounting of future rewards and more dysfunctional beliefs about sleep would associate with late chronotype and higher social jetlag.

1.7.2 The COVID-19 pandemic and data collection

It must be noted that the majority of the data presented in this research were collected during the pandemic. Chapters 3, 4, 5 and 6 refer to data collected between April 2020 and April 2021. The social and travel restrictions imposed to mitigate the spread of the virus has had unprecedented effect on mobility and social interactions around the world. The data presented here need to be viewed in the context of this unique circumstance. Figure 1.13 is a timeline of the start of the pandemic related restrictions in Ireland and highlights some of the restrictions imposed and the duration of each round of restrictions.

Figure 1.13 Timeline of the COVID-19 pandemic and restrictions in Ireland from February 2020 through to April 2021



February 2020
29th Feb: 1st confirmed case.

March-May 2020
11th March: 1st confirmed death

WHO declares pandemic

27th March: First nation-wide full restrictions.
- Work from home order
- All household visits prohibited
- Non-essential retail closed

Restrictions in place till May 2020

11th April -4th June:
Chapters 3 and 4 data collection

30th April-19th May
Chapter 6 data collection
(Time 1)

June-September 2020
Decrease in disease incidence from end of April to July

Schools open. Work from home still in place

Cases up again in August and full reopening postponed.

Regional restrictions imposed in September

October-November 2020
Deteriorating epidemiological trend.
Infections and hospitalizations up.

22nd Oct: Second nation-wide full restrictions.

Restrictions in place till 18th December 2020 (some restrictions were eased eg. travel outside county, households visits allowed).

December 2020
26th Dec: Third nation-wide full restrictions.
- School/work from home
- Essential travel and retail only
- All household and social gatherings prohibited.

Restrictions in place till May/June 2021

2nd -22nd December 2020
Chapter 5 data collection

19th March – 9th April:
Chapter 6 data collection
(Time 2)

Chapter 2

Examining the associations between social jetlag, midsleep timings and sleep quality.

This chapter has been published as:

Raman, S., & Coogan, A. N. (2020). A cross-sectional study of the associations between chronotype, social jetlag and subjective sleep quality in healthy adults. *Clocks & Sleep*, *2*(1), 1-6. https://doi.org/10.3390/clockssleep2010001

Abstract

Social jetlag and late midsleep timing on work-free day (chronotype) may be factors associated with poor quality sleep. This study examined the association of social jetlag and chronotype with subjective sleep quality ratings in a healthy young adult cohort and interrogated the moderating effects of sex and age on these associations. Additionally, the association between midsleep timings on workdays and sleep quality was examined as well. A total of 1322 participants aged 18 to 40 completed the Pittsburgh Sleep Quality Index (PSQI) and the Munich Chronotype Questionnaire. Late chronotype had a moderate (rho = 0.212, $p < 0.001$) association with poor subjective sleep quality for both females and males and across all age groups. Social jetlag's association with poor sleep quality was observed only in younger males. Higher social jetlag had a weak association with poor subjective sleep quality ratings (rho = 0.077) and this effect was moderated by sex with there being a relationship between social jetlag and sleep quality only in males. Midsleep workday had a weak association with social jetlag (rho = -0.098, p =0.007) and sleep quality (rho = 0.180, $p < 0.001$), for both females and males and across all age groups. Although social jetlag demonstrated a strong correlation to midsleep timings, it did not mediate the association between late chronotype and poor sleep quality. Other traits and states commonly associated with late chronotypes and poor sleep quality, such as depression and anxiety, may mediate the chronotype-sleep quality relationship. These results indicate differential relationships of chronotype and social jetlag with sleep quality and indicate that sex may be a moderating factor for sleep quality's relationship with social jetlag.

2.1 Introduction

In sleep research, much attention is paid to the constructs of sleep duration and sleep quality. Good quality sleep is indicated by factors such as short sleep latency, greater sleep efficiency and fewer awakenings after sleep onset (Ohayon et al., 2017). Sleep is fundamentally a biological process driven by homeostatic and circadian processes (Borbély et al., 2016); these biological drivers of sleep are, however, subject to extrinsic societal forces, and as such, understanding how homeostatic and circadian processes influence sleep quality directly and interact with social factors will increase understanding of the determinants of sleep quality (Pilz et al., 2018).

Chronotype (midsleep timings on work-free days) may refer to the preferred timing of sleep-wake behaviours (Adan et al., 2012), and individuals with evening preference/late sleep-wake timings may experience impaired sleep quality (Núñez et al., 2019; Przepiórka et al., 2019). Similarly, social jetlag, the manifestation of differences in sleep-wake timings on work and work-free days arising as a conflict between social schedules and the internal circadian clock (Roenneberg et al., 2019), may also be associated with impaired sleep quality (Sűdy et al., 2019). Furthermore, midsleep on work-free day is influenced by sex and changes through the lifespan (being male, and an adolescent or young adult, are associated with later midsleep timings (Roenneberg & Merrow, 2007).

Greater social jetlag is most common with later midsleep timings (Roenneberg et al., 2019), and therefore, by extension, may be influenced by age and sex as being males and in the age range of the late teens to early twenties is associated with both greatest social jetlag and later midsleep timing (Roenneberg et al., 2019). Subjective sleep quality on the other hand decreases with increasing age (Gadie et al., 2017).

This study aimed to better understand the relationship of higher social jetlag and later midsleep timings with poor sleep quality, hypothesizing that higher social jetlag and later midsleep timing will associate with poorer sleep, and that this association will be influenced by age and sex.

2.2 Methods

2.2.1 Recruitment and data collection

This study was a secondary analysis of data collected, between September and December from 2012–2017, as part of final year undergraduate research projects investigating sleep in a young adult sample. 1322 participants aged between 18-40 (male = 39%; 18–25 years old = 84%; mean age = 22.66) and residing in Ireland had complete responses on the sleep timing and sleep quality measures. Participants were either students of Maynooth University or were acquaintances of students of Maynooth University. Ethics approval was from the Maynooth University Research Ethics Committee. Recruitment was by convenience sampling via flyers, emails or personal contacts. Respondents were non-shift workers and did not report any significant health issues. All participants completed the questionnaires in pen and paper form.

2.2.2 Measures

Subjective sleep quality was assessed using the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989). The total score was used as a continuous score with a cut-off score of more than five indicating poor sleep quality, and this was used to form good and poor sleep groups. The Munich Chronotype Questionnaire (MCTQ) was used to assess sleep-wake timings. The key output from the MCTQ is the time of midsleep (halfway between sleep onset and offset) on work (MSW) and work-free days (MSF). As per standard protocol for calculating midsleep values for work-free days, a sleep correction was applied to work-free day midsleep timings (MSFsc) for participants who had longer sleep duration on work-free days; these participants slept longer on work-free days to compensate for sleep debt accumulated over the week, which was adjusted for to obtain their most reliable work-free day midsleep timing as accurately as possible ((MSFsc=MSF– (SDf-SDweek)/2); Roenneberg & Merrow, 2007). Social jetlag was calculated as the absolute difference between MSW and MSF (Wittman et al., 2006). As mentioned above, this study was a secondary data analysis. Only participants with scorable social jetlag and MSFsc were included in the final analysis.

In preliminary correlational analyses, neither social jetlag nor midsleep timings correlated with average weekly sleep duration (rho = −0.074, p = 0.052 and rho = −0.034, p = 0.32 repetitively), and inclusion of average sleep duration as a covariate did not alter the relationships between social jetlag/midsleep and PSQI scores. Thus, sleep duration was not included as a variable of interest in this investigation.

2.2.3 Statistical analyses

Statistical analyses were conducted using SPSS. The SPSS PROCESS macro (version 3.3 (Hayes, 2018) was used to perform simple moderation analyses (model 1) with midsleep timings and social jetlag (continuous measures) as independent variables, and for mediation analysis (with social jetlag as the mediator between midsleep timings and PSQI, PROCESS model 4). Age was treated as a continuous variable and also dichotomized to produce a categorical variable for ANOVAs. Collinearity between midsleep timings, social jetlag and PSQI was inspected using VIF values which revealed no significant multi-collinearity (VIF values of 1.4, 1.3 and 1.1 respectively). $p < 0.05$ was taken as indicating a statistically significant effect for non-parametric correlations, and $p < 0.01$ for ANOVAs to account for the non-normal distributions of social jetlag and PSQI. Effect sizes were calculated as partial ETA squared values and interpreted according to Cohen (1988).

2.3 Results

The distribution of midsleep, social jetlag and PSQI scores, by age group and sex, is shown in Figure 2.1 (A, B) and Figure 2.2 (midsleep timings on workdays), and descriptive statistics are presented in Table 2.1. 39.5% were males (mean age of total sample was 22.66 (SD=5.26)) and there was no difference in mean age between the females and males (22.2 (SD=4.6) and 22.9 (SD=4.8) respectively). 41.4% of the participants were students aged 20 years old or younger. Mean social jetlag was 1hr 40m (SE=1.05), midsleep timings on work-free days was 05:13 (SE=1.41) and midsleep timings on workdays was 04:11(SE=0.04). Mean sleep quality rating was 6.98 (SE=2.95), with 77% of participants rating their sleep as poor.

N=1322 (Mean age =22.66 (SD=5.26)	
Age groups	
≤ 20 years old	41.4%
≥ 21 years old	58.6%
Sex	
Females	60.6%; Mean age =22.2 (SD=4.6)
Males	39.4%; Mean age= 22.9 (SD=4.8)
Social jetlag	1hr 40m (SE=1.05)
Midsleep work-free day (hh:mm)	05:13 (SE=1.41)
Midsleep workday (hh:mm)	04:11 (SE=0.04)
Sleep quality (PSQI total score)	6.98(SE=2.95)
Good sleep	23.1%
Poor sleep	76.9%

Table 2.1 Descriptive statistics of the study cohort.
Sample was predominately females. There was no difference in mean age between the females and males. A score of >5 on the PSQI indicates poor sleep, with the mean for this sample above this cut-off.

For the factorial ANOVA analysis age was dichotomized as 20 years or younger and 21 years or older, operationalized as such as there is an inflection point for late midsleep timings (chronotype) in the early 20s (Fischer et al., 2017; Roenneberg et al., 2004). The analysis revealed significant effects of age (Figure 2.1C, p< 0.001, partial ETA^2= 0.021) and sex (p< 0.001, partial ETA^2 = 0.032) on midsleep timings on work-free days, but no interaction between sex and age group (p= 0.92). Likewise, there were effects of age (p < 0.001, partial ETA^2= 0.005) and sex (p< 0.001, partial ETA^2= 0.014) on social jetlag, but no sex and age group interaction (p = 0.76). There was an effect of sex (p< 0.001, partial ETA^2= 0.011) and a marginal effect of age (p = 0.042) on sleep quality (PSQI) scores, but with no age and sex interaction (p= 0.863). Finally, there were significant effects of age (Figure 2.2, p=0.02, partial ETA^2= 0.007) and sex (p< 0.001, partial ETA^2 = 0.017) on midsleep timings on workdays, but no interaction between sex and age group (p= 0.229).

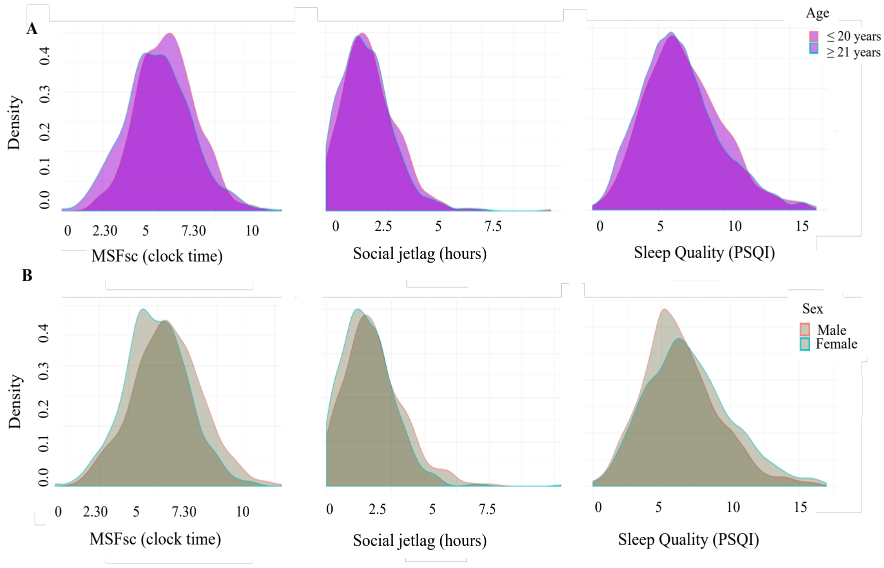


Figure 2.1A-B Density plots for chronotype, social jetlag and sleep quality

Density plots showing the distribution of midsleep timings on work-free days (chronotype), social jetlag and sleep quality (PSQI scores) in **(A)** participants 20 years old or younger, and those of 21 years or older and **(B)** males and females.

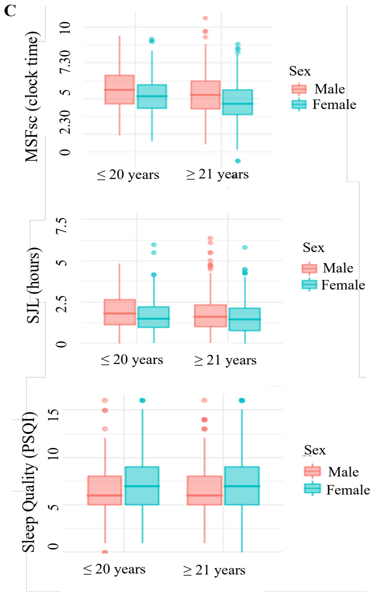


Figure 2.1C. Effects of sex and age on chronotype, social jetlag and sleep quality

Box plots showing the main effects of sex and age on midsleep timings on work-free days (chronotype) and social jetlag, and sex on sleep quality (PSQI), but no age group and sex interactions effects on midsleep, social jetlag or sleep quality.

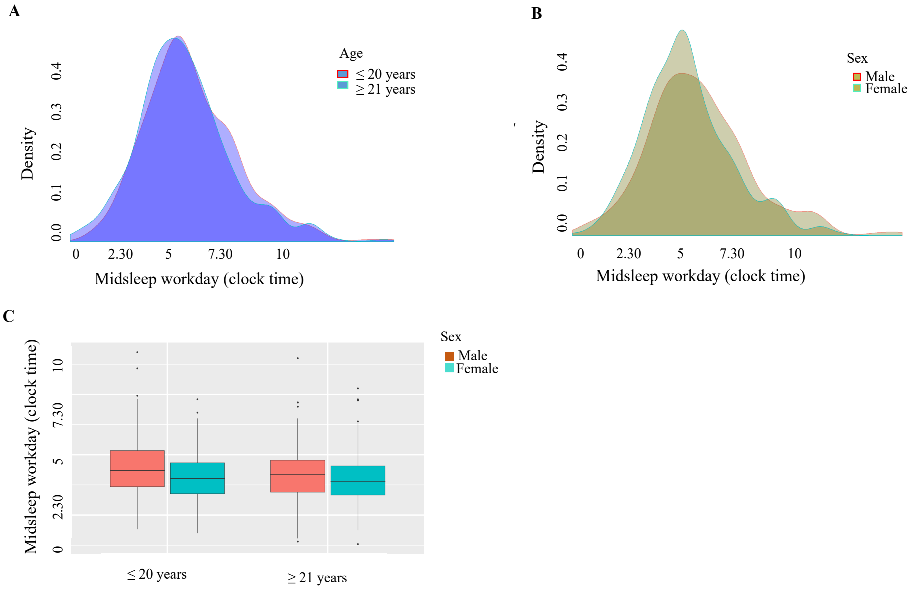


Figure 2.2. Midsleep workday by age and sex
Density plots showing the distribution of midsleep timings on workdays in **A.** participants 20 years old or younger, and those of 21 years or older and **B.** males and females. **C.** Box plot showing the main effects of sex and age on midsleep workday

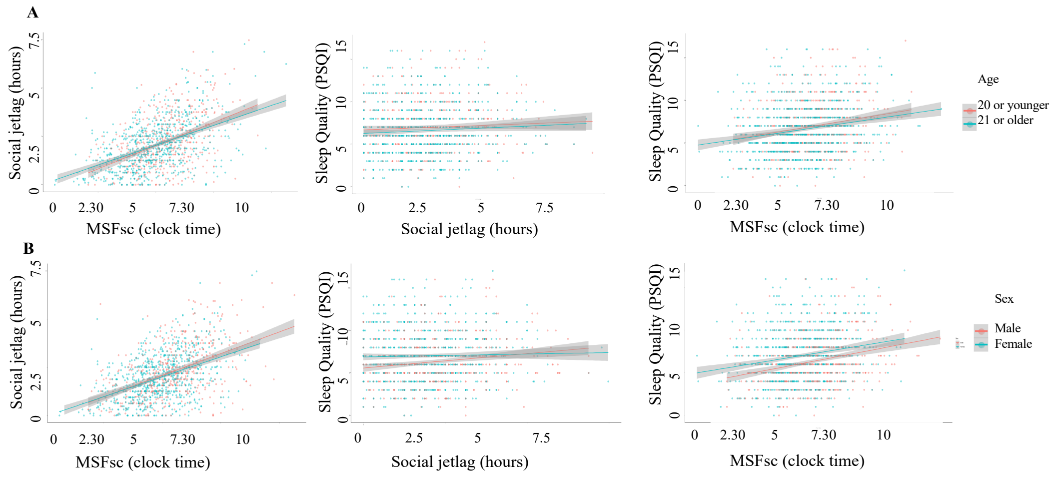


Figure 2.3. Associations between chronotype, social jetlag and sleep quality
Late chronotype associated with poor sleep quality scores ($p<0.001$) and there was an association between social jetlag and sleep quality ($p<0.001$). These relationships persisted when controlling for **A.** age and **B.** sex.

A correlation analysis showed a moderate positive relationship between midsleep timings on work-free days and sleep quality (later midsleep timings associating with poorer quality sleep scores; Figure 2.3; rho = 0.212, Bootstrap 95% CI lower bound = 0.157, upper bound = 0.263, *p* < 0.001). There was a statistically significant, but weak association between social jetlag and sleep quality (Figure 2.3; rho = 0.077, Bootstrap 95% CI lower bound = 0.02, upper bound = 0.136, *p* = 0.005). There was a statistically significant, but weak association between midsleep timings on workdays and sleep quality (rho = 0.180, Bootstrap 95% CI lower bound = 0.108, upper bound = 0.250, *p* = <0.001; Figure 2.4).

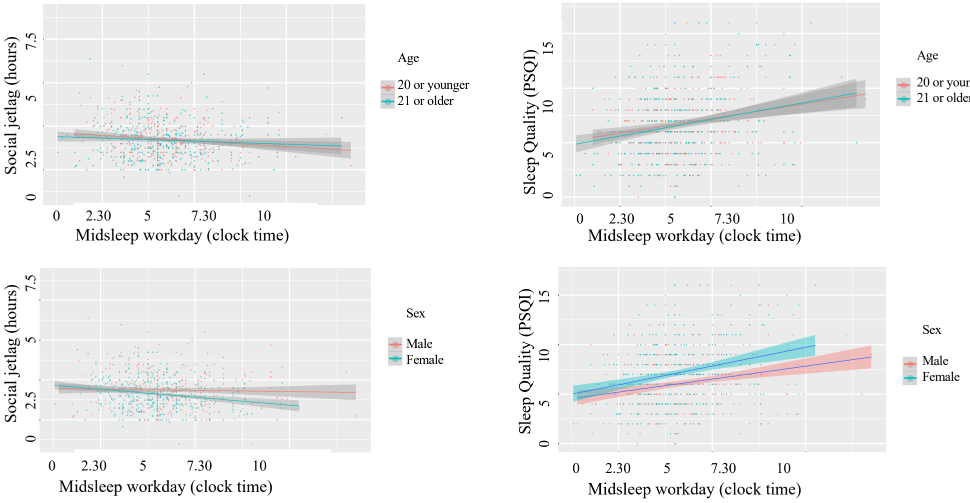


Figure 2.4. Associations between midsleep timings on workdays, social jetlag and sleep quality.
Earlier workday midsleep timings associated with higher social jetlag (*p*<0.001) and poorer quality sleep scores (*p*<0.001). These relationships persisted when controlling for **A.** age and **B.** sex.

There was an expected positive strong correlation between social jetlag and midsleep timings on work-free days (Figure 2.3; rho = 0.468, Bootstrap 95% CI lower bound = 0.42, upper bound = 0.514, *p*< 0.001). Late midsleep timings on work-free days, late chronotype, correlated with higher social jetlag. There was a small negative correlation between midsleep timings on workdays and social jetlag (Figure 2.4; rho = -0.098, Bootstrap 95% CI lower bound = -0.170, upper bound = -0.025, *p*= 0.007); earlier midsleep timings on workdays correlated with higher social jetlag. The potential confounding effect of age on the relationships between midsleep timings /social jetlag and sleep quality were examined with partial correlations: the relationship between midsleep timings (both work and work-free days) and sleep quality, and social jetlag and sleep quality persisted when controlling for age and sex.

Moderation analyses (sex as a moderator between midsleep timings or social jetlag and sleep quality scores) revealed the relationship between midsleep timings and sleep quality was not moderated by sex (R^2 = .069; p = 0.52) but there was a significant moderating effect of sex (R^2= 0.023; p = 0.032) on the relationship between social jetlag and sleep quality; post-hoc analysis revealed this relationship was only significant in males (r = 0.184, p < 0.001) and not in females (r = 0.029, p = 0.42). No moderation effects for age were found in the relationships. A mediation analysis revealed social jetlag did not mediate the relationship between midsleep timings on work-free days and sleep quality scores. This indicates that social jetlag did not account for the association between midsleep and sleep quality (Figure 2.5).

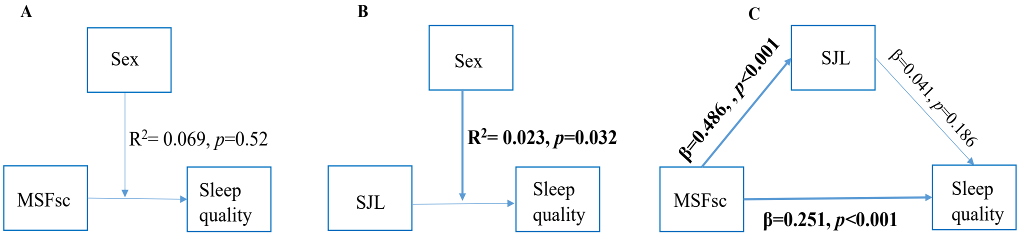


Figure 2.5. Mediation and moderation analyses
A. The relationship between work-free day midsleep and sleep quality was not moderated by sex, but **B.** there was a significant moderating effect of sex on the relationship between social jetlag and sleep quality; post-hoc analysis revealed the relationship was only statistically significant in males and not in females. **C**. Social jetlag did not mediate the relationship between work-free day midsleep and sleep quality scores.

2.4 Discussion

The results of this study indicate differential relationships between subjective sleep quality and midsleep timings on work- free day (chronotype) and social jetlag. Late midsleep timings on work-free days is associated with poor sleep quality, and this association is independent of sex and age. Higher social jetlag is also associated with poor sleep quality, but this association is weaker and is observed only in younger males. There are suggestions in the literature that sex may moderate the effects of social jetlag on various health parameters; for example, Cespedes Feliciano et al. (2019) demonstrated that adiposity was associated with social jetlag in adolescent girls but not boys. It is not currently clear what mechanisms might underpin the differential sex effects of social jetlag on various psychological and physiological outcomes, but hormonal differences and gendered differences in affective and other psychosocial parameters are plausible factors of interest. The overall relationship between social jetlag and sleep quality (PSQI scores) in this study is small, but this may be accounted for by the lack of association in females.

An important consideration for the interpretation of the current findings is the report of Pilz and colleagues (2018) demonstrating that PSQI scores reflect sleep quality on workdays and not on work-free days during which sleep quality was improved. Furthermore, In the Pilz et al. (2018) study the difference between workday and work-free day PSQI scores was related to midsleep timings (late chronotypes having larger discrepancies in their sleep quality), and this effect was mediated through social jetlag. The current study did not differentiate between PSQI scores on work and work-free days, and it will be of clear interest for future studies to do so. As social jetlag did not mediate the association of late midsleep timing on work-free day (late chronotype) with poor quality sleep in this sample, it may be that other traits associated with chronotype mediate this relationship; for example, late chronotype is associated with more depression and anxiety symptoms, which, in turn, are associated with poor quality sleep (Kivelä et al., 2018; Pilcher et al., 1997).

Another important caveat that frames the interpretation of the current results is that there is risk of sampling bias in the primarily student sample and consequent potential limitation of generalizability. Furthermore, the gender composition of the sample is biased towards females, and as such, the interpretation of the results should be nuanced in this context.

Another important factor to consider is the effect of seasonal changes on sleep. Studies have shown that sleep lengthens or shortens in response to seasonal light and temperature changes (Yetish et al., 2015). One important feature of the current study is that the data were collected in the same season (late autumn–winter) and potential confound of seasonal changes in sleep timings and sleep quality should not be in play. However, the period of data collection also included the seasonal clock change at the end of October. The transitions into and out of the seasonal clock changes are associated with adjustments in sleep with large delays in sleep timings observed with the end of daylight-saving time (Kantermann et al, 2017). This may have impacted, in particular, ratings of social jetlag. Information to exclude data from the period immediately after the end of the daylight-saving time was unavailable in this dataset. This is a significant limitation that should be considered when interpreting the results.

Another important consideration to the interpretation of the study is that the PSQI provides an estimate of sleep over a course of a month as perceived by the participants, and some studies have shown that subjective PSQI scores do not correlate with objective actimetry measures of sleep (Van der Berg et al., 2018). Furthermore, future work exploring the associations between midsleep timings, social jetlag and sleep quality in other age groups (e.g., children or older adults) would shed important light on developmental trajectories of such associations.

2.5 Conclusion

This study explored the relationship between social jetlag, midsleep timings and sleep quality, to examine if higher social jetlag and later midsleep timings may be determinants of poor sleep quality. Findings from this study identify both social jetlag and midsleep timings as close associates of poor sleep quality but suggests a differential relationship. Late sleep timings consistently associated with poor sleep quality. However, the association between higher social jetlag and poor sleep quality was found only among young male adults. Furthermore, social jetlag did not mediate the association between late chronotype and poor-quality sleep in this sample; it may be that other traits and states commonly associated with late chronotypes such as depression and anxiety, which are strongly associated with poor sleep quality, may mediate the chronotype-sleep quality relationship.

Chapter 3

Examining the chronobiological underpinnings of the preference for daylight saving time

Parts of this chapter have been published as:

Coogan A., Richardson S., & Raman S. (2022). A data informed perspective on public preferences for retaining or abolishing biannual clock changes. *Journal of Biological Rhythms*. https://doi.org/10.1177/07487304221096390

Abstract

This chapter examines the general preferences for clock changes and standard time versus daylight saving time (DST), and if these preferences are influenced by sleep and chronobiological measures, hypothesizing that those with late sleep-wake preferences would favour DST. This is a cross-sectional study of 894 Irish adults (797 participants were used for the sleep timing analysis after exclusion of shift workers; 60% females, mean age = 39.7 (SD=12.7)) after the transition to DST in spring 2020. 55% of the respondents experienced the switch to DST positively and a significant number of people rated their experience of standard time negatively (40%). The positive experience of the change to DST was associated with a preference for abolishing the clock changes (58% supported abolition) and adopting permanent DST (52%). There was a small association of lower social jetlag (1h 2min ± 0.04 for abolish vs. 1h 14min ± 0.05 for retain, *p*=0.003; r=0.11) in those preferring abolishing clock changes and slightly earlier midsleep timings (04:02h ± 0:03 vs 04:09h ± 0:04, *p*=0.02, d=0.17) in those preferring abolition. However, there was no effect of either social jetlag or midsleep timings on the preferred option of permanent DST or standard time. The results suggest that chronobiological factors are not strong influences on attitudes to the clock change but rather the preferences are driven by the experiences of the summer months. The results are surprising from a chronobiological perspective and highlights a current disconnect between the lived experiences of the general public and scientific recommendations. This may present a challenge in translating chronobiological science into society-wide policy changes and may be a missed opportunity to reduce social jetlag and improve sleep quality and public health.

3.1 Introduction

The European Union (EU) has proposed abolishing the switching of the clocks, and member states such as Ireland are free to decide between permanent standard time or daylight saving time (DST; EU Parliament, 2018). Warning bells have already been sounded about the deleterious impact of adopting perennial DST, when the United States adopted year-round DST during the oil crisis and later abandoned it (Rishi et al., 2020) and the unequivocal recommendation from experts is for adopting perennial standard time (Rishi et al., 2020; Roenneberg 2019b). However, in a survey of EU residents (EU commission report 2018), there was an overwhelming preference for permanent DST.

In that same EU survey, a majority of respondents cited human health as the reason for voting to abolish clock switching, suggesting a recognition of the adverse effects of the clock switching on health. The preference for DST however indicates a disconnect from the scientific community's recommendations. Historically, arguments in favour of the transition into and out of DST have focused on extension of the working day during the DST period, energy savings related to less demand for evening electric lighting in the DST period, recreational amenity resulting from the perception of longer hours of evening sunshine in the DST period, increased opportunities for commerce and perceived road traffic safety improvements relating to more hours of evening sunlight (Committee on Science, 2001). More recent concerns around DST centre on chronobiological and/or sleep concerns relating to increased desynchrony between internal circadian time and societal schedules (social jetlag) during DST (Roenneberg et al. 2019b).

While politician and business stakeholders' preference for DST might be commerce and economic reasons, the scientific community's recommendations are based on evidence from studies associating DST with adverse effects on health (Manfredini et al., 2018) and road traffic accidents (Fritz et al., 2020). The association between DST and sleep have been purported to be via the impact of the clock switching and DST on the human circadian system (Putilov et al., 2020) which in turn delays sleep-wake times (Toth Quintilham et al., 2014), affects sleep quality (Lahti et al., 2008; Tonetti et al., 2013) and increases social jetlag. Social jetlag is the chronic circadian misalignment due to the constant struggle between biological and social time; the one-hour shift during DST pushes this misalignment further and increases the gap between social and biological time. Individuals with a preference for later bedtime and waketime, known as late chronotypes, are likely to face greater negative effects from DST than the early chronotypes (Roenneberg et al., 2019b). It is believed that late chronotypes, who already struggle with having to wake earlier than their natural body clock during standard time, suffer greater disruptions to their circadian systems and internal clocks (Putilov et al., 2020; Roenneberg 2019b) under DST and run the risk of greater social jetlag.

One current knowledge-gap in this matter is the extent to which individuals' preference for switching of the clocks and time preferences for DST or standard time, are associated with their individual circadian and sleep characteristics. This study investigated the association of sleep-wake timings, sleep duration, sleep quality, and social jetlag on DST or standard time preferences, hypothesizing later sleep-wake timings (by extension higher social jetlag) would associate with preference for DST which would provide more hours of evening daylight for social activities. The study further queried how the public experienced the transitions in and out of DST and standard time (positive or negative) and if that influenced the general preference for the adoption of year-round DST, testing the hypothesis that positive experience of perennial switch into DST would be associated with a preference for the adoption of year-round DST.

3.2 Methods

3.2.1 Recruitment and data collection

Ireland switches to DST (GMT+1) in the spring on the last Sunday in March, and back to standard time on the last Sunday in October. Data was collected from 11th April 2020 to 4th June 2020, approximately two weeks after the clocks switched to DST. Adults living in Ireland were recruited via the Brainstorm blog of the national broadcaster (Radio Television of Ireland), personal contacts, social media posts, and via Qualtrics Research Participants service. Ethical approval was granted by the Research Ethics Committee of Maynooth University and informed consent was indicated by all participants whose data was included in the analysis.

3.2.2 Measures

Respondents completed a questionnaire on experiences of and prospective preferences for clock change, which was adapted from the EU commission survey (European Commission Report, 2018). DST and standard time were referred to as summertime and wintertime respectively in the survey. The ultra-short version of the Munich Chronotype Questionnaire (μMCTQ; Ghotbi et al. 2020) was used to assess sleep-wake timings and social jetlag. The data collection period overlapped with the early stages of the COVID-19 pandemic and the imposition of societal restrictions in Ireland, which was associated with marked changes in sleep timing in Ireland and elsewhere (Leone et al., 2020; Korman et al., 2020). To control for the impact of COVID-19 mitigation measures on sleep-wake behaviours, participants were asked to score their usual sleep-wake behaviours prior to the pandemic. Participants were also requested to rate their sleep quality prior to the pandemic on a single item of zero to ten, with higher scores indicating better sleep.

3.2.3 Statistical analyses

The Chi-square tests to assess associations between categorical variables, *t*-tests or one-way analysis of variance or the Mann-Whitney U or the Kruskal-Wallis Test to assess between-groups differences (depending on the distribution, and continuous or categorical nature, of the variables), with $p<0.05$ as indicating a statistically significant effect. Effect sizes were expressed as Cramer's v for non-parametric tests or Cohen's d for parametric tests.

3.2.4 Pilot data

Additionally, a separate dataset from a pilot study was collected from 14th to the 28th November 2019 (the change from DST to standard time occurred on the 27th October). Data was collected from a total of 201 adults via convenience sampling; when screened for exclusion of shift workers, non-Irish residents and incomplete responses, 172 sets of responses were included for analysis. For the pilot study, individuals completed the full MCTQ (Roenneberg et al., 2003), the Pittsburgh Sleep Quality Scale (PSQI; Buysse et al., 1989) as well as the same questionnaire for experiences of and attitudes to clock changes that was subsequently used in spring 2020. As this dataset was collected prior to the COVID-19 pandemic, there were no mentions of or adjustments for travel and social restrictions. The fall 2019 data is, considering the significant psychological context of the COVID-19 pandemic, not intended as a direct comparison but only as a scoping to highlight if there may be seasonal differences warranting future investigations. Due to differences in methodology and sample sizes between the spring 2020 study and the fall 2019 pilot study, direct inferential comparisons were not undertaken between the cohorts.

3.3 Results

894 participants (mean age=39.7 (SD=12.7);60% females) answered questions on their experience of and preferences for the clock switching in the spring 2020 sample. Shift workers were excluded from the social jetlag and sleep-wake timing analysis (N=797). Midsleep timings on work-free days (04:08am; SEM=0.04; SD=1.17), average weekly sleep duration (7 hours 56 minutes; SEM=0.04; SD= 1.22) and midsleep timings on workdays (03:25am; SEM=0.04; SD=1.04) exhibited normal distribution. Social jetlag (1 hour 7 minutes; SEM=0.03; SD= 0.93) was a slightly asymmetrical distribution, skewed towards lower values of social jetlag. Sleep duration was within the normal range of the recommended 7-9 hours per night (Hirshkowitz et al., 2015) and 78% rated their sleep quality as good. 172 participants (mean age = 35.8, SD=15.1; 69% females) were included from the fall 2019 sample. Tables 3.1 and 3.2, summarize participant demographics.

N=894; Mean age =39.7 (SD=12.7)		
Sex		
	Female	60%
	Male	40%
Age groups		
	18-25	15%
	26-35	24%
	36-45	28%
	46-55	21%
	56-65	9%
	>65	3%
Shift worker		11%

Table 3.1 Descriptive statistics of the spring sample.
Sample was predominately female and older. Shift workers were excluded from the social jetlag and sleep-wake timing analysis

3.3.1 Preferences for keeping or abolishing, and experience of, the clock switching

55% said they had a positive experience with the switching of the clocks forward to summertime (DST), while only 16% reported negative experience and 29% had no opinion (Figure 3.1A). 40% said they had negative experience with the switching of the clocks back to wintertime (standard time), while 32% reported positive experience and 28% had no opinion (Figure 3.1B). 58% of those surveyed said they would prefer to abolish rather than switch the clocks twice a year (Figure 3.1C). If the clock change was to be abolished, 52% said they favoured permanent DST while only 23% voted for standard time, with 25% saying they had no opinion/ I don't know (Figure 3.1D).

N=172; Mean age =35.8 (SD=15.5)		
Sex		
	Female	69%
	Male	31%
Age groups		
	18-25	44%
	26-35	13%
	36-45	12%
	46-55	19%
	56-65	10%
	>65	2%

Table 3.2 Descriptive statistics of the fall pilot sample.
Sample was predominately female, but unlike the spring sample, the fall sample was younger.

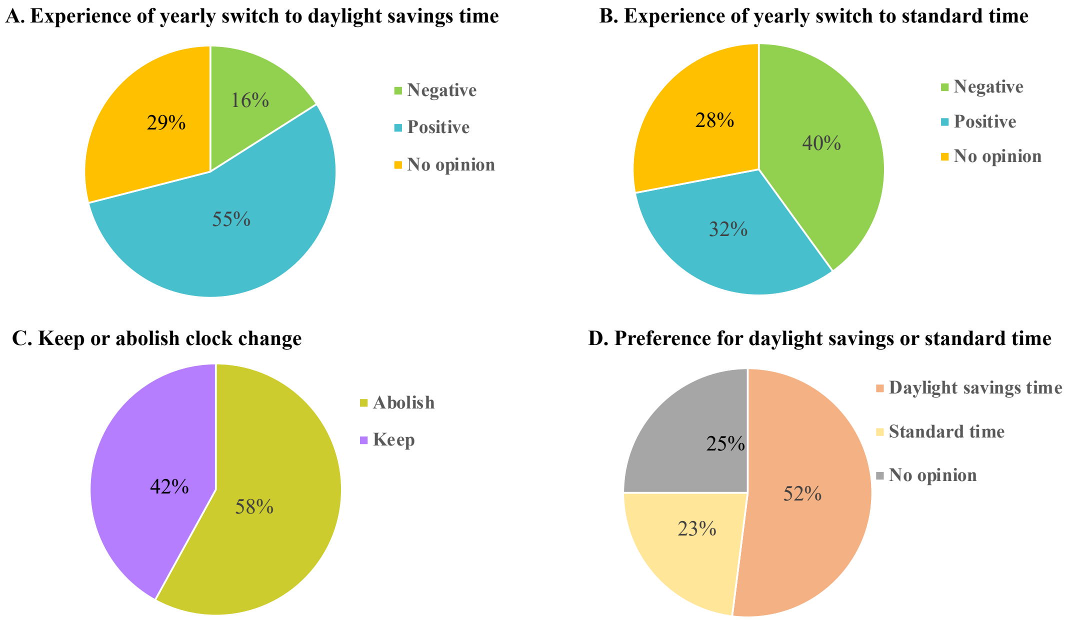


Figure 3.1 Spring data -experience of and preference for switching and DST versus standard time
Majority experienced the switch to **A.** DST positively and **B**. standard time negatively. Majority voted to **C.** abolish clock switching and **D.** adopt DST as permanent time.

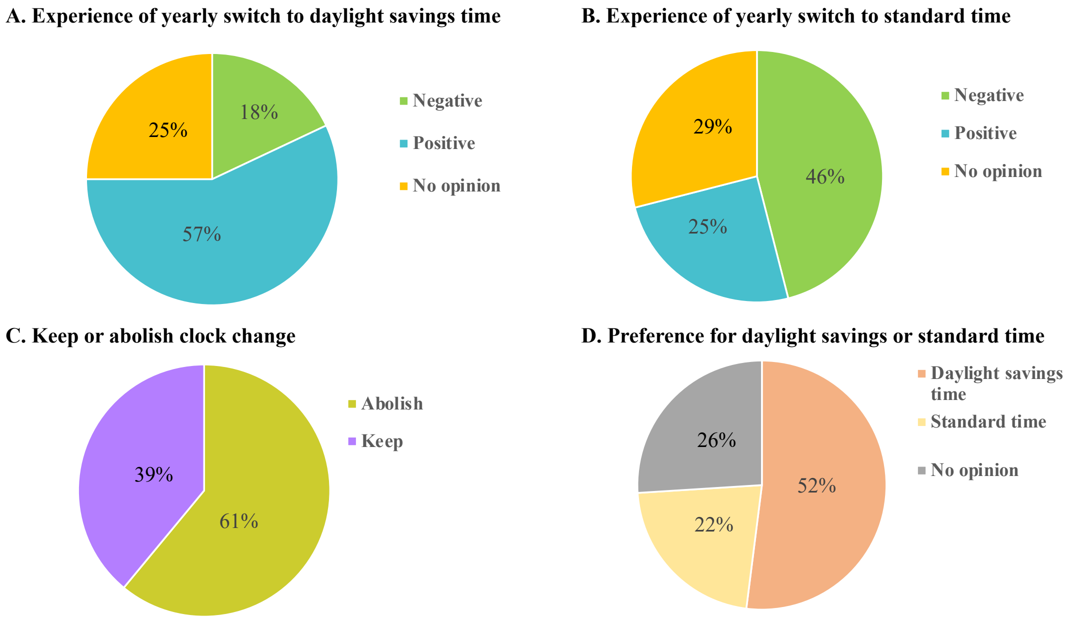


Figure 3.2 Fall data -experience of and preference for switching and DST versus standard time
Majority experienced the switch to **A.** DST positively and **B**. standard time negatively. Majority voted to **C.** abolish clock switching and **D.** adopt DST as permanent time.

Results from the fall 2019 data set showed very similar results: 46% expressed negative experience of the switch to standard time, 57% expressed positive experience of the switch to DST, 61% preferred abolition of the clock change and 52% preferred adoption of year-round DST (Figures 3.2 A-D).

Participants' preference to keep or abolish clock switching had a moderate association with their experience of switching to DST (X^2= 60.26, *p*=0.00, df=2, v=0.26); those reporting negative experience of the annual switch to DST were more likely to express a preference for clock change abolition (Figure 3.3A). Similarly, there was a significant association between switching to standard time and the preference for abolishing or keep switching (X^2= 140.46, *p*=0.00, df=2, v=0.40), with those with a negative experience of the transition to standard time more likely to express a preference for abolition of the clock change (Figure 3.3B).

The preference for DST versus standard time as a permanent time was also associated with the participants' experience of the switching of the clocks, with participants reporting negative experience with the switch to standard time preferring permanent DST (X^2= 81.80, *p*=0.00, df=4, v=0.2; Figure 3.3C), and those reporting positive experience with the DST switch also preferring permanent DST (X^2= 65.70, *p*=0.00, df=4, v=0.19; Figure 3.3D).

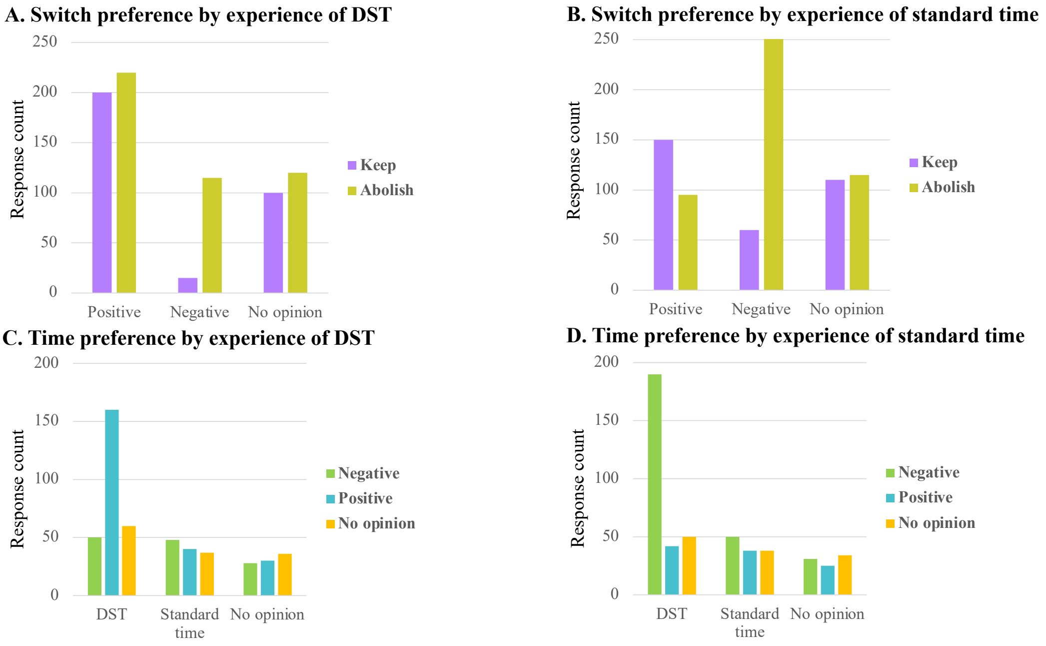


Figure 3.3 Spring data- association between experience of switch and time preference
Bar graphs showing the association between experience of the yearly switch **A.** into and **B.** out of DST with preference to keep/abolish the clock switching.

Similar results were found in the fall 2019 dataset, with preference for abolition of the clock change associating with negative experience of the switch to DST (X^2= 17.9, p<0.001, v=0.32) and to standard time (X^2= 29.9, p<0.001, v=0.42; Figure 3.4A+B). Further, in the fall 2019 dataset preference for year-round DST was also associated with positive experience of the switch to DST (X^2=20.7, p<0.001, v=0.244; Figure 3.4C) and with negative experience of the switch to standard time (X^2=24.1, p<0.001, v=0.263; Figure 3.4D).

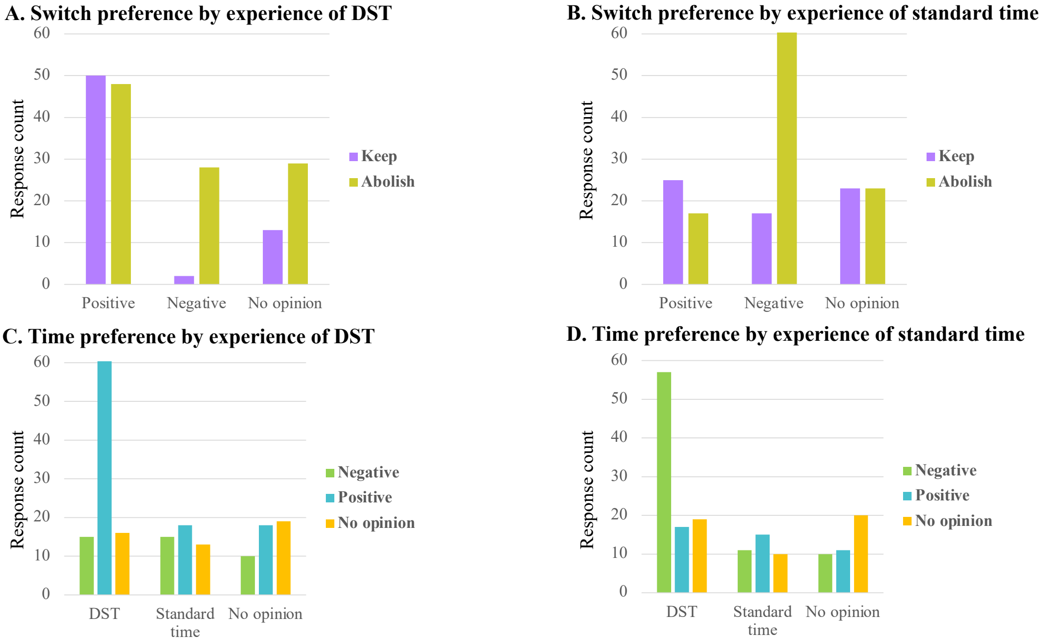


Figure 3.4 Fall data- association between experience of switch and time preference
Bar graphs showing the association between experience of the yearly switch **A.** into and **B.** out of DST with preference to keep/abolish the clock switching.

When selecting reasons for their preference to keep or abolish the clock switching, participants who preferred to keep switching endorsed “Leisure Activities in the Evening” as their top reason (37%) followed by “Health” (22%; Figure 3.5). For those who expressed a preference for abolishing the clock change, the most frequently endorsed top reason for this preference was “Health” (40%) followed by “Leisure Activities in the Evening” (28%; Figure 3.5). These differences in the endorsed leading reasons for the keep/abolish preferences were statistically significant (X^2=54.6, p<0.001, v=0.262).

3.3.2 Influence of demographic factors on preferences

Participants in permanent regular employment showed clear preference for abolition and permanent DST, although comparison with other categories was not meaningful given the small numbers of respondents in other categories (Figure 3.6A+B). Those that preferred abolition of the clock change were also older (mean age 41.4 ±0.6 years for abolish vs. 38.3 ± 0.7 years for keep; t=-3.406, *p*=<0.001, Figure 3.6C) and were more likely to be male (X^2=6.5, *p*=0.038).

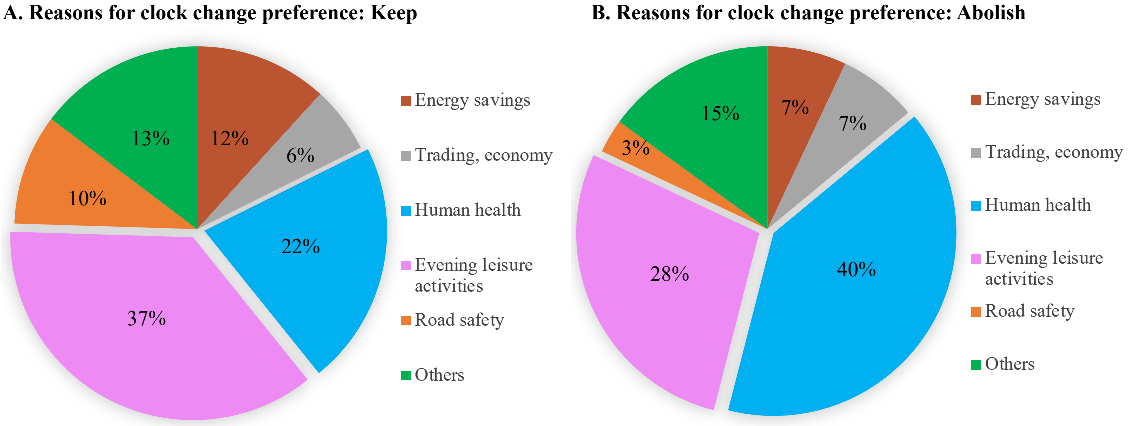


Figure 3.5 Reasons for clock change preference
Health was a primary reason for the preference for abolishing clock switching, and evening leisure activities were the main reason for preference for keeping the current clock switching arrangement.

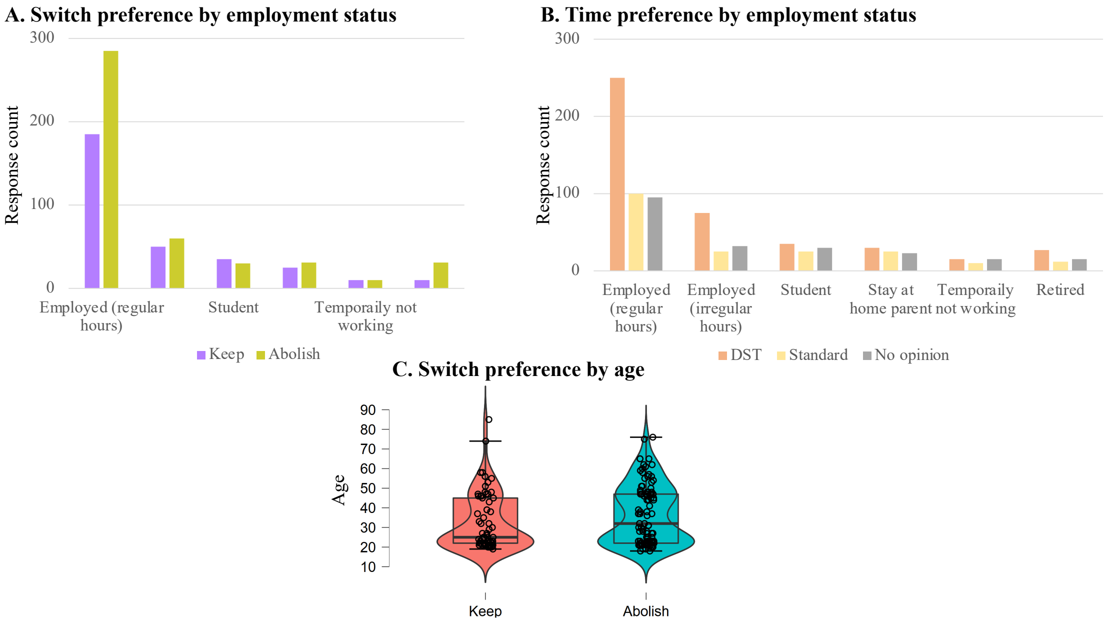


Figure 3.6 Demographics influence on preferences
Employment status associated with a clear preference for abolition and permanent DST. Older age was associated with a preference for abolition.

3.3.3 Influence of chronobiological sleep parameters on preferences

When sleep and chronobiological variables were assessed across attitudes around maintaining or abolishing the biannual clock change, social jetlag was found to vary according to abolish or keep preference, with those expressing preference to abolish the clock change experiencing less social jetlag (1h 2min ± 0.04 for abolish vs. 1h 14min ± 0.05 for retain; Mann-Whitney U=67068.50, z=-3.006, *p*=0.003; Figure 3.7A). Respondents who preferred abolishing the clock change also had earlier midsleep timings on work-free days than those who preferred to keep switching (04:02h ± 0:03 vs 04:09h ± 0:04, *t*=3.203, *p*=0.02; Figure 3.7B). There was no significant association between sleep duration (*p*=0.42) or sleep quality (*P*=0.40) and keep or abolish preference (Figure 3.7C-D). There was no significant association between all sleep variables (social jetlag, *p*=0.94; midsleep free, *p*=0.21; sleep duration, *p*=0.14; sleep quality, *p*=0.26) and participants' choice of permanent DST or standard time. Similar associations were also found in the fall 2019 dataset (social jetlag of 1h 13min ± 0.09 for abolish vs. 1h 31min ±0.13 for retain, *p*=0.045; midsleep timings on work-free days of 04:00h ± 0:07 for abolish vs. 04:17h ± 0:12 for retain, *p*=0.036; Figure 3.8A-D).

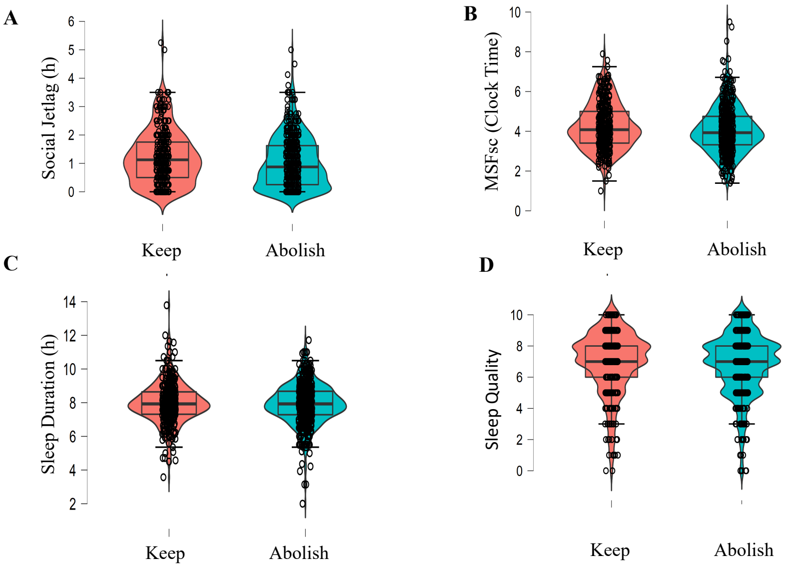


Figure 3.7 Spring data -chronobiological variables and preferences
A. Participants experiencing less social jetlag expressed preference for abolishing clock change. **B.** Those who preferred to keep switching had a late chronotype. **C. /D.** There was no significant association between sleep duration or sleep quality and keep or abolish preference. There was no significant association between all sleep variables and choice of permanent DST or standard time.

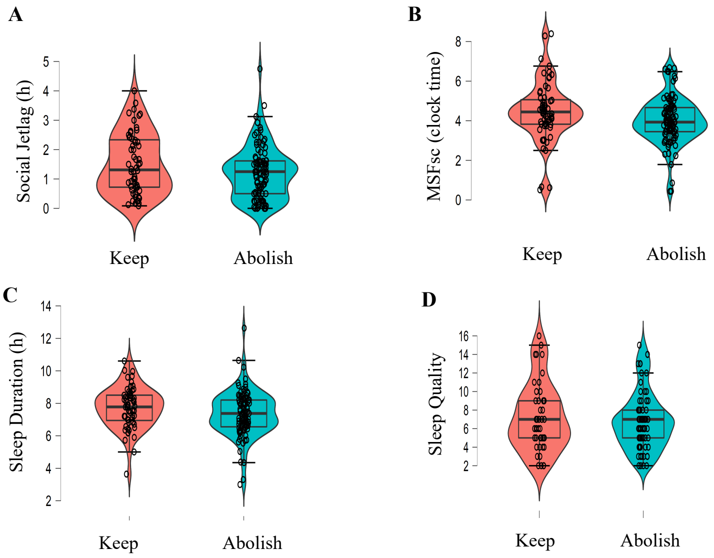


Figure 3.8 Fall data-Chronobiological variables and preferences
Similar associations, as in the spring data, between chronobiological variables and preferences were found in the fall data. Less social jetlag and earlier work-free day midsleep timing associated with preference for abolishing clock change and there was no significant association with sleep variables and preference for DST or standard time.

3.4 Discussion

The finding of this study that a majority of respondents expressed a preference for abolition of the biannual clock changes and preferred permanent DST is in line with prior polling carried out by the Irish Government and the European Commission (EU Commission Report, 2018; Irish Department of Justice and Equality, 2019), and with a recent study of ~47,000 Norwegian respondents that reported 78.2% were in favour of abolishing the clock change (Bjorvatn et al., 2021).

The current results also indicate a link between experiences of the switch into and out of DST and preferences to keep/abolish the switch and adopt permanent DST; positive experience of the switch to DST was associated with a preference for permanent DST, as was a negative experience of the switch to standard time. These results indicate that preferences for prospective changes in the regime are strongly grounded in existing experiences and perceptions. Those who favoured abolition were on average somewhat older, a finding that was also reported in the study of Bjornvatn et al. (2021). The main reason expressed most frequently for preferring abolition of the clock changes is health, whilst it was recreation for those expressing a preference to retain the current system. This finding would suggest that the messages regarding the adverse effects of the biannual clock changes from scientific studies and circadian scientists (e.g., Roenneberg et al., 2019b) may have reached the general public and helped shape public preferences.

More importantly and of greater interest is the finding that the DST (summertime) switch was perceived favourably while there was a negative reaction to the transition back to standard time (wintertime). Given the strong public preference here and in other studies for abolition, the reporting of positive experience of the switch to DST and preference for permanent DST may be surprising from a chronobiological perspective. It is surprising as prior studies show that the switch to DST entails longer time for re-synchronization of sleep-wake rhythms than the switch to standard time (Kantermann et al., 2007) and is believed to negatively impact on sleep and overall life satisfaction and by extension a negative experience.

This highlights two key points. First is the ambiguity in interpretation of the questions in the survey. The question simply asked participants to rate their experience when the clock switched to DST, which may have been interpreted as the period of DST, the summer months, rather than the switch itself. The terminology used in the survey was also summertime. Thus, the image of summer, with long daylight hours and warm weather as opposed to standard time as dark and cold wintertime may have played a part in the preference (Putilov et al., 2020). However, there is a clear and consistent preference for DST by the general public across different polls and different jurisdictions (Bjornvatn et al. 2021; Sladek et al., 2020). Therefore, the preference should not be dismissed merely as the product of the emotional valence of the semantics used (Blume and Schabus, 2020). This highlights the second point that the general public's lived experience of the clock switching, and of DST in particular, may be diametrically opposed to the science behind the recommendations against adopting perennial DST.

This study queried if sleep and chronobiological factors may explain this divergence in opinion, based on the hypothesis that those with later sleep-wake preferences would favour clock time that provides more hours of evening daylight for social activities and thus favour DST. The study reports small effects of preference to keep/abolish the clock changes according to social jetlag (with lower amounts in those preferring abolishing clock changes) and midsleep timings (with slightly earlier midsleep timing in those preferring abolition), and these associations were found in both the spring and fall cohorts. Other studies have however reported a relationship between chronobiological factors and the preferences. Bjornvatn et al. (2021), for example, reported that evening orientation (late sleep-wake preference) was associated with a preference for abolition of the clock change, although the majority of all chronotype groupings assessed, including extreme morning types (early sleep-wake preference), favoured abolition.

In this current study there was no effect of either social jetlag or midsleep timings on the preferred option of permanent DST or standard time if the clock change was abolished; as such, it appears that chronobiological factors are not strong influences on attitudes to the clock change. It appears that experiences during the summer months are more relevant factors than social jetlag or late sleep-wake timings in shaping attitudes to the clock changes.

The preference for adoption of year-round DST may not be the most chronobiologically appropriate course. For example, Sladek et al. (2020), estimated that based on assessment of midsleep timing values for the Czech Republic (central European country) that all-year standard time would best align with the underpinning distribution of sleep-wake timings of the population. Borisenkov et al. (2017) reported that the adoption of all-year DST in the Russian Federation between 2011 and 2014 was associated with an increase in social jetlag and winter low-mood in children and adolescents.

The results of this study highlight the dilemma surrounding clock change decisions; politicians and general public favouring DST and the scientific community recommending standard time. The position statements of chronobiology and sleep medicine (Roenneberg et al. 2019; Rishi et al. 2019; Watson 2019) is in favour of the adoption of year-round standard time, which is a clear disconnect from the preference by the general public for DST across different surveys and jurisdictions. Considering majority public opinions is important for public buy-in to society-wide policies regarding clock changes and adoption of permanent time (Blume & Schabus, 2020). However, this may present a challenge given the divide as discussed before and may result in status quo (clocks keep switching back and forth) or in adoption of DST regardless of scientific warnings, and a missed opportunity to reduce social jetlag and improve sleep and public health.

One way to mitigate the current divide in opinion and to promote good sleep hygiene is to educate the general public on the effects of DST and the importance of sleep regularity. A similar approach has been proposed to inform teachers and parents about the effects of sleep disturbances on school performance, and to include them in the implementation of policies that recommend late school start timings (Fitpatrick et al., 2020).

3.4.1 Limitations and further considerations

There are several important caveats and contextual factors that should be taken into consideration when interpreting the results of the current study and applying them to more generalized debates around DST. Firstly, geographical and political circumstances unique to Ireland may have influenced the results of this study. Northern Ireland is part of the United Kingdom, and no longer part of the European Union. Given that the UK had stated that it would not be altering its clock change arrangements, the risk of the Republic of Ireland being in a different time zone to Northern Ireland may shape preferences for clock changing; a survey by the Irish Government indicated that 82% of respondents would not favour a solution that imposed different time zones in the Republic of Ireland and Northern Ireland (Irish Department of Justice and Equality, 2019).

Ireland is relatively far north and experiences a near 10-hour difference in hours of sunlight between the summer and winter solstices; at 53.41291, -8.24389 Ireland is located relatively northerly, and in the west of the Greenwich Mean Time Zone. Latitude matters when considering DST as there will be considerable differences in the public experience of DST depending on its location-specific effect and the magnitude of the seasonal change in natural photoperiod (Martín-Olalla, 2019). Westerly locations with any given time zone have also been proposed to increase social jetlag (Roenneberg et al., 2019b) and this may in turn impact behaviour (e.g., decreased prosocial behaviours; Holbein et al., 2019) and physical health outcomes (e.g., increased cancer risk; Gu et al., 2017).

From a European perspective, under DST the time of sunset in Dublin at the summer solstice is approximately 10pm and there is ~17hours of daylight, whilst at the winter solstice in standard time sunset is 4:15pm after only 7.5h of daylight. In comparison, those same local values for another European capital city, Rome, are sunset at 8.50pm after ~15.25h of sunlight in the high summer and sunset at 4:45pm with ~9.1 hours of daylight in late December. As such, the loss of 1h of daylight in the high summer with a switch to year-round standard time may be even more negatively appraised in Rome than it is in Dublin, whilst Dubliners will experience short hours of winter daylight irrespective of how social activity is synchronized to sun-time. The switch to standard time in Ireland may be conflated with the onset of short winter days and cold and dark weather; however, the similar preferences reported from the fall 2019 pilot study may suggest this is not a major factor.

Secondly, another factor, as discussed earlier, is the possibility of influence of semantics of standard time as “wintertime” and DST as “summertime”, but others have noted that such clear and consistently expressed preferences should not be dismissed merely as the product of the emotional valence of these phrases (Blume & Schabus, 2020). Thirdly, another important consideration is that the spring 2020 dataset was collected around the onset of the COVID-19 pandemic, and the imposition of societal restrictions and mitigation measures which previously have been reported to have had profound impacts on sleep timing in Ireland and other jurisdictions (Korman et al. 2020; Leone et al., 2020; Wright et al., 2020). Steps were taken to partially control for this by asking participants to report their usual sleep timing prior to the imposition of restrictions and the fall 2019 pilot dataset, collected prior to the COVID-19 pandemic, yielded results that were remarkably similar to those in spring 2020 and as such COVID-19 control measures may not have strongly influenced the results. However, clearly there are particular psychological context for the period of data collection, and as such the current data should be interpreted appropriately.

Future research, post-COVID-19, could consider data collection in both spring and fall to help resolve this issue, but as the pandemic appears to become endemic it is unclear when this may be in Ireland. Approaches utilizing longitudinal designs may better reveal how reported experiences and attitudes are shaped by the timing of any survey between spring and fall; nationally representative samples in longitudinal designs would also address concerns around non-responder biases in cross-sectional designs. The addition of objective data on sleep-wake behaviours, such as from actigraphy data, could enhance our understanding, for example by providing individual-level data on re-entrainment of sleep-wake rhythms following clock changes and their association with expressed preferences. Finally, future research may also consider how psychological factors, such as conspiratorial thinking and trust in government and science associate with attitudes towards the clock changes (Pennycook et al. 2020).

3.5 Conclusion

The current data indicates that attitudes towards the biannual clock switching are associated with existing experiences of the transitions in and out of the switch to DST and standard time, that a majority of people experience the switch to summertime positively and that permanent DST is the favoured option. Sleep-wake timings and key sleep parameters appear to have a minimal association with such preferences. Despite the position statements of chronobiology and sleep medicine experts in favour of the adoption of year-round standard time, there appears to be a disconnect between the lived experiences and preferences of the general public and the scientific community on this topic. The importance of considering existing public opinion in any attempt to translate chronobiological science into society-wide policy changes may present a challenge to adopting standard time should clock changes be abolished and may be a missed opportunity to reduce social jetlag and improve sleep and public health.

Chapter 4

Examining the effects of socially imposed timings on social jetlag

This chapter has been published as

Raman, S., & Coogan, A. N. (2021). Effects of societal-level COVID-19 mitigation measures on the timing and quality of sleep in Ireland. *Sleep Medicine*. https://doi.org/10.1016/j.sleep.2021.02.024

Abstract

This study reports a cross-sectional study assessing pre-and during pandemic sleep-wake timings of 797 adults (excluding shift workers; 63% females, mean age=40.2 (s.d=12.7), 17% essential workers) in Ireland. Participants were resident in Ireland in March 2020 during the first COVID-19 restrictions. Midsleep timings on workdays became later (03:25 vs 04:19; $p<0.001$) and there was a significant reduction in social jetlag (1h 06 mins vs 37 mins; $p<0.001$) following the imposition of restrictions. Those who worked from home had longer sleep duration on workday and had a significantly larger difference in sleep end on workday than essential workers (1hr vs 17 minutes; $p<0.001$) who continued to attend their normal place of work. Essential worker status had a significant effect on the change in social jetlag ($F_{2, 796}= 10.9$, $F_{1, 771}= 21.98$ $p<0.001$, partial $\text{eta}^2= 0.028$), with those who were working from home experiencing the largest reduction in social jetlag. The results suggest that the changes observed in social jetlag in this study were driven primarily by changes in sleep timings on workday (r =-0.57, $p<0.001$). This study reinforces the importance of working and commuting schedules for determining sleep-wake timings and indicates workday sleep-wake timings as a strong influencer, and as a modifiable risk factor, of social jetlag. Sleep quality reduced significantly during the restrictions (6.87+0.07 to 5.69+0.09, $p<0.001$); realigning sleep timings across the week and reducing social jetlag did not associate with better sleep quality. This may be due to the context of the emotional and psychological stress of the COVID-19 pandemic. Factors such as depression and anxiety, may have a stronger influence on sleep quality.

4.1 Introduction

Following the establishment of community transmission of the SARS-CoV2 virus and increasing rates of the disease COVID-19 in Ireland, on March 12th 2020 the Government of Ireland announced the implementation of a broad range of societal-level non-pharmacological steps to mitigate the national epidemic. These steps included the closure of schools and child-care facilities and the discontinuation of on-campus university tuition and were augmented on the 27th March 2020 with the introduction of more radical measures, requiring home working except for designated key workers and the suspension of all non-essential travel (Government of Ireland, n.d.). Refer to figure1.13 in chapter 1 for a timeline of nation-wide full restrictions and the type of restrictions imposed in Ireland from March 2020 to October 2021.

Various data indicate that social and travel restrictions implemented in response to COVID-19 resulted in a remarkable decrease of human mobility across the globe (Bonaccorsi et al., 2020; Hadjidemetriou et al., 2020). For the vast majority of non-essential workers in Ireland, travel restrictions resulted in a requirement to work from home, and students were tutored at home by their caregivers and/or virtual tuition. As such, commuting was not required for the majority of workers and students, and there may have been an increase in flexibility for scheduled work and study duties throughout the day; clearly, there are potential implications for the timing and quality of sleep that may arise from such radical re-arrangements of daily schedules.

Under usual circumstances, almost 80% of participants in Europe reported using an alarm clock on workdays (Roenneberg et al., 2012). This indicates widespread sleep loss resulting from the conflict between the circadian clock (the endogenous near 24-hour timekeeping system that imposes a temporal architecture on physiology and partially dictates sleep time) and socially required waking times to meet school or work obligations. This conflict between internal biological time and social schedules is termed social jetlag. Social jetlag is formally described as the discrepancy in the timing of midsleep (the midpoint between sleep start and wakening) between work and work-free days (Roenneberg et al., 2019). The timing of midsleep on work-free days, when corrected for sleep debt accumulated during workdays, is believed to indicate the phase of entrainment of the circadian clock (the timing of a circadian event relative to the 24-hour day; Roenneberg et al, 2019). As such, midsleep on work-free days may be used as an indicator of chronotype (individuals' tendency towards earlier or later sleep-wake cycles). Inter-individual difference in circadian processes manifest themselves in sleep-wake timing differences (Adan et al., 2012; Roenneberg & Merrow, 2007). School and work schedules tend to be early in industrialized societies leading to greater conflict and discrepancy between work and work-free day sleep for those with a predisposition for late sleep start and wake times.

The radical societal-level mitigation measures introduced in Ireland and other countries during the COVID-19 pandemic presented a unique natural experiment through which to examine the effects of work schedules on the timing of sleep-wake activity. The current study sought to examine these effects by assessing sleep-wake timings before and during restrictions, the relationship between changes in key sleep parameters following imposition of the restrictions and the impact of worker status during restrictions on sleep timing and duration.

4.2 Methods

4.2.1 Recruitment and data collection

Adults resident in Ireland were invited to take part in an on-line survey, via the Qualtrics survey platform (an on-line research services provider, www.qualtrics.com). The survey went online on 11th April 2020 and concluded on 4th June 2020 (when travel was still restricted to within five kilometres and non-essential workers and students were still required to work and study from home). Recruitment was via the Brainstorm blog of the national broadcaster (Radio Television Eireann), personal contacts, social media posts, and recruitment via Qualtrics research services. Ethical approval was granted by the Research Ethics Committee of Maynooth University and informed consent was indicated by all participants whose data was included in the analysis.

4.2.2 Measures

The ultra-short version of the Munich Chronotype Questionnaire (μMCTQ; Ghotbi et al.,2020) was used to assess sleep-wake timings and calculate midsleep timings and social jetlag. The participants were asked to report their sleep-wake timings before and after the introduction of COVID-19 measures (which were characterized as before and during "lockdown" in the survey). Social jetlag was calculated as the absolute difference between midsleep on workday and work-free day, both before and during restrictions. A work-free day is any day when sleep start (the night before the work-free day) and sleep end (in the morning of the work-free day) times are not dictated by work or school commitments. As per standard protocol for calculating midsleep values for work-free days, a sleep correction was applied to work-free day midsleep timings (MSFsc) for participants who had longer sleep duration on work-free days; these participants slept longer on work-free days to compensate for sleep debt accumulated over the week, which was adjusted to obtain the most reliable work-free day midsleep timing as accurately as possible ((MSFsc=MSF– (SDf-SDweek)/2); Roenneberg & Merrow, 2007).

Key sleep parameters, such as sleep start, sleep end and sleep duration were also calculated for both before and during restrictions. To recognise the potential reduction in accuracy associated with retrospective application of the μMCTQ, the sleep-wake timings before restrictions were rounded up or down to the nearest 15-minutes intervals, and for consistency the same rounding was applied to the timings reported for during restrictions. The Pittsburgh Sleep Quality Index (Buysse et al., 1989) was also administered to assess sleep quality during restrictions, but for the brevity of survey, participants were not asked to complete the PSQI retrospectively. Instead, participants were requested to rate their sleep quality before and during restrictions with two questions, on a single item scale of zero to ten, with higher scores indicating better sleep. Further demographic information was also obtained, including age, sex and shift and essential work status during the period of restrictions.

4.2.3 Statistical analyses

Statistical analysis was conducted in SPSS (IBM Coroporation). Paired sample *t*-tests or Wilcoxon Signed Rank tests were used to compare mean values of midsleep, social jetlag and sleep debt before and during restrictions, depending on whether the dependent variable was normally distributed. Chi-square tests for independence were used for relationships between categorical variables. Correlation analysis was conducted with either Pearson's product moment correlation or with Spearman's Rho, depending on the distributions of the variables of interest.

Between-groups multivariate analysis of covariance (MANCOVA), controlling for age and sex, was conducted to examine the effects of work status on the change in sleep timings and social jetlag. For paired tests $p<0.05$ was taken as indicating a statistically significant effect and a more stringent value of $p<0.01$ was applied for the MANOVA, as the assumption of equality of variance was not fulfilled with this sample. Effect sizes were calculated as eta^2 for *t*-tests and partial eta^2 for the MANCOVA, and interpreted according to Cohen's guidelines (Cohen, 1988).

4.3 Results

Table 4.1 shows the demographic profile of the study sample (63% females, mean age =40.2 (s.d=12.7)). Following the exclusion of shift workers, a total of 797 participants were included. Of these participants, 80% indicated they were not essential workers whilst 17% identified as essential workers and continued to attend their place of work during the restrictions (information on work status was missing for 3% of participant). At the time of the survey completion participants had been under restrictions (required to work from home) for 2-4 weeks.

N=797 **Mean age = 40.2 (SD=12.7)**		
	n	%
Sex		
Female (mean age=40.0, SD= 12.2)	499	62.7
Male (mean age= 40.5, SD= 13.6)	298	37.3
Age groups		
18-25	109	14
26-35	195	25
36-45	217	27
46-55	176	22
56-65	76	10
>65	24	3
Work status		
Essential services (mean age=39.5, SD=10.12; 67.4% females	132	17
Work from home (mean age=40.3, SD=13.20; 61.9% females)	641	80
Information missing (mean age=39.1, SD=13.46; 45.8% females)	24	3

Table 4.1 Demographic constitution of the study sample
Shift workers were excluded. Of the non-shift work participants, 17% were essential workers (work status information was missing for 3%). The sample was predominately female, and nearly half of the sample was aged between 36-55.

4.3.1 Sleep-wake timings before and during the pandemic

The introduction of restrictions was associated with changes in the timing of midsleep on work and work-free days and in social jetlag (Table 4.2 and Figures 4.1A-D). Midsleep on workdays was significantly later following the introduction of restrictions (03:25 vs 04:19; t=18.164, df=796, SE=0.05, $p<0.001$; Figure 4.1C). A smaller change of 31 minutes was observed in midsleep on work-free days during the restrictions (04:08 vs 04:39; t= 13.721, df=796, SE=0.04, $p<0.001$; Figure 4.1A-B). Social jetlag decreased by 29 minutes following the imposition of restrictions (1h 06 mins vs 37 mins; Z=-14.583, $p<0.001$; Figure 4.1D). There was a decrease in number of participants with midsleep on workdays in the early hours of the morning (midnight-2am and 2am-4am), and an increase in later midsleep timings (from 4am to 6am and later than 6am; $p<0.001$; Table 4.2). Similarly, on work-free days, there was a decrease in number of participants with early midsleep timings between 2am-4am, but there was an increase in midsleep timings between 4am-6am and after 6am ($p<0.001$; Table 4.2). Notably the percentage of participants reporting no social jetlag increased from 18% before restrictions to 45% during restrictions ($p<0.001$; Table 4.2). The proportion of participants who reported using an alarm clock on workday fell from 80% before restrictions to 38% during restrictions ($p<0.001$; Table 4.2).

During restrictions, sleep-wake timings on workdays shifted closer to sleep-wake timings on work-free days, resulting in a number of changes in key sleep parameters and social jetlag (Table 4.2). Both sleep start and sleep end on work and work-free days during restrictions were later than before restrictions. Restrictions were also associated with changes in differences in sleep end time between work and work-free days: before restrictions, the mean sleep end time on work-free days was 1 hour 31 minutes later than on workdays, but during restrictions this difference was only 45 minutes ($p<0.001$). Similarly, sleep start time difference between work and work-free days reduced during restrictions, from a mean of 38 minutes before to 21 minutes during restrictions ($p<0.001$).

Consequently, the amount of sleep debt accumulated in the working week reduced during restrictions (20 minutes before restrictions and 11 minutes during restrictions; *p*<0.001). However, the average sleep duration for workdays was only 8 minutes longer than before restrictions (*p*=0.012) and work-free day sleep duration was shorter by a mean of 22 minutes during restrictions (*p*<0.001). This result indicates that for a 5 workdays/2 work-free days week the total change in sleep duration over the work week (5x8min=40min) is balanced by shorter work-free day sleep (2x22min=44min). The mean difference in sleep duration between work and work-free days was smaller during restrictions than before, 53 minutes before and 23 minutes during restrictions (*p*<0.001).

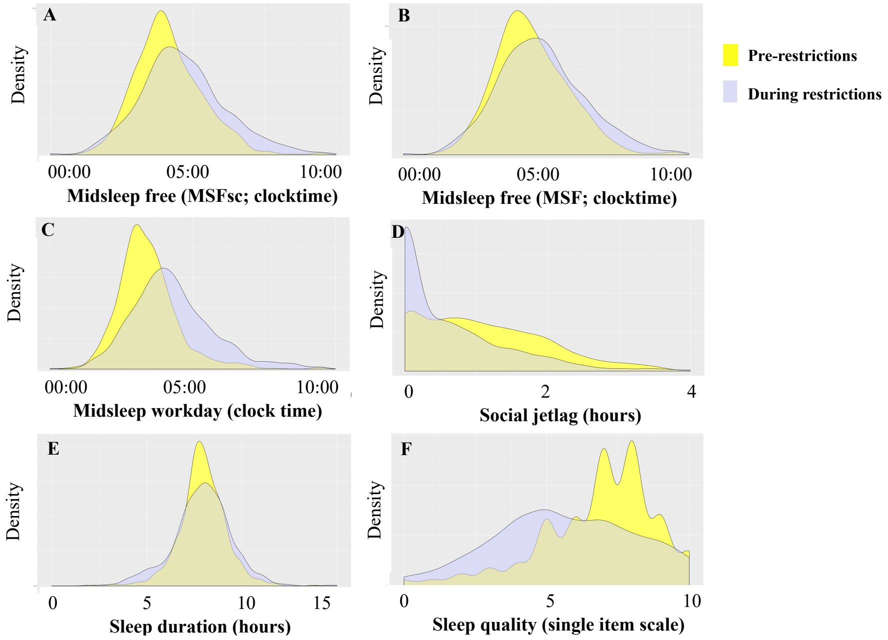


Figure 4.1. Sleep timings and social jetlag before and during the restrictions

Density plots illustrating the distributions of measures of sleep timing and quality before (yellow) and during the COVID-19 restrictions in Ireland. **A**. MSFsc for time of midsleep on work-free days, corrected for sleep debt; **B.** MSF for the time of midsleep on work-free days, not adjusted for sleep debt; **C**. MSW for the time of midsleep on workdays; **D.** SJL for Social Jetlag; **E.** SD for average sleep duration across the week; **F**. SQ for the single-item measure of sleep quality.

	Before Restrictions	**During Restrictions**
Alarm clock use ($p<0.001$)		
Yes	639 (80%)	306 (38%)
No	162 (20%)	495 (62%)
Midsleep workday ($p<0.001$)	03:25 (SE=0:04)	04:19 (SE=0:06)
Midnight-2am	32 (4%)	22 (3%)
2am-4am	566 (71%)	313 (39%)
4am-6am	178 (22%)	359 (45%)
Later than 6am	25 (3%)	107 (13%)
Midsleep free day$_{sleep\ corrected}$ **($p<0.001$)**	04:08 (SE=0:04)	04:39 (SE=0:05)
Midnight-2am	13 (2%)	20 (2%)
2am-4am	371 (46%)	234 (29%)
4am-6am	354 (44%)	398 (50%)
Later than 6am	63 (8%)	149 (19%)
Social Jetlag ($p<0.001$)	1h 6 min (SE=0:03)	37 min (SE=0:03)
No SJL	148 (18%)	361 (45%)
Less than 1 hour	236 (30%)	223 (28%)
1-2 hours	310 (39%)	168 (21%)
2-3 hours	82 (10%)	33 (4%)
More than 3 hours	25 (3%)	16 (2%)
Sleep quality (1-10 scale; $p<0.001$)	6.87 (SE=0.07)	5.69 (SE=0.09)
Sleep quality (PSQI)		
Good sleep	-	205 (27%)
Poor sleep	-	549 (73%)
Sleep start workday ($p<0.001$)	23:35 (SE=0:04)	00:23 (SE=0:05)
Sleep end workday ($p<0.001$)	07:15 (SE=0:04)	08:11 (SE=0:06)
Sleep start free day ($p<0.001$)	00:13 (SE=0:05)	00:44 (SE=0:06)
Sleep end free day ($p<0.001$)	08:46 (SE=0:06)	08:56 (SE=0:07)
Sleep duration workday ($p=0.012$)	7h 40mins (SE=0:04)	7h 48mins (SE=0:06)
Sleep duration free day ($p<0.001$)	8h 33mins (SE=0:05)	8h 11mins (SE=0:06)
Sleep debt ($p<0.001$)	20 min (SE=0:01)	11min (SE=0:01)

Table 4.2 Sleep timing and social jetlag before and during restrictions

Pandemic restrictions were associated with changes in sleep timings, social jetlag and sleep quality. Workday midsleep was significantly later following the introduction of restrictions. The gap between work and work-free day midsleep became smaller and sleep debt reduced, which resulted in a significant reduction in social jetlag during the pandemic.

4.3.2 Relationship between changes in sleep parameters during the pandemic

Next, the relationship of the change in social jetlag to the changes in the various other sleep parameters following imposition of societal restrictions (Figure 4.2) was examined. To do this, the change (Δ; from before to during restrictions) for each participant for each parameter was calculated. Δ social jetlag was strongly associated with Δ midsleep workday (r =-0.57, $p<0.001$) indicating an association between later midsleep on workdays during restrictions and decreased social jetlag; Δ sleep start workday (r =-0.45, $p<0.001$) indicating an association between a move towards later sleep start times on workdays during restrictions and decreased social jetlag; and Δ sleep end workday (r=-0.52, $p<0.001$) indicating an association between a move to later wake times on workdays during restrictions and decreased social jetlag .

Δ social jetlag was more weakly associated with sleep timings on work-free days; Δ midsleep on work-free days (r=-0.11, $p<0.01$) and Δ sleep duration work-free days (r=0.19, $p<0.001$), indicating that longer sleep duration on work-free days during restrictions was associated with increases in social jetlag. Δ social jetlag was not associated with changes in sleep start /sleep end timings on work-free days. These data would suggest that the reduction observed in social jetlag is primarily driven by the changes in sleep-wake timing on workdays following the introduction of restrictions.

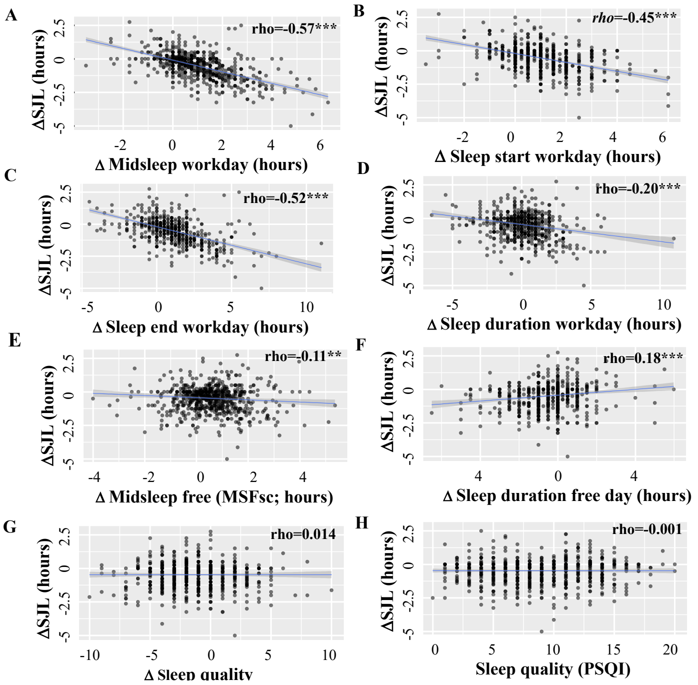


Figure 4.2. Correlations between Δsocial jetlag and other sleep parameters.

Scatterplots illustrating the correlations between the change in social jetlag following the imposition of restrictions and in other parameters of sleep timing. Δ social jetlag was strongly associated with Δ midsleep workday, Δ sleep start workday and Δ sleep end workday, indicating an association between a move to later sleep-wake times on workdays during restrictions and decreased social jetlag.

4.3.3 Sleep quality during the pandemic

Participants were asked to rate their sleep quality before and during restrictions on a one to ten scale, with higher scores indicating better sleep quality. This rating declined after the imposition of restrictions (6.87+0.07 to 5.69+0.09, $p<0.001$, Table 4.2 and Figure 4.1F). 73% of the participants who completed the PSQI reported poor quality sleep during the restrictions (indicated by PSQI global scores of >5; Table 4.2). The ten-point scale rating of sleep quality during restrictions had a strong negative correlation with global PSQI score (r=-0.764, $p<0.001$), suggesting that the single item rating was a reasonable indicator for comparison of sleep quality before and during restrictions. PSQI score associated with Δ midsleep workday (r=0.12, $p<0.001$), Δ midsleep work-free day (r=0.08, $p<0.05$), Δ sleep start workday (r=0.30, $p<0.001$) and Δ sleep start work-free day (r=0.27, $p<0.001$). There was no significant association between Δ social jetlag and PSQI scores.

4.3.4 Impact of work status on social jetlag during the pandemic

Shift workers were excluded from the main analysis to study the impact of the restrictions on sleep-wake timing independent of the effects of varied work schedules. Shift work was defined as work schedules that included working between 12-7am in the morning. This section examines the effects of work status (essential worker versus working from home) on sleep-wake timings during the restrictions. During the restrictions, students and most office workers worked from home (80% of the sample), while only essential workers (17% of the sample) providing essential services such as healthcare, food/grocery or public transportation continued to go to work.

A between- groups multivariate analysis of variance was conducted to examine the effects of essential services work on Δ sleep start and end, Δ midsleep, Δ sleep duration and Δ social jetlag. Essential worker status had a significant but small effect on Δ midsleep work day ($F_{2, 796}$= 11.9, $F_{1, 771}$= 23.00 p<0.001, partial eta^2= 0.029), Δ social jetlag ($F_{2, 796}$= 10.9, $F_{1, 771}$= 21.98 p<0.001, partial eta^2= 0.028), Δ sleep duration work day ($F_{2, 796}$= 8.4, $F_{1, 771}$= 16.11 p<0.001, partial eta^2= 0.021) and Δ sleep end on work day ($F_{2, 796}$= 15.5, $F_{1, 771}$= 30.06 p<0.001, partial eta^2= 0.038). For all of these measures, the change in sleep timing associated with the imposition of restrictions was lower for essential workers compared to those who were working from home. There were no significant differences between essential and non-essential workers in the changes in sleep start or end times or sleep duration on work-free days.

The changes in sleep parameters, for essential workers was significantly different than those who were required to work from home (Table 4.3). Essential workers had a 28 minutes and 16 minutes shift to later midsleep on workday and work-free day respectively, while those who worked from home had significantly larger shifts in workday midsleep (1 hour) and work-free day midsleep (34 minutes). Essential workers had a modest later workday sleep end of 17 minutes while those who worked from home reported a later workday sleep end of 1 hour.

Essential workers experienced a smaller reduction in social jetlag (only 10 minutes) compared to those working from home (32 minutes) and rated their sleep quality poorer than those who worked from home.

Δ during-to-before restrictions (Mean ±SEM)	**Essential Worker**		*p*	Partial Eta^2
	No	**Yes**		
Δ Midsleep work day (mins)	+58 (±3)	+28 (±3)	*<0.001*	0.029
Δ Midsleep free day (mins)	+34 (±3)	+16 (±5)	*0.002*	0.013
Δ Social jetlag (mins)	-32 (±2)	-10 (±4)	*<0.001*	0.028
Δ Sleep duration work day (mins)	+14 (±4)	-21(±7)	*<0.001*	0.021
Δ Sleep duration free day (mins)	-22 (±4)	-5 (±8)	*0.917*	0.000
Δ Sleep start work day (mins)	+51 (±3)	+38 (±6)	*0.035*	0.006
Δ Sleep end work day (mins)	+64 (±4)	+17 (±6)	*<0.001*	0.038
Δ Sleep start free day (mins)	+34 (±4)	+27 (±6)	*0.231*	0.002
Δ Sleep end free day (mins)	+12 (±3)	+4 (±6)	*0.241*	0.002

Table 4.3 Between-groups analysis of changes in sleep timings and social jetlag by work status
Change in mean sleep timings, sleep duration and social jetlag are shown in hours/minutes with standard error of means in parenthesis. Work status had a significant impact on changes in sleep timings, sleep duration and social jetlag during the pandemic. Those who worked from home had the most significant shifts in sleep timings on workdays. Essential workers had smaller changes to social jetlag.

4.4 Discussion

This study along with other sleep studies conducted during the first wave of the COVID-19 pandemic (Blume et al., 2020; Wright et al., 2020) illustrate, through the prism of the unique natural experiment of the radical COVID-19 restrictions, the profound influence of work and social schedules on the timing of sleep behaviour. The study provides evidence for the strong influence of work schedules on sleep-wake timing, and how changes to sleep timing on workdays could reduce social jetlag.

The most marked changes were associated with working days, and included later timing of midsleep, later wake times and markedly decreased use of alarm clocks. Although a later time of midsleep on work-free days during restrictions was observed, changes to work-free day sleep timings were lesser when compared to the changes in workday sleep. Furthermore, the findings of this study show that sleep timings were associated with work status. While working from home associated with an hour later sleep end on workday, essential workers who were required to attend their place of work in-person experienced smaller shifts to later timings on both work and work-free days. Although essential workers had later sleep end time on workdays the change was not as large as the change experienced by non-essential workers. This suggests that the time saved from commuting to a physical space for work may have been added onto the workday sleep timing for non-essential workers resulting in the changes observed.

Reduction in social jetlag observed during the restrictions were largest in those who were working from home. Those who worked from home had significant shifts to later sleep timings on workdays. Importantly, the results of this study suggest that the changes observed in social jetlag during the pandemic were driven by changes in sleep timings on workdays. This suggests that workday sleep influences social jetlag, and that an adjustment to sleep timings on workday through modified work schedules may facilitate reduction of social jetlag. This finding further reinforces the importance of working and commuting schedules for determining sleep timing in industrialized societies.

A reduction in social jetlag may represent a beneficial outcome as social jetlag is associated with a number of adverse health including metabolic disorders (Kelly et al., 2018), cognitive and affective impairments (McGowan et al., 2016), and lower academic achievement and quality of life (Chang & Jang, 2019). However, in this study as well as in that of Blume et al (2020), decreased social jetlag and longer sleep duration during COVID-19 restrictions were not associated with better subjective sleep quality.

Indeed, some studies have reported high prevalence of insomnia and daytime sleepiness during COVID-19 restrictions (Janati Idrissi et al., 2020), suggesting that there are other significant COVID-19 related factors that may override any benefits derived from changes in sleep timing and reductions in social jetlag. Clearly the impact of the COVID-19 restrictions on sleep behaviours may not be homogenous across the population and may be moderated by factors such as household composition and family structure, socioeconomic status, age and caregiver duties (Usher et al., 2020).

Mental health is another such factor that may influence sleep quality. For example, increased anxiety levels have been previously reported during epidemics and pandemics as a result of heightened fear of contagion, fear of possible death, loss of contact with loved ones and financial worries (Brooks et al., 2020; Taha et al., 2014). Similarly, during the COVID-19 pandemic high prevalence of anxiety and worries have been noted (Jungmann & Withhof, 2020; Lades et al., 2020). Given the intimate relationship between sleep quality and affect (Konjarski et al., 2018), it is therefore not surprising that potential benefits from the reduction of social jetlag did not translate into increases in subjective sleep quality. This study did not assess psychological distress and as such the relationships between changes in sleep timing, sleep quality and psychological distress could not be directly tested.

4.4.1 Limitations

There are a number of important caveats and limitations to consider in the interpretation of the current study. It is unclear if the changes in workday sleep timing are directly from the time saved from commuting or if there was an official change to work start times. There is no record on prepandemic commuting times that might have provided insight into factors responsible for the changes; previous research has indicated an inverse linear relationship between commuting times and sleep duration (Petrov et al., 2018). It may be that those with the longest prepandemic commute experienced the greatest changes in sleep timing following the imposition of restrictions and the flexibility built into working from home allowed a self-dictated work start time.

All measures were based on subjective measures, and the assessment of measures prior to the imposition of restrictions was by necessity retrospective. This clearly introduces the risk of recall bias. Given the nature of the sudden onset of the COVID-19 crisis in Ireland in spring 2020, a prospective approach was not feasible. Further, to increase participant completion rate a single-item rating scale for sleep quality before and during restrictions was used.

The sample was collected by convenience and should not be treated as nationally-representative. A majority of the respondents were females, and older. The study did not assess if the participants had children or caregiver duties; attending to home schooling or caring for a sick family member could have resulted in different results than observed here. Females and older participants may have had a different experience of the restrictions and working from home, have experienced different caregiving or other family duties such as supervising home schooling (Banks & Xu, 2020).

Another important limitation is that this study did not assess daylight exposure and engagement in physical activity. Daylight is considered an important zeitgeber in the synchronization of the internal sleep-wake rhythms and a reduction in daylight exposure during the pandemic has been linked to delayed midsleep timings (Korman et al., 2022).

4.5 Conclusion

This study reinforces the importance of working and commuting schedules for determining sleep timing in industrialized society and identifies workday sleep timings as a strong influencer, and as a potential modifiable risk factor, of social jetlag. However, benefits arising from aligning sleep timings across the week and reducing social jetlag may be offset by other factors, and sleep quality may not necessarily improve. Factors such as psychological distress, for example depression and anxiety, may have a stronger influence for sleep quality. The lack of comparable improvement in sleep quality may well be contextual to the emotional and psychological stress of the COVID-19 pandemic.

Chapter 5

Examining the associations between midsleep timings, demographic factors and insomnia, and social jetlag

Abstract

This study set out to describe the association between social jetlag and midsleep timings before and during the pandemic. The study further explored the associations between social jetlag and demographics, insomnia, depression and anxiety during the pandemic. There was a moderately strong association between chronotype and social jetlag in the prepandemic reference samples and the association was weaker during the pandemic. The strength of the association between social jetlag and midsleep timings on workdays was relatively stronger but was still in the weak range. Midsleep timings presented with the strongest association with social jetlag as expected, and additionally higher social jetlag associated with younger age, longer weekly number of hours worked and urban locations. Late chronotype associated with later midsleep timings on workdays, male sex, younger age, longer weekly sleep duration, urban location and having no caregiver responsibilities. Late midsleep timings on workdays associated with being male, younger, and sleeping longer. Earlier midsleep timings on workdays associated with longer weekly number of hours worked. Insomnia, depression and anxiety did not associate with social jetlag. There was an association between late chronotype and depression symptoms. Early chronotype associated with anxiety symptoms. Late midsleep timings on workdays associated with depression symptoms, and early midsleep timings on workdays associated with insomnia symptoms. Participants with insomnia symptoms had significantly higher depression and anxiety symptoms. Although midsleep timings on workdays, chronotype and social jetlag are closely associated with one another, the results in this study suggests they may be differentially associated with risk factors. Furthermore, sleep quality and insomnia may be distinct sleep parameters and the factors that associate with these constructs may have differential impact on social jetlag and midsleep timings.

5.1 Introduction

Significant changes to sleep behaviours have been recorded since the implementation of social and travel restrictions that many countries had imposed to mitigate the spread of the COVID-19 virus. As office workers and students around the globe came under work-from- home orders, the influence of work and social schedules on sleep became clearer: sleep timings on workdays generally became later and the gap between work and work-free day sleep timings became smaller leading to a reduction in social jetlag around the world (Blume et al., 2020; Korman et al., 2020; Leone et al., 2020; Wright et al., 2020;). Prepandemic sleep on workdays was often dictated by early work or school start times the next day, resulting in sleep loss especially for individuals who prefer, or whose internal body clocks are timed for, late bedtimes and wake timings.

While sleep-wake timings on workdays are dictated by socially imposed schedules, sleep-wake timings on work-free day, unencumbered by external time obligations, are freer to align with the actual biological propensity for sleeping and waking. Sleep on work-free day is believed to be the most reliable indicator of the phase of entrainment of the internal clocks for sleep-wake rhythms (Roennenberg et al., 2019). In Ireland, work-free day sleep timings became later during the first round of restrictions but only marginally compared to the shift in workday sleep-wake timings (see chapter 4). Similarly, Korman et al., 2020 (a study involving 40 different countries) reported that while workday sleep duration increased by 6% in their study, work-free day sleep duration decreased by only 2%. This, they argued, is indication that longer sleep on work-free days is not merely a compensation for the accumulated sleep loss over the week but represents the actual individual sleep requirement.

Typically, late chronotypes struggle to fall asleep earlier on workdays to compensate for waking up earlier for work obligations (Roenneberg et al., 2019 Wittman et al., 2006), and often the workday sleep cycle of late chronotypes is interrupted by alarm clocks. Nearly 56% of participants in a database (the MCTQ from Germany) presented with a midsleep timing on work-free day between 04:30 and 11:00 (categorized as slightly late to extremely late; Roenneberg et al., 2019). In the same database, nearly 40% presented with 1-3 hours of social jetlag

These are significant percentages of a given population considering the database had some 300,000 (as of 2019) participants and indicates how widespread late chronotypes and social jetlag are in industrialized countries. As social jetlag is the difference between the midsleep timings on work and work-free day, individuals with late chronotypes typically present with higher social jetlag as their sleep-wake timings on work-free days is significantly later than their workday sleep-wake timings. The later the chronotype and the wider the gap between work and work-free day midsleep timings, the higher the social jetlag. The two sleep parameters are close associates with prepandemic studies identifying chronotype as a key predictor of social jetlag (Pilz et al., 2018; Reis et al., 2020).

As both work and work-free day midsleep timings are components of the construct of social jetlag, it is not surprising that a change in one of them results in a change in social jetlag. This study examines the association and relationship between social jetlag and midsleep timings on work and work-free days further by comparing the strength of the relationship before the pandemic and querying if there is a change in the strength during the pandemic. In the previous study (chapter 4), the primary focus of assessment was sleep-wake timings and how changes during the pandemic affected social jetlag. In this study, other factors that may have an influence on social jetlag are also explored.

Both chronotype and social jetlag are known to vary by age and sex; with younger age and males most often associated with late chronotype and higher social jetlag (Fischer et al, 2017; Roenneberg et al, 2004). Studies have also shown chronotype is earlier in rural societies (Carvalho et al., 2014). Activities during waking hours, such as working late hours and the extension of the biological night with the aid of artificial light (Lunn et al., 2017; Ohida et al. 2001; Roenneberg & Merrow, 2007), may affect bedtimes. Providing care for someone (for example, a family member with an illness or children) has been associated with more sleep problems, shorter sleep duration, more somatic symptoms, negative health outcomes and generally lower life satisfaction (Haugland et al., 2019; Johnson et al., 2018; Rowe et al., 2008). Thus, during the pandemic, working hours, caregiver responsibilities, and city versus rural location may have been factors impacting social jetlag and midsleep timings. This study explored if there was an association between these variables and social jetlag.

The reduction in social jetlag during the pandemic did not necessarily result in a corresponding improvement in subjective sleep quality. On the contrary, poor sleep quality and insomnia have been reported to have been on the rise since the start of the pandemic (Janati Idrissi et al., 2020; Kokou-Kpolou et al., 2020; Lahiri et al., 2021; Mandelkorn et al., 2021; Pieh et al., 2021; Voitsidis et al., 2020). A study from the Netherlands reported varied sleep quality, with poor prepandemic sleep associating with improved sleep quality and good prepandemic sleep associating with reduced sleep quality during restrictions (Kocevska et al., 2020). The International COVID-19 Sleep Study (ICOSS) reported a high prevalence of insomnia symptoms, depression and anxiety during the early stages of the pandemic across 13 different countries (Morin, et al., 2021).

At the start of the pandemic a significant increase in psychological distress was predicted (Pfefferbaum & North, 2020; Xiang et al., 2020). While one review did find evidence of psychological distress in some populations at the start of the pandemic (Rajkumar, 2020), another review indicated that the high prevalence of distress observed in the initial months of the pandemic (between March -April 2020) returned to prepandemic levels in the later months (around May -July 2020; Robinson et al., 2022).

Overall, these studies suggest that the impact of the pandemic on sleep quality and psychological distress could be highly country-specific and an individualized experience. As sleep is known to be negatively impacted by mood and affect (Konjarski et al., 2018), variability found in sleep quality during the pandemic could be explained by the differential emotional responses to the pandemic. Studies found sleep quality ratings were poorer in those with higher negative affect and worries than those without (Kocevska et al., 2020).

Based on the current literature, this study hypothesized higher jetlag and late chronotype would associate with younger age, longer working hours, caregiver responsibilities, urban locations and more depression and anxiety symptoms. A further hypothesis is that both chronotype and social jetlag would associate with insomnia symptoms, and insomnia symptoms would associate with higher depression and anxiety symptoms.

5.2 Methods

5.2.1 Recruitment and data collection

Sleep-wake timings during the pandemic were collected as part of a larger UK based study (the COVID-19 Psychological Research Consortium (C19PRC); McBride et al., 2020). The Irish arm of the C19PRC study was launched to assess the mental health impact of COVID-19 in Ireland in the first year of the pandemic. Adult participants residing in Ireland were recruited via quota sampling (based on age, sex and geographical distribution as per the 2016 Irish census) to ensure a nationally representative sample. After excluding shift workers, only participants aged 18 years and older, residing in Ireland during the pandemic, and with complete responses to the sleep-wake questions on the survey were included in this study. Ethical approval was granted by the Research Ethics Committee of Maynooth University. A methodological protocol paper on the C19PRC data is available (Spikol et al., 2021).

The longitudinal survey, completed in five waves over 12 months, was conducted online via the Qualtrics survey platform (www.qualtrics.com). The survey started with Wave 1 in March/April 2020 during the first week of the first country-wide full restrictions in Ireland, and ended with Wave 5 in March/April 2021, a year late and while Ireland was under a third nation-wide full restrictions. Sleep timing specific questionnaire (the MCTQ) was only added at Waves 4 and 5. This study is based on data collected from Wave 4 (hereinafter December 2020; completed from 2nd to 22nd December 2020) and Wave 5 (hereinafter March 2021; completed from 19th March to 9th April 2021). The first work-from-home orders and suspension of non-essential retail and travel in Ireland were imposed on 27th March 2020. Full restrictions were eased in various stages over the summer months. In October 2020 a second full restriction was ordered, with yet a third country-wide full restriction imposed on 24th December 2020.

December 2020 data collection was completed just before the third full country-wide restrictions and approximately eight months after the start of the pandemic. At the time of March 2021 data collection, Ireland was three months into the third restrictions and had been under various social and travel restrictions for a year. Refer to figures 1.13 in chapter 1 for a timeline of the nation-wide full restrictions in Ireland during the periods of data collection.

Prepandemic midsleep timings and social jetlag values from the reference samples are from datasets discussed in chapters 2 and 4. Reference sample 1 was collected between 2012–2017, as part of final-year undergraduate research projects investigating sleep in a young adult sample (refer to chapter 2/ Table 5.1). Reference sample 2 was collected from 11th April to 4th June 2020 during the first wave of restrictions in Ireland, but participants were asked to retrospectively report their sleep-wake timings from before the restrictions were enforced (refer to chapter 4/Table 5.1). All participants in the reference samples, after exclusion of shift workers, were adults and resident in Ireland at the time of completing the surveys. Recruitment was by convenience sampling via national media posts, personal contacts, social media or research recruitment services. Ethical approval for all surveys was granted by the Research Ethics Committee of Maynooth University and informed consent was indicated by all participants whose data was included in the analysis.

5.2.2 Measures

Midsleep timings and social jetlag were assessed via the Munich Chronotype Questionnaire (MCTQ) before the pandemic and the ultra-short version of the MCTQ (µMCTQ; Ghotbi et al., 2020) during the pandemic. Midsleep timings on work-free days was used as an indicator for chronotype. A sleep correction was applied to the calculation of midsleep on work-free days, for participants who slept longer on work-free days to compensate for sleep debt accumulated over the week (MSFsc=MSF– (SDf-SDweek)/2); Roenneberg & Merrow, 2007). Social jetlag was calculated as the absolute difference between midsleep on work and work-free days.

The Sleep Condition Indicator (SCI; Espie et al., 2014), an eight item self-report scale, was used to assess insomnia symptoms. The SCI is designed to facilitate diagnosis of insomnia based on the DSM-5 threshold criteria for insomnia disorder (Espie et al., 2014). The first four items assessed ease of falling asleep (from 0-15 min to >61mins), duration of night-time awakenings (from 0-15 min to >61mins), number of nights in a week with trouble sleeping (0-7 days) and sleep quality (from “very good” to “very poor”). The next three items asked participants if their sleep problems affected their mood, personal relationships, concentration, productivity and troubled them in general (from “not at all” to “very much”). The final question assessed how long the participants have had problems with sleep (from “I don’t have a problem” to “>1 year”). The responses were rated on a five-point Likert scale from zero to four, with possible total scores between zero and 32. Higher scores reflect better sleep quality and a score of 16 or less is indicative of possible insomnia.

The Patient Health Questionnaire-9 (PHQ-9; Kroenke et al., 2001) was used to assess symptoms of depression. The PHQ-9 has a score range from zero-27. Higher scores on the PHQ-9 indicate more symptoms of depression with a score of 10 or more indicating a possible DSM-5 diagnosis of depression. The Generalized Anxiety Disorder 7-item scale (GAD-7; Spitzer et al., 2006), with a score range from zero-21, was used for anxiety with a score of ≥ 10 indicating presence of anxiety symptoms. Demographics, work and psychological distress variables from the C19PRC surveys used in this study include age/sex, urban or rural location, caregiver responsibilities, weekly hours worked, depression symptoms, anxiety symptoms and insomnia symptoms.

5.2.3 Statistical analyses

Reference sample 1 is independent of the other samples used in this study. Reference sample 2 and March 2020 sample consist of same set of participants (the sample used in chapter 4) with sleep-wake timings before and during the pandemic. The December 2020 and March 2021 samples collected during the pandemic are from a different dataset and independent of the other samples (refer to Table 5.1 for number of participants in each sample). The March 2021 sample consist of some repeat participants from December 2020 (refer to Table 5.2).

There was a difference in the age profile, social jetlag and midsleep timings between the prepandemic reference samples, as well as between reference sample 1 and the pandemic samples. Furthermore, reference sample 2 was a retrospective reporting of sleep-wake timings before the pandemic (it refers to the prepandemic sleep-wake timings of participants in the March 2020 sample). As such, all comparisons of prepandemic and pandemic midsleep timings and social jetlag, and the changes in the association between these variables, are qualitatively described. The threshold scores on the insomnia and psychological distress measures were used for reporting prevalence of participants meeting the criteria for diagnosis of insomnia, depression and anxiety disorders in December 2020 and March 2021.

Statistical analyses were conducted in SPSS (IBM Corporation). The correlation between social jetlag and midsleep timings were assessed via Spearman's Rho. A paired sample *t*-tests or Wilcoxon Signed or the Chi-square tests for independence were used to assess within participant changes in social jetlag, midsleep timings and weekly sleep duration, and to assess statistical differences in participants who responded in March 2021 and those who did not.

The associations between social jetlag and insomnia, psychological distress (depression/anxiety) and other factors (urban/rural location, caregiver responsibilities, weekly hours worked) in December 2020 and March 2021 were assessed cross-sectionally via standard multiple regression. Standard multiple regression analysis was conducted with social jetlag as the dependent variable and demographic factors (urban/rural location, caregiver responsibilities, weekly hours worked), insomnia, depression and anxiety as predictor variables. Midsleep timings on work and work-free days and age/sex were included in the model. The associations between these variables and midsleep timings were analyzed as well (one model each for workdays and work-free days).

Independent-sample *t*-test (for midsleep timings on work-free day) or the Mann Whitney U test (for social jetlag) were used for groupwise analyses. A multivariate analysis of variance (MANOVA) was used to assess mean differences in psychological distress for participants with and without insomnia symptoms, controlling for age and sex. $p<0.05$ was taken as indicating statistical significance and the strength of the relationship between variables were assessed according to Cohen's (1988) guidelines.

5.3 Results

5.3.1 Demographics of study samples

830 participants (mean age: 46.91, SD=15.97; 54% females) were included in December 2020. 55% were 45 years old or older, 25% reported living in a city and 25% reported they were caring for someone. The average hours worked was 19.72 (SE=0.63). 29% met the criteria for insomnia disorder, 23% met the criteria for clinical depression and 17% met the criteria for anxiety disorder. In March 2021, 843 participants (mean age: 46.14, SD=15.98; 54% females) were included. 51% were 45 years old or older and 22% reported living in a city. Information on caring responsibilities

and working hours were unavailable in March 2021. 28% met the criteria for insomnia disorder, 18% met the criteria for clinical depression and 13% in March 2021 met the criteria for anxiety disorder. Participants in the reference sample 1 were primarily students at the university (mean age=22.7, SD=5.26) and predominately females. Participants in the reference sample 2 were older (mean age=40.2, SD=12.7) and predominately females (refer to Table 5.1). Participants had been under social and travel restrictions for 5-7 weeks and 10-13 weeks in December 2020 and March 2021, respectively.

	Before pandemic Sample 1 N=1322	**Before pandemic Sample 2 N=797**	**During pandemic March 2020 N=797**	**During pandemic December 2020 N= 830**	**During pandemic March 2021 N= 843**
Age	22.7 (SD=5.26)	40.2 (SD=12.7)	40.2 (SD=12.7)	46.9 (SD=15.97)	46.1 (SD=15.98)
Sex (% females)	60.6%	62.7%	62.7%	54%	54%
City dwelling	-	-	-	25%	22%
Caring for someone	-	-	-	25%	-
Hours worked weekly	-	-	-	19.72 (SE=0.63)	-
Social jetlag	1h 40mins (1.05)	1h 6 mins (0:03)	37 mins (0:03)	38 mins (0.03)	37 mins (0.03)
Midsleep workday	04:11(0.04)	03:25 (0:04)	04:19 (0:06)	03:45 (0.05)	03:44 (0.05)
Midsleep work-free day	5:13 (1.41)	04:08 (0.04)	04:39 (0.05)	04:06 (0.05)	04:07 (0.06)
SCI score/ insomnia	-	-	-	21.48 (0.28); 29%	21.63(0.28); 28%
PHQ score/depression	-	-	-	5.86 (0.23); 23%	4.99 (0.19); 18%
Anxiety scale score/anxiety	-	-	-	4.58 (0/19); 17%	3.76 (0.17); 13%

Table 5.1 Demographics of study sample, social jetlag and midsleep timings during the pandemic
Values presented here for social jetlag, midsleep timings, insomnia and psychological variables values are means (standard error of means in parenthesis). Sleep timings/social jetlag are in clock time or hours/minutes. Percentages for insomnia and psychological distress variables are participants meeting the threshold for a diagnosis or the presence of the condition measured; a score of ≤ 16 on the Sleep Condition Indicator for DSM-5 Insomnia Disorder, ≥ 10 on the Patient Health Questionnaire -9 for DSM-5 clinical depression, ≥ 10 on the Generalized Anxiety Disorder Scale for anxiety.

5.3.2 Associations between midsleep timings and social jetlag during the pandemic

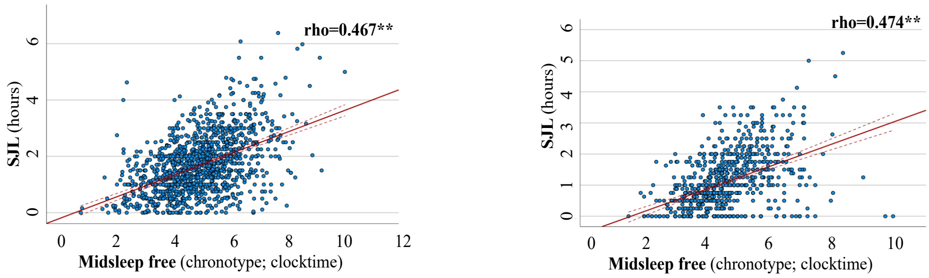
At the start of the pandemic in Ireland (March 2020), midsleep timing on workdays was 04:19h (SE=0.06), midsleep timing on work-free days was 04:39 (SE=0.05), and social jetlag was 37 minutes (SE=0.03). In December 2020, nearly 8 months into the pandemic, midsleep timing on workdays was 03:45h (SE=0.05), midsleep timing on work-free days was 04.06h (SE=0.05) and social jetlag was 38 minutes (SE=0.03). In March 2021, a year into the pandemic, midsleep timing on workdays was 03:44h (SE=0.05), midsleep timing on work-free days was 04.07h (SE=0.06) and social jetlag was 37 minutes (SE=0.03).

Midsleep timings on workday, midsleep timings on work-free day (chronotype) and social jetlag before the pandemic for the younger reference sample were 04:11h (SE=0.04), 05:13h (SE=1.41) and 1 hour 40 minutes (SE=1.05) respectively. The older reference sample, as expected and supported by studies that highlight the impact of age on sleep timings and social jetlag (Fischer et al., 2017; Roenneberg et al., 2004), presented with midsleep timings on workdays (03:25h, SE=0.04) and work-free days (04:08h (SE=0.04) that were earlier, and lower social jetlag (1 hour 6 minutes, SE=0.03) than the younger sample. Most notably, midsleep timings on work-free days was 1 hour 5 minutes later for the younger sample, with social jetlag higher by 34 minutes (and a difference of 46 minutes between the samples for midsleep timing on workdays).

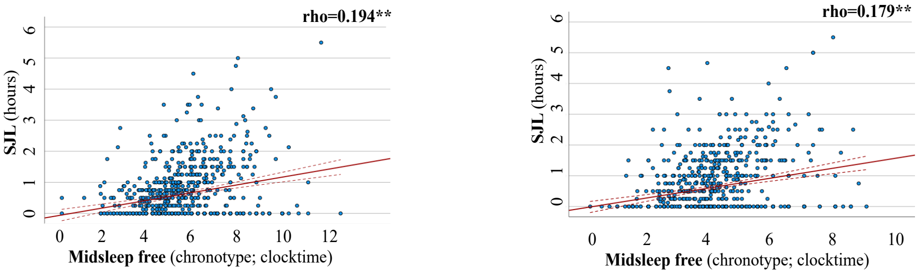
A correlation analysis revealed, as expected, a moderately strong and positive association between social jetlag and chronotype before the pandemic (Figure 5.1A-B). The correlation between social jetlag and midsleep timings on work-free days for the reference sample 1 (younger sample) was rho= 0.467 and the reference sample 2 (older sample) it was rho=0.474 (both significant at *p*<0.001). The association is weaker in different cohorts and during the pandemic (Figure 5.1C-E). In March 2020, during the first restrictions, the association was rho= 0.194, in December 2020 it was rho= 0.179, and in March 2021, it was rho=1.999 (all significant at *p*<0.001).

Social jetlag and midsleep timings on workdays demonstrated a negative association before the pandemic (Figure 5.2A-B). The correlation between social jetlag and midsleep timings on workdays for the reference sample 1 was rho= -0.098 and the reference sample 2 was rho= -0.104 (both significant at *p*<0.001). In contrast to the associations between social jetlag and midsleep timings on work-free days, social jetlag's association with midsleep timings on workdays was marginally stronger than the prepandemic associations but remained in the weak range. In March 2020, during the first restrictions, the association was rho= -0.142, in December 2020 it was rho= -0.220, and in March 2021, it was rho= -0.201 (all significant at *p* <0.001; Figure 5.2C-E).

A. Reference sample 1 (mean age= 22) **B. Reference sample 2 (mean age= 40)**



C. March 2020 **D. December 2020**



E. March 2021

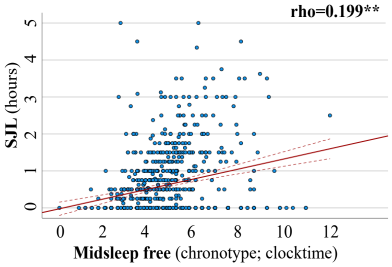


Figure 5.1 Association between social jetlag and midsleep timings on work-free day before and during the pandemic

There was a moderately strong and positive association between social jetlag and midsleep timings on work-free day (chronotype) before the pandemic **(A-B)**. However, the association became weaker during the pandemic **(C-E)**. ***p*<0.001.

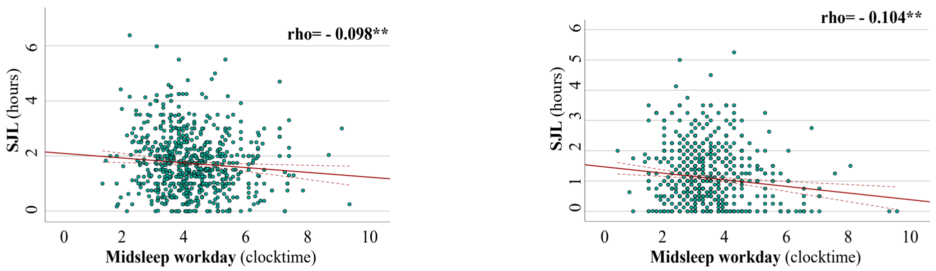
5.3.3 Within-participant changes in sleep-wake timings and social jetlag

There were 830 participants in December 2020. Of these, 330 (recontact rate =39.7%) responded to the call to participate in March 2021. Recontacts at March 2021, when compared to the non-recontacts were significantly more likely to be male (χ^2 (1, n = 829) = 6.94, p =.008) and older (t (829) = 7.43, p < .001). The recontacts and non-recontacts did not differ significantly in terms of midsleep timings, social jetlag and sleep duration. Table 5.2 summarizes the key comparisons between recontacts and non-recontacts.

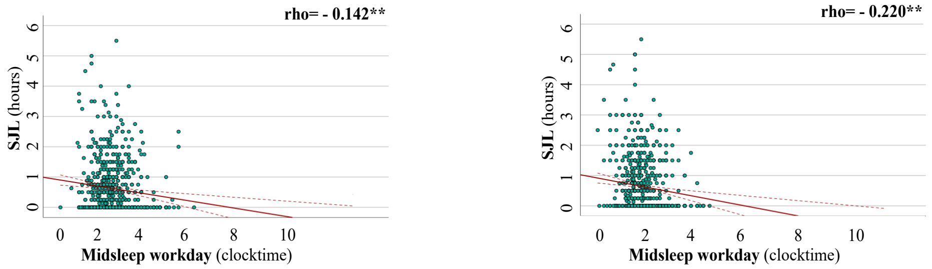
There were no significant differences in midsleep timings on workdays (03:38 vs 03:40, p=0.239, in December 2020 and March 2021 respectively) and work-free days (04:00 vs 03:59, p=0.415, in December 2020 and March 2021 respectively) for participants who responded at both assessment time points. There were also no significant differences in weekly sleep duration (7 hours 53 minutes vs 7 hours 58 minutes, p=0.149, in December 2020 and March 2021 respectively) and social jetlag (35 minutes vs 31 minutes, p=0.148, in December 2020 and March 2021 respectively) in the within participant analysis.

	December 2020 **N=830**	**Recontact** **N=330**	**Non-recontact** **N=500**
Age (*mean, std. dev)*	46.9 (SD=15.97)	51.80 (15.34)	43.64 (15.60)
Age groups (%)			
18-24	10	4	14
25-34	15	12	18
35-44	20	17	22
45-54	17	16	17
55-65	22	28	18
> 65	16	23	11
Sex (% females)	54%	48%	58%
Social jetlag	38 mins (0.03)	35 minutes (0.04)	39 minutes (0.04)
Midsleep workday	03:45 (0.05)	03:38 (0.07)	03:50 (0.07)
Midsleep work-free day	04:06 (0.05)	04:00 (0.07)	04:10 (0.06)
Weekly sleep duration	7 hours 55 mins(0.06)	7 hours 53 mins(0.08)	7 hours 56 mins(0.08)

Table 5.2 Sample demographics, and differences between recontacts in March 2021 and non-recontacts
Participants in December 2020 who also responded at March 2021 (recontacts; n=330) when compared to the non-recontacts (n=500) were more likely to be males (χ^2 (1, n = 829) = 6.94, p =.008) and older (t (829) = 7.43, p < .001). The responders and non-responders did not differ significantly in terms of the midsleep timings, social jetlag and sleep duration.


A. Reference sample 1 (mean age= 22)

B. Reference sample 2 (mean age= 40)


C. March 2020

D. December 2020

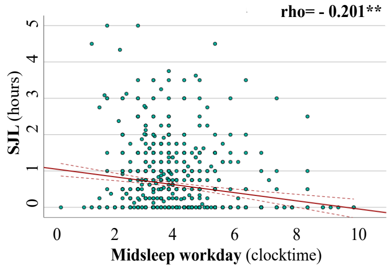

E. March 2021

Figure 5.2 Association between social jetlag and midsleep timings on workday before and during the pandemic
There was a weak negative association between social jetlag and midsleep timings on workdays before the pandemic **(A-B)**. This association remained in the weak range during the pandemic **(C-E)**. ** *p* <0.001.

5.3.4 Associations between demographic factors and social jetlag

The standard multiple regression model for social jetlag included midsleep timings on work and work-free days, weekly sleep duration, age/sex, weekly hours worked (only in December 2020), urban/rural location, caregiver responsibilities (only in December 2020), insomnia, depression and anxiety. The model as a whole accounted for 42.8% and 65.8% of the variance in social jetlag in December 2020 and March 2021 respectively (F(11,818)=55.686, *p*<0.001 in December 2020; F(9,833)=177.705, *p*<0.001 in March 2021). There were significant associations with midsleep timings, age, weekly hours worked and urban/rural location (Tables 5.3, 5.4, Figure 5.3).

Midsleep timing on work-free days (chronotype) had the strongest association (ß=0 .640, *p*< 0.001 in December 2020; ß=1.450, *p*<0.001 in March 2021), followed by midsleep timings on workdays (ß=-0.506, *p*<0.001; ß=-1.442, *p*<0.001 in March 2021). Social jetlag demonstrated a negative association with age (ß=-0.120, *p*<0.001 in December 2021; ß=-0.098, *p*=0.001 in March 2021), and a positive association with weekly hours worked (ß=0.357, *p* <0.001 in December 2020), suggesting younger age and more hours spent working associated with higher social jetlag (Figure 5.3.A-C). City/rural location demonstrated a small positive association with social jetlag but only at one time point (ß=0.061, *p*=0.004 in March 2021; Figure 5.3D). There was no association between urban/rural location and social jetlag in December (ß=0.049, *p* =0.076).

There were no associations between social jetlag and sex (ß=0.022, *p*=0.441in December 2020; ß=-0.023, *p=0.*285 in March 2021), caregiver responsibilities (ß=-0.008, *p*=0.756 in December) and sleep duration (ß=0.008, *p*=0.789 in December 2020; ß= -0.018, *p*=0.409 in March 2021). To summarize, midsleep timings presented with the strongest association with social jetlag, and additionally higher social jetlag associated with younger age, longer weekly number of hours worked and urban locations.

	Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for B	
	B	Std. Error	ß	*t*	*p*	Lower Bound	Upper Bound
Midsleep timing work-free day	0.418	0.027	0.640	15.694	0.000	0.366	0.470
Midsleep timing workday	-0.303	0.024	-0.506	-12.538	0.000	-0.351	-0.256
Weekly sleep duration	0.004	0.016	0.008	0.267	0.789	-0.027	0.036
Weekly hours worked	0.017	0.001	0.357	11.754	0.000	0.014	0.020
Age	-0.007	0.002	-0.120	-3.646	0.000	-0.010	-0.003
Sex	0.038	0.049	0.022	0.770	0.441	-0.059	0.135
Urban/rural	0.098	0.055	0.049	1.777	0.076	-0.010	0.207
Caregiver	-0.017	0.054	-0.008	-0.311	0.756	-0.123	0.090
Insomnia symptoms	-0.002	0.004	-0.016	-0.432	0.666	-0.010	0.006
Depression symptoms	0.007	0.007	0.049	0.922	0.357	-0.007	0.021
Anxiety symptoms	-0.012	0.008	-0.075	-1.502	0.134	-0.028	0.004

Table 5.3 Regression model for social jetlag (December 2020)
The model as a whole accounted for 42.8% variance in social jetlag in December 2020. F(11,818)=55.686, *p*<0.001. The analysis revealed significant associations with midsleep timings, age and weekly hours worked.

	Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for B	
	B	Std. Error	ß	*t*	*p*	Lower Bound	Upper Bound
Midsleep timing work-free day	0.917	0.026	1.450	34.680	0.000	0.865	0.968
Midsleep timing workday	-0.941	0.027	-1.442	-35.107	0.000	-0.993	-0.888
Weekly sleep duration	-0.010	0.012	-0.018	-0.827	0.409	-0.033	0.013
Age	-0.005	0.001	-0.098	-4.222	0.000	-0.008	-0.003
Sex	-0.039	0.037	-0.023	-1.069	0.285	-0.111	0.033
Urban/rural	0.127	0.044	0.061	2.921	0.004	0.042	0.213
Insomnia symptoms	-0.002	0.003	-0.019	-0.661	0.509	-0.008	0.004
Depression symptoms	0.008	0.006	0.052	1.316	0.189	-0.004	0.020
Anxiety symptoms	0.005	0.006	0.031	0.834	0.404	-0.007	0.018

Table 5.4 Regression model for social jetlag (March 2021)
The model as a whole accounted 65.8% of the variance in social jetlag in March 2021. F(9,833)=177.705, *p*<0.001. The analysis revealed significant associations with midsleep timings, age, and urban/rural location.

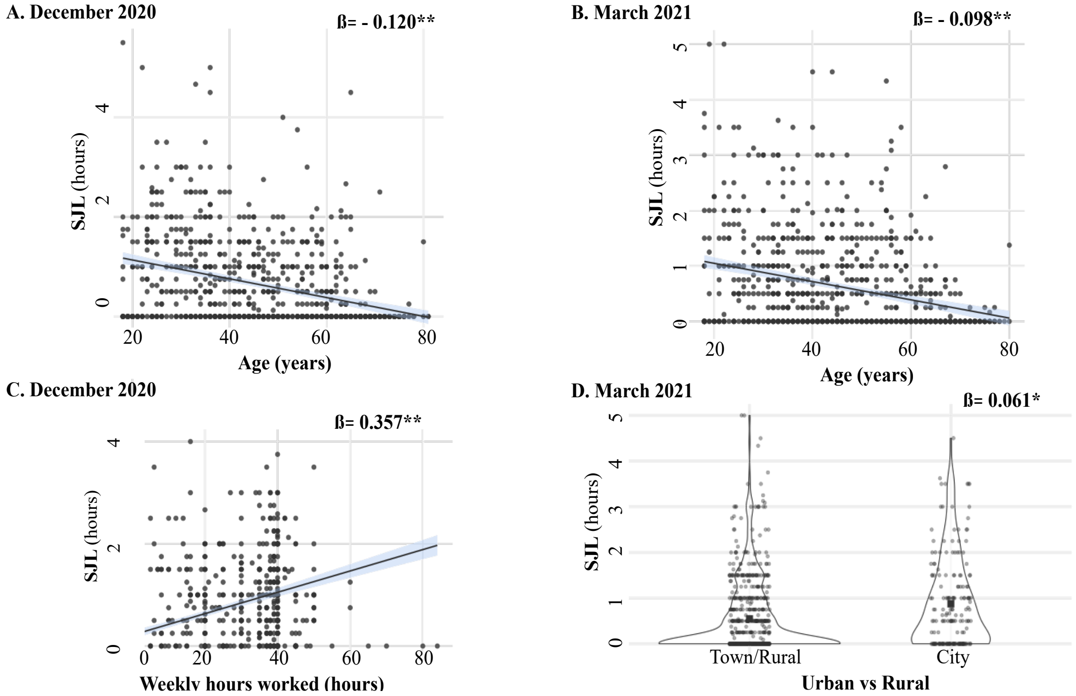


Figure 5.3. Significant associations with social jetlag during the pandemic
Younger age **(A-B)** associated with higher social jetlag. **(C)** Longer working hours associated with higher social jetlag. **(D)**Participants living in cities presented with higher social jetlag than those living in smaller towns or rural locations. ** *p*<0.001, * *p*<0.05.

5.3.5 Associations between demographic factors and chronotype

The regression model for midsleep timings on work-free days (chronotype) included midsleep timings on workdays, weekly sleep duration, age/sex, weekly hours worked (only in December 2020), urban/rural location, caregiver responsibilities (only in December 2020), insomnia, depression and anxiety. The model as a whole accounted for 58.0% and 76.5% of the variance in midsleep timings on work-free days in December 2020 and March 2021 respectively (F(10,819)=113.117, *p*=<0.001 in December 2020; F(8,834)=338.865, *p*=<0.001 in March 2021). The analysis revealed significant associations with midsleep timings on workdays, sleep duration, age, urban/rural location and caregiver responsibilities (Tables 5.5, 5.6, Figure 5.4).

	Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for B	
	B	Std. Error	ß	*t*	*p*	Lower Bound	Upper Bound
Midsleep timing workday	0.637	0.023	0.693	28.137	0.000	0.592	0.681
Weekly sleep duration	0.057	0.021	0.067	2.714	0.007	0.016	0.097
Weekly hours worked	-0.001	0.002	-0.011	-0.423	0.672	-0.005	0.003
Age	-0.015	0.002	-0.176	-6.402	0.000	-0.019	-0.010
Sex	-0.032	0.065	-0.012	-0.498	0.619	-0.160	0.095
Urban/rural	0.088	0.073	0.028	1.208	0.227	-0.055	0.230
Caregiver	-0.228	0.071	-0.074	-3.222	0.001	-0.367	-0.089
Insomnia symptoms	-0.007	0.005	-0.043	-1.319	0.188	-0.018	0.003
Depression symptoms	-0.004	0.009	-0.017	-0.376	0.707	-0.022	0.015
Anxiety symptoms	0.006	0.011	0.024	0.553	0.580	-0.015	0.026

Table 5.5 Regression model for midsleep timings on work-free days (December 2020)
The model as a whole accounted for 58.0% variance in midsleep timings on work-free days in December 2020. F(10,819)=113.117, *p*=<0.001. The analysis revealed significant associations with midsleep timings on workdays, sleep duration, age and caregiver responsibilities.

	Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for B	
	B	Std. Error	ß	*t*	*p*	Lower Bound	Upper Bound
Midsleep timing workday	0.871	0.018	0.844	48.455	0.000	0.836	0.906
Weekly sleep duration	0.007	0.015	0.009	0.475	0.635	-0.023	0.038
Age	-0.012	0.002	-0.136	-7.280	0.000	-0.015	-0.008
Sex	-0.105	0.048	-0.038	-2.176	0.030	-0.199	-0.010
Urban/rural	0.123	0.057	0.037	2.163	0.031	0.011	0.235
Insomnia symptoms	-0.004	0.004	-0.024	-1.039	0.299	-0.012	0.004
Depression symptoms	0.020	0.008	0.083	2.539	0.011	0.005	0.036
Anxiety symptoms	-0.028	0.008	-0.102	-3.363	0.001	-0.044	-0.012

Table 5.6 Regression model for midsleep timings on work-free days (March 2021)
The model as a whole accounted for 76.5% variance in midsleep timings on work-free days in March 2021. F(8,834)=338.865, *p*<0.001. The analysis revealed significant associations with midsleep timings on workdays, age, sex, urban/rural location, depression and anxiety symptoms

Midsleep timings on workdays had the strongest association (ß=0.693, $p<0.001$ in December 2020; ß=0.844, $p<0.001$ in March 2021), followed by age (ß=-0.176, $p<0.001$; ß= -0.136, $p<0.001$ in March 2021), suggesting late midsleep timings on workdays and younger age associated with late chronotype. Late chronotype associated with longer weekly sleep duration, but only at one time point (ß=0.067, $p=0.007$ in December 2020; ß=0.009, $p=0.635$ in March 2021). Late chronotype associated with sex, but only at one time point (ß=-0.012, $p=0.619$ in December 2020; ß=-0.038, $p=0.030$ in March 2021). Late chronotype also associated with urban/rural location, but only at one time point (ß=0.028, $p=0.227$ in December 2020; ß=0.037, $p=0.031$ in March 2021). Caregiver responsibilities associated with early chronotype (ß=-0.074, $p=0.001$ in December 2020). To summarize, late chronotype associated with late midsleep timings on workdays, male sex, younger age, longer weekly sleep duration, urban/rural location and having no caregiver responsibilities.

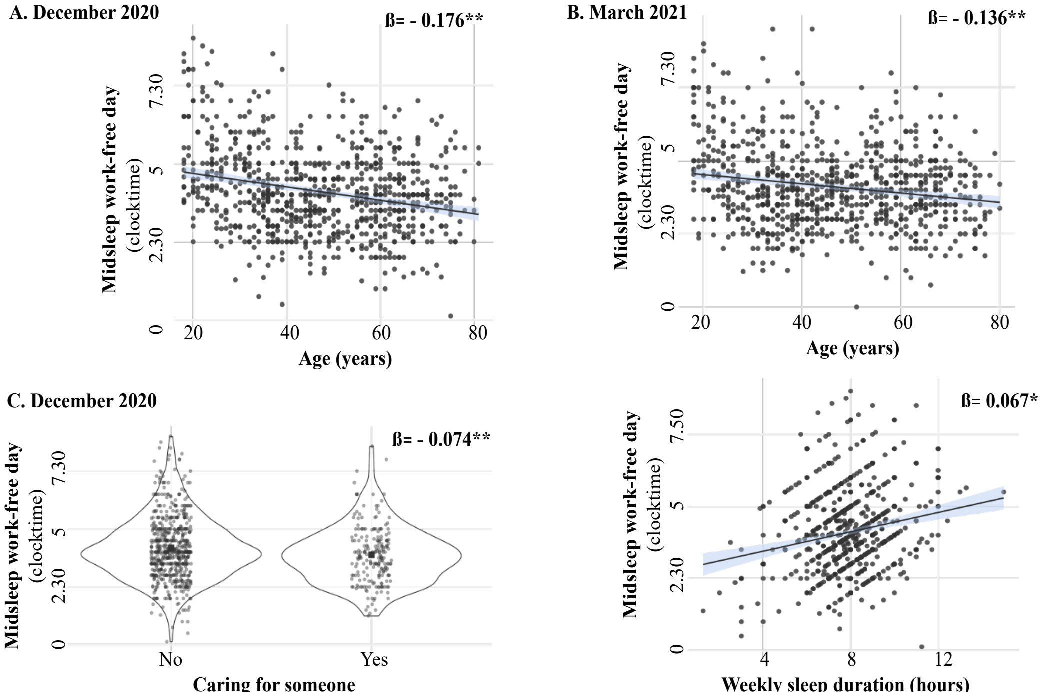


Figure 5.4. Significant associations with chronotype during the pandemic
(A-B) Younger age associated with later chronotype. **(C)** caring for someone associated with earlier chronotype **(D)** longer weekly sleep duration associated with later chronotype.
** $p<0.001$, * $p<0.05$

5.3.6 Associations between demographic factors and workday midsleep timings

The regression model for midsleep timings on workdays included weekly sleep duration, weekly number of hours worked (only in December 2020), age/sex, urban/rural, caring responsibilities (only in December 2020), insomnia, depression and anxiety. The model as a whole accounted for 15.6% and 7.1% of the variance in midsleep timings on workdays in December 2020 and March 2021 respectively (F(9,820)=16.777, *p*=<0.001 in December 2020; F(7,835)=9.066, *p*=<0.001 in March 2021). The analysis revealed significant associations with sleep duration, weekly number of hours worked, age and sex (Tables 5.7, 5.8, Figure 5.5).

Weekly hours worked had the strongest association with midsleep timings on workday (ß=-0.329, *p* <0.001 in December 2020), suggesting longer hours worked associated with earlier midsleep timings on workdays. Longer weekly sleep duration associated with late midsleep timings on workdays (ß=0.160, *p*<0.001 in December 2020; ß=0.172, *p*<0.001 in March 2021). Younger age associated with late midsleep timings, but only at one time point (ß=-0.162, *p*< 0.001; ß=0.004, *p*<0.909 in March 2021). Male sex associated with late midsleep timings on workdays, but only at one time point (ß=-0.072, *p* =0.035 in December 2020; ß=-0.030, *p*=0.394 in March 2021).

There were no associations between midsleep timings on workdays and urban/rural location (ß=-0.044, *p*=0.183 in December 2020; ß=0.000, *p*=0.992 in March 2021) and caregiver responsibilities (ß=-0.048, *p*=0.141 in December 2020). To summarize, late midsleep timings on workdays associated with being male, younger, and sleeping longer. Earlier midsleep timings on workdays associated with longer weekly number of hours worked.

	Unstandardized Coefficients		Standardized Coefficients	*t*	*p*	95.0% Confidence Interval for B	
	B	Std. Error	ß			Lower Bound	Upper Bound
Weekly sleep duration	0.146	0.032	0.160	4.599	0.000	0.084	0.208
Weekly hours worked	-0.026	0.003	-0.329	-9.379	0.000	-0.032	-0.021
Age	-0.015	0.004	-0.162	-4.197	0.000	-0.022	-0.008
Sex	-0.211	0.100	-0.072	-2.112	0.035	-0.407	-0.015
Urban/rural	-0.149	0.112	-0.044	-1.332	0.183	-0.368	0.071
Caregiver	-0.161	0.109	-0.048	-1.473	0.141	-0.374	0.053
Insomnia symptoms	-0.016	0.008	-0.090	-1.952	0.051	-0.033	0.000
Depression symptoms	0.028	0.014	0.126	1.947	0.052	0.000	0.057
Anxiety symptoms	-0.025	0.016	-0.094	-1.549	0.122	-0.057	0.007

Table 5.7 Regression model for midsleep timings on workdays (December 2020)
The model as a whole accounted for 15.6% of the variance in midsleep timings on workdays in December 2020. F(9,820)=16.777, *p*=<0.001. The analysis revealed significant associations with sleep duration, weekly number of hours worked, age and sex.

	Unstandardized Coefficients		Standardized Coefficients	*t*	*p*	95.0% Confidence Interval for B	
	B	Std. Error	ß			Lower Bound	Upper Bound
Weekly sleep duration	0.143	0.029	0.172	4.866	0.000	0.085	0.200
Age	0.000	0.003	0.004	0.114	0.909	-0.006	0.006
Sex	-0.079	0.092	-0.030	-0.853	0.394	-0.260	0.103
Urban/rural	-0.001	0.110	0.000	-0.010	0.992	-0.216	0.214
Insomnia symptoms	-0.018	0.008	-0.110	-2.358	0.019	-0.033	-0.003
Depression symptoms	0.059	0.015	0.248	3.828	0.000	0.029	0.089
Anxiety symptoms	-0.032	0.016	-0.119	-1.975	0.049	-0.063	0.000

Table 5.8 Regression model for midsleep timings on workdays (March 2021)
The model as a whole accounted for 7.1% variance in midsleep timings on workdays in March 2021. F(7,835)=9.066, *p*<0.001. The analysis revealed significant associations with weekly sleep duration, insomnia symptoms and depression.

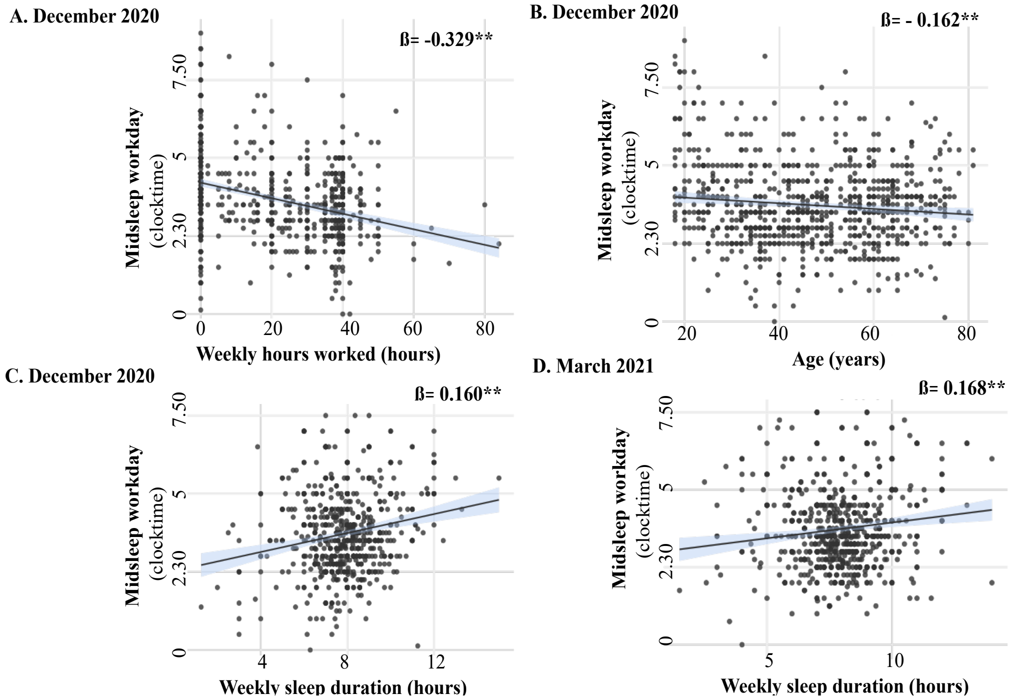


Figure 5.5. Significant associations with midsleep timings on workdays during the pandemic **(A)** More weekly number of hours worked associated with earlier midsleep timings on workdays. **(B)** Younger age associated with later midsleep timings on workdays. **(C-D)** Longer weekly sleep duration associated with later midsleep workdays. **p<0.001

5.3.7 Associations between insomnia, and social jetlag and midsleep timings

There were no associations between social jetlag and insomnia (ß=-0.016, *p* =0.666 in December 2020; ß=-0.019, *p*=0.509 in March 2021), depression (ß=0.049, *p*=0.357 in December 2020; ß=0.052, *p*=0.189 in March 2021) and anxiety (ß=-0.075, *p*=0.134 in December 2021; ß=0.031, *p*=0.404 in March 2021).

There were no associations between chronotype and insomnia (ß=-0.043, *p*=0.188 in December 2020; ß=-0.025, *p*=0.420 in March 2021). There was an association between late chronotype and depression, but only at one time point (ß=-0.017, *p*=0.707 in December 2020; ß=0.083, *p*=0.011 in March 2021). There was an association between early chronotype and anxiety, but only at one time point (ß=0.024, *p*=0.580 in December 2020; ß=-0.102, *p*=0.001in March 2021).

There was an association between midsleep timings on workdays and insomnia but only at one time point (ß=-0.090, *p*=0.051 in December 2020; ß=-0.110, *p*=0.019 in March 2021). There was an association between late midsleep timings on workdays and depression, but only at one time point (ß=0.126, *p* =0.052 in December 2020; ß=0.248, *p*<0.001 in March 2021). There were no associations between midsleep timings on workdays and anxiety (ß=-0.094, *p*=0.122 in December 2020; ß=-0.119, *p* =0.049 in March 2021).

To summarize, insomnia, depression and anxiety did not associate with social jetlag. There was an association between late chronotype and depression symptoms. Early chronotype associated with anxiety symptoms. Late midsleep timings on workdays associated with depression symptoms, and early midsleep timings on workdays associated with insomnia symptoms.

5.3.8 Groupwise analyses (urban/rural locations, caregivers and non-caregivers)

A Mann Whitney U test revealed that participants in urban locations experienced higher social jetlag (U=47491.500, *z*=-4.618, *p*=<0.001, r=0.16); median social jetlag was 30 minutes in the cities and 0 minutes in rural areas. The significant association between chronotype and caregiver responsibilities was analyzed further in a groupwise independent-sample t-test. Caregivers' midsleep timings on work-free days was 18 minutes earlier than non-caregivers (03:52am vs 4:10am, *p*=0.006, respectively). Although there was a difference in chronotype, there was no difference between caregivers and non-caregivers in levels of social jetlag (36 minutes vs 38 minutes, *p*=0.642, respectively for caregivers and non-caregivers).

A closer look at the sleep-wake timings of both groups showed that caregivers' sleep start and sleep end on workdays were 17 minutes and 18 minutes earlier than non-caregivers (23:38pm vs 23.55pm, *p*=0.016; 07:22am vs 07:40am, *p*=0.022, respectively). Caregivers also had earlier sleep start and sleep end on work-free days (12pm vs 0:14am, p=0.021; 08:09am vs 08:31am, *p*=0.012, respectively). There was no significant difference in sleep duration between caregivers and non-caregivers.

Caregivers had a 22-minutes difference between their sleep start on workdays and work-free days while non-caregivers had a difference of 20 minutes. Caregivers had a 47-minutes difference between their sleep end on workdays and work-free days while non-caregivers had a difference of 51 minutes. A further analysis of the difference in sleep timing variance revealed that these differences were not statistically significant (*p*=0.676 and *p*=0.569, respectively for sleep start and sleep end). The within-group difference in sleep-wake timings of each group was not statistically different from the other. In other words, both groups had variability in sleep-wake timings on work and work-free days, but the variability was not significantly different. This may explain the lack of significantly different levels of social jetlag between the two groups.

5.3.9 Associations between insomnia symptoms, and depression and anxiety

A MANOVA analysis revealed that participants with total SCI scores meeting the threshold for a diagnosis of insomnia disorder had significantly higher depression and anxiety symptoms, (both depression and anxiety symptoms at $p<0.001$, at both time points) than those without scores endorsing insomnia. In December 2020 and March 2021, respectively, insomnia accounted for 29% and 28% of the variance in depression scores, and 23% and 21% of the variance in anxiety scores (Figure 5.6).

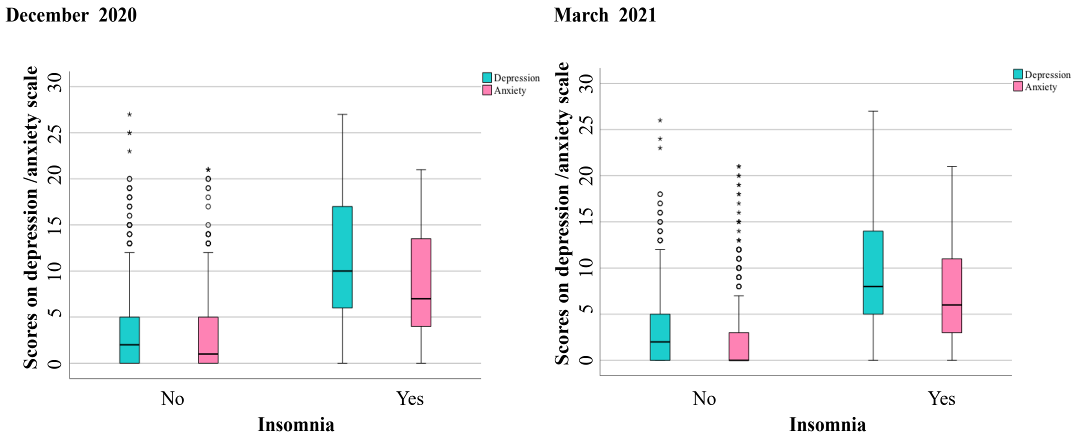


Figure 5.6 Association between insomnia symptoms and psychological distress
MANOVA analysis revealed that participants with total SCI scores meeting the threshold for a diagnosis of insomnia disorder had significantly higher depression and anxiety symptoms, (both depression and anxiety symptoms at $p<0.001$, at both time points). In December 2020 and March 2021, respectively,

5.4 Discussion

This study set out to examine the association between social jetlag and midsleep timings on workdays and work-free days (chronotype) before and during the pandemic. The study further explored the associations between social jetlag and sex/age, caregiver responsibilities, weekly number of hours worked, insomnia symptoms, depression and anxiety at two time points during the pandemic (December 2020 and March 2021, 8 months and a year into the pandemic in Ireland, respectively). The associations between these variables and midsleep timings were explored as well.

Using two reference samples from before the pandemic, the correlation between social jetlag and chronotype during the pandemic was examined. The direction of the relationship between social jetlag and chronotype (still positive and late chronotype associated with higher social jetlag) did not change but the strength of that relationship was weaker. The strength of the social jetlag-midsleep timings on workdays, although relatively stronger than before the pandemic, remained within the weak range during the pandemic.

The results suggest that the association between chronotype and social jetlag did not disappear, and that chronotype was still a significant determinant of social jetlag during the pandemic. This is in line with recent prepandemic studies that have demonstrated a strong association between chronotype and social jetlag. Pilz et al., (2018) reported in their study that chronotype predicted social jetlag (β=0.55, $p<0.001$) in a sample of non-clinical population (while assessing the mediatory role of social jetlag in the relationship between chronotype and the difference in work and work-free day sleep quality). In a similar study, Reis et al. (2020) assessed if social jetlag and chronotype were associated with changes in work and work-free day sleep quality in a sample of patients with sleep disorders. They too reported that chronotype had a predictive effect on social jetlag (β =0.30, $p< 0.001$).

On the other hand, midsleep timings on workdays in the reference samples had a weaker and negative relationship with social jetlag. This suggests chronotype may have had a larger role in determining social jetlag before the pandemic. As discussed in chapter 4, the changes to midsleep timings on workdays were the primary driving force for the reduction in social jetlag during the pandemic. It appears that the strong relationship between social jetlag and chronotype observed before the pandemic may have been due largely to the pressure imposed by workday sleep timings; the further away sleep-wake timings on workdays are from an individual’s chronotype, or the individual's true sleep propensity, the higher the social jetlag. Thus, sleep on workdays may have been the crucial factor linking chronotype to social jetlag. When the pressure to conform to socially imposed timings on workdays was released during the pandemic, the pressure on the chronotype-social jetlag relationship may have been released a little as well.

The results of this study highlight an interesting observation. Although midsleep timings on workdays, chronotype and social jetlag are close associates, the factors associated with the three constructs appear to have differential impact on them. For example, age associated with all three, as expected from prior studies that have highlighted the developmental trajectory of chronotype and social jetlag (Fischer et al., 2017). Younger people reported late midsleep timings on workdays, late chronotype and higher social jetlag.

Caregiver responsibilities was a factor that displayed differential relationships with social jetlag, chronotype and midsleep timings. Caregiver responsibilities during the pandemic associated with early chronotype, but not lower social jetlag. Providing care for someone has been associated with sleep disturbances, daytime sleepiness and lower life satisfaction (Haugland et al., 2020; Liu et al., 2017). A study on caregivers of teenagers with Asthma found that caregivers on average reported a sleep duration of 5.9 hours, with a significant percentage (72%) reporting less than 7 hours of sleep (Johnson et al., 2018).

Caring for someone might require the caregivers having to adapt their sleep-wake timings to accommodate the routine (for example, medication, food, school start time) of the person they are caring for. Caregiver responsibilities could be at odds with their own sleep-wake cycles and make them vulnerable for social jetlag. Furthermore, unlike work demands, which are absent on work-free days when sleep can shift to its natural preference, caregiver demands may limit opportunities for respite from sleep disturbances.

A significantly earlier chronotype did not necessarily result in significantly lower social jetlag in this sample. This could be because the caregivers and non-caregivers in this sample did not differ in terms of the variability in their work and work-free day sleep start and sleep end timings. This could in turn be due to the nature or role of the caregivers that was not clarified in the study.

At the time of the data collection for this study, caregiver responsibilities could have referred to many possible scenarios, from caring for elderly parents who were cocooning (term used in Ireland to refer to staying at home and avoiding social contact) to home schooling children or caring for someone with long COVID.

Thus, the results need to be interpreted with caution in the context of the pandemic, and further studies on the specific aspects of caregiver responsibilities that may impact variability in sleep-wake timings and thus social jetlag need to be clarified. The relationship between caregiving and sleep variability, chronotype and social jetlag warrants further investigation beyond what is covered in this research.

Schredl and Goritz (2020) recently reported that those living in urban locations presented with late chronotypes. This study was based on data collected before the pandemic. Previously, light exposure and work conditions in urban locations have also been identified as risk factors for late chronotypes and higher social jetlag (Lunn et al., 2017; Ohida et al.2001; Roenneberg & Merrow, 2007). Somewhat surprisingly, in the current study, urban locations only associated with higher social jetlag and late chronotype at one of the time points assessed (March 2021).

Pandemic specific factors, such as social distancing regulations, may explain the results. Restaurants were closed and nearly all social events were cancelled or restricted in Ireland at the time when the data was collected. The absence of evening activities in cities during the pandemic may have reduced the variability in sleep-wake timings between work and work-free days previously observed between rural and urban areas. Moreover, studies have documented other significant differences between urban and rural areas during the pandemic. For example, Zenic et al., reported that the decrease in physical activity levels during the pandemic was larger in urban than rural locations. Similarly, Rice et al., (2020) reported that mobility and outdoor recreational activities declined significantly more in urban locations than compared to rural locations. Urban families have also been observed to suffer more decreases in household consumption than rural families (Liu et al., 2020).

The differences in how rural and urban dwellers may have experienced the pandemic could explain the lack of association between rural/urban location and social jetlag and chronotype in December 2020. This however does not explain the association observed in March 2021, when most of the pandemic related restrictions were still in place. The current research is limited in clarifying the full extent of the changes in the Irish rural and urban areas during the pandemic that may explain the results.

In the current study, there was no association between social jetlag and insomnia symptoms, contrary to other studies that have identified an association. Brandao et al. (2021), for example, reported an association between the increases and decreases in social jetlag during the pandemic to more insomnia symptoms. Furthermore, chronotype did not associate with insomnia as well. Late midsleep timings on workdays and late chronotype associated with depression while early chronotype associated with anxiety.

The results of this study with regards to insomnia, depression and anxiety could be sample specific as other studies have shown an association between late chronotype, social jetlag and insomnia (Brandao et al., 2021; Li et al., 2018). Merikanto et al. (2022) showed that late chronotypes had more depression and anxiety symptoms than intermediate or early chronotypes during the pandemic, contrary to the current findings that early chronotype associated with anxiety. It is unlikely that differences in age and sex compositions of the studies may be responsible for the results as Merikanto et al.'s study participants were on average 41 years and 66% females, which is similar to the age and sex profile of the samples assessed in the current study. Other sample specific or pandemic specific factors that were unique to Ireland may be responsible for the different results.

Studies conducted during the pandemic have consistently highlighted a strong link between poor sleep quality/insomnia symptoms and psychological distress (Kocevska et al., 2020; Kokou-Kpolou et al., 2020; Meaklim et al., 2021). In line with these results, in the current study, participants with insomnia symptoms reported higher depressive moods and anxiety those without insomnia symptoms, across both time points assessed. This suggests a differential relationship between insomnia, depression, anxiety and the chronobiological sleep variables. Sleep quality and insomnia may be distinct sleep parameters and the factors that associate with these constructs may have differential impact on social jetlag and midsleep timings.

Finally, the within-person analysis of changes in the two time periods assessed in this study highlight that the midsleep timings on workdays, while reverting closer to prepandemic timings (compared to the reference sample), still remained later than the prepandemic timings. The gap between workday and work-free day midsleep timings was still smaller than before the pandemic, and consequently the reduction in social jetlag observed at the start of the pandemic was sustained at the later time points. An inference that may be gleaned from the current study results is that the large changes observed in sleep-wake timings at the start of the pandemic (March 2020 in Ireland) may have been a transitory response to the novel social and work circumstances induced by the global onset of the pandemic. Such large changes may not be sustained over time, but more moderate changes to sleep-wake timings seem to suffice for a reduction in social jetlag.

5.4.1 Limitations

A number of caveats apply to the interpretation of the results of this study. There is a difference in the age profile of the reference samples, and reference sample 2 was a retrospective reporting of sleep-wake timings before the pandemic (it refers to the prepandemic sleep timings of participants in the March 2020 sample). The participants in March 2020, December 2020 and March 2021 were predominately older. As a result of the differences between the samples, the changes in the associations between social jetlag and midsleep timings are qualitatively described and statistical significance was not tested. Women and young adults in particular have been identified to be vulnerable (Banks & Xu, 2020) to the impact of the pandemic. The results presented here may not be generalizable to the general population. As such, all results and discussions presented here are to be interpreted with caution.

The within-participant differences in sleep-wake timings between the two time points were compared to the reference samples (and chapter 4 findings) qualitatively. Such analysis could have been enhanced with a longitudinal within-participant analysis with same participants at the start of the pandemic and a year late. As it stands, the interpretation of the comparison to sleep-wake timing at the start of the pandemic should be treated with caution as the results have not been statistically verified.

Future experimental or longitudinal study designs with a more diverse population in terms of age may yield better insights into the age/sex specific differences in the associations found in the study. Furthermore, the lack of consistent associations across the two time periods may indicate complex relationships between midsleep timings, social jetlag, and the variables assessed. Such relationships could have been tested further with potential mediating or moderating variables. For example, urban/rural locations associated with social jetlag and chronotype at only one time point. It would be interesting to investigate if evening activities and social engagements on work-free days differed significantly between rural and urban locations during the pandemic, and how such differences may have impacted midsleep timings and social jetlag.

5.5 Conclusion

This study set out to describe the associations between midsleep timings on workdays, chronotype and social jetlag before and during the pandemic. There was a moderately strong prepandemic association observed between chronotype and social jetlag. During the pandemic the association was relatively weaker. Younger age, more hours spent working, and living in a city associated with higher social jetlag. Social jetlag did not associate with insomnia symptoms and depression and anxiety. Insomnia, on the other hand associated strongly with psychological distress, suggesting a differential relationship may exist between psychological distress and key sleep parameters. Although midsleep timings on workdays, chronotype and social jetlag are closely associated with one another, the results of this study suggests they may associate with risk factors differentially.

Chapter 6

Examining the association between insomnia and depression during the pandemic

This chapter has been published as:

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Abstract

The longitudinal association between insomnia symptoms and depression at the start of the pandemic and at approximately a year later, and the role of COVID-19 anxiety and age and sex in this association, were examined via a cross-lagged panel model analysis. There were 1032 participants at Time 1 (52% females; mean age= 44.86 years (SD= 15.74)) and 388 of these participants had participated at Time 2. Insomnia symptom at Time 1 was a significant predictor of Time 2 depression symptom (ß=-0.115, *p*<0.05). Depression at Time 1 was a significant predictor of Time 2 insomnia symptom (ß=-0.163, *p*<0.001). Insomnia was highly predictive of itself at Time 2 (ß=0.691, *p*< 0.001), and likewise depression at Time 1 was highly predictive of itself at Time 2 (ß=0.652, *p*< 0.001). Higher COVID-19 anxiety associated with insomnia symptoms (ß=-0.278, *p*<0.001) and depression symptoms (ß=0.292, *p*<0.001) at Time 1. Younger participants reported more insomnia symptoms (ß=0.202, *p*<0.001) and depression symptoms (ß=-0.396, *p*<0.001); suggesting young adults may be particularly vulnerable to depression and insomnia during the pandemic. Insomnia symptoms and depression appear to have differential temporal relationship with age, sex and COVID-19 anxiety, and with each other. The results suggest insomnia and depression are mutually dependent constructs sharing a dependent relationship with COVID-19 anxiety and age at a concurrent assessment time point, but their predictive relationship on each other and on themselves at a later time point appears to be fairly robust and independent of these confounding variables. This cross-lagged analysis identifies a bidirectional risk, suggesting an equal consideration of risk assessments and intervention for both insomnia symptoms and depression symptoms. Identifying the long-term bidirectional risk insomnia and depression present on each other might shed light on the aetiology and persistence of both disorders during the pandemic and have implications in terms of public health measures targeting prevention and management.

6.1 Introduction

Recent studies assessing the impact of the COVID-19 pandemic on psychological distress and/or sleep disturbances have reported an increase in poor sleep quality and depression and anxiety in the initial months of the pandemic, while others reported no change or minimal changes that reverted to prepandemic levels in the later months (Hyland et al., 2021; Kocevska et al., 2020; Mandelkorn et al., 2021; Pieh et al., 2021; Robinson et al., 2021). This suggests the restrictions, such as the stay-at-home orders and social distancing measures, enforced to mitigate the spread of the virus has had differential impact on mental health and sleep health globally. Emerging evidence from these early studies however highlight a consistent and strong link between sleep disturbances and psychological distress during the restrictions; depression, negative affect, lower social interactions and loneliness were associated with poor sleep quality (Kocevska et al., 2020; Kokou-Kpolou et al., 2020; Xiao et al., 2020). This is perhaps not surprising as prepandemic epidemiological research and reviews have highlighted sleep disturbances are associated with adverse physical health such as cardiovascular and metabolic disorders and mental health such as depression and anxiety (Fernandez-Mendoza & Vgontzas, 2013; Ford & Kamerow 1989).

Sleep surveys indicate short sleep duration and sleep disturbances as a world-wide problem (Carskadon et al., 2006; Kronholm et al., 2008; Stranges et al., 2012). Insomnia is defined as difficulty initiating or maintaining sleep or sleep that is non-restorative (American Psychiatric Association, 2013) and chronic insomnia symptoms as a disorder was assessed to affect 10% of the population with sporadic insomnia symptoms estimated to affect nearly 30% of the population (Ohayon, 2002). Depression is a common psychiatric disorder worldwide, with scientists back in 2001 predicting 5.8% of men and 9.5% of women will experience a depressive episode in their lifetime (WHO, 2001) and that depression will be one of the top three health concerns by the year 2020 (Murray & Lopez, 1997).

There are various forms of sleep disturbances associated with depression, but insomnia is one form most commonly investigated in relation to depression as insomnia symptoms commonly coexist with depression symptoms (Hertenstein et al., 2019; Lichstein, 2006; Riemann & Voderholzer, 2003; Reimann et al., 2020). While high prevalence of insomnia in depression led research to previously explore insomnia as a comorbid symptom secondary to depression, in later research the question of interest was if insomnia was a risk for the onset of depression (Lichstein, 2006; Riemann & Voderholzer, 2003).

Johnson et al. (2006) found insomnia occurred first in 69% of cases with concurrent depression and insomnia; Baglioni et al. (2011) showed insomnia had an odds ratio of 2.60 (95% CI = 1.98–3.42) for predicting later depression; and in a more recent meta-analysis Li et al. (2016) found that the risk for depression increased two-fold in those with insomnia compared to those without. These findings support the hypothesis that insomnia symptoms might not be merely an epiphenomenal behavioural outcome of depression, but that it may have predictive impact for the onset of depression at a later time.

Insomnia symptoms are recognized as significant risk factors in the aetiology of depression, and a bidirectional relationship - that insomnia symptoms predict and are predicted by depression -has also been proposed (Alvaro et al., 2013; Johnson et al., 2006). Additionally, insomnia and depression disorders both have common triggers and neurophysiology; stressful events and hyperactivity in the hypothalamic-pituitary-adrenal (HPA) axis in response to stressful events has been associated with both insomnia and depression symptoms (Balbo et al., 2010; Pillai et al., 2014). In the context of the COVID-19 pandemic, extreme stress induced by fear of the contagious disease and changes to daily routines may trigger sleepless nights culminating in the development of later depressive mood symptoms, or insomnia symptoms may be early signs of depression from the loneliness and reduced social support imposed by travel restrictions and social distancing measures.

The predictive directional relationship may be hard to tease apart, as the association between insomnia and depression may not be exclusive and may be confounded by other concurrent mental health distress such as anxiety or by age and sex. Anxiety, for example, may play a role in the association between insomnia symptoms and depression as insomnia is indicated in anxiety disorders and anxiety may share common symptomatology with depression (Alvaro et al., 2013; Johnson et al., 2006). Furthermore, intercorrelations have been observed amongst the three (Oh et al., 2019).

Studies conducted during the pandemic have highlighted the prevalence of insomnia (Alimoradi et al., 2021; Morin et al., 2021), and have identified COVID-19 infection, female sex, younger age, long confinement periods, financial worries and living alone as some factors associated with higher odds of insomnia (Morin et al., 2021). Associations with anxiety and depression have frequently been reported as well (Alimoradi et al., 2021; Morin et al., 2021).

While there is strong evidence that insomnia is a key associate of depression during the pandemic, the direction of risk that insomnia symptoms and depression pose for each other and for themselves over time is not clear from the early cross-sectional pandemic studies. Furthermore, anxiety specifically related to concerns about the pandemic, referred to in this study as COVID-19 anxiety, presents as a unique variable of interest to investigate in the association between insomnia symptoms and depression. This current study aimed to examine (a) the concurrent (cross-sectional) association and the predictive impact (cross-lagged) of insomnia symptoms and depression during the first year of the pandemic in Ireland, and (b) to explore if COVID-19 anxiety, sex and age as control variables at the start of the pandemic had an impact on the temporal relationship between insomnia symptoms and depression approximately a year later.

6.2 Methods

6.2.1 Recruitment and data collection

The Irish arm of the COVID-19 Psychological Research Consortium (C19PRC) study (McBride et al., 2021) was launched to assess the mental health impact of COVID-19 in Ireland in the first year of the pandemic. Participants aged 18 years or older and residing in Ireland were recruited via quota sampling (based on age, sex and geographical distribution as per the 2016 Irish census) to ensure a nationally representative sample. The longitudinal survey, completed in five waves over 12 months, was conducted online via the Qualtrics survey platform (an on-line research services provider, www.qualtrics.com). The survey started with Wave 1 in March/April 2020 during the first week of the first country-wide full restrictions in Ireland, and ended with Wave 5 in March/April 2021, a year later and while Ireland was under a third full restrictions. Ethical approval was granted by the Research Ethics Committee of Maynooth University. A methodological protocol paper on the C19PRC data is available (Spikol et al., 2021). See Figure 1.13 for a timeline of nation-wide full restrictions and the type of restrictions imposed in Ireland from March 2020 to October 2021.

While scales for depression and COVID-19 anxiety were used in all five waves, the sleep specific questionnaire was only added from Wave 2, which was approximately six weeks into the first restrictions. This study is based on the entire sample at Wave 2, referred to as Time 1 in the analysis (data collection was between April 30th and May 19th 2020), and the Wave 2 participants who participated at Wave 5, referred to as Time 2 (data collection was between March 19th and April 9th, 2021).

6.2.2 Measures

The Sleep Condition Indicator (SCI) was used to assess insomnia symptoms. The SCI is a self-report scale designed to facilitate diagnosis of insomnia based on the DSM-5 threshold criteria for insomnia disorder (Espie et al., 2014). The eight items on the SCI are rated on a five-point Likert scale from zero to four, with possible total scores between zero and 32. Higher scores reflect better sleep quality and a score of 16 or less is indicative of possible insomnia. The internal reliability of the SCI at Time 1 ($\alpha = .88$) was excellent.

The Patient Health Questionnaire-9 (PHQ-9; Kroenke et al., 2001) was used to assess symptoms of depression. Higher scores on the PHQ-9 indicate more symptoms of depression with a score of 10 or more indicating a possible DSM-5 diagnosis of depression. The PHQ-9 includes a sleep item. To avoid multicollinearity with the SCI, this item was removed from the total score of the PHQ-9. The internal reliability of the PHQ-9 at Time 1 ($\alpha = .91$) was excellent. The diagnostic categories were used for a descriptive reporting of prevalence of depression and insomnia in the sample at Time 1, and the total scores from both the PHQ-9 (higher scores corresponding to depression symptoms) and SCI (lower scores corresponding to insomnia symptoms) were used in the path model analysis.

COVID-19 anxiety was assessed via a single question “How anxious are you about the COVID-19 pandemic?”, with a scale ranging zero to 100 and higher scores reflecting higher anxiety. A single item measure may have psychometric limitations. The General Anxiety

Disorder 7-item scale (GAD-7; Spitzer et al., 2006) was included in the survey. The single item measure was used in this study instead as it specifically refers to anxiety about the pandemic while the items on the GAD referred to general worrying, feeling anxious and restless, and being afraid. A correlation test between the single item COVID-19 anxiety question and the total score on the GAD was conducted. There was a moderate correlation ($r=0.347$, $p<0.001$) between COVID-19 anxiety at Time 1 and the total score on the GAD. This may suggest that the single item rating may be a reasonable indicator for anxiety.

6.2.3 Statistical Analysis

Cross-lagged path modelling was conducted using Mplus version 8.2 (Muthen & Muthen, 2017). Cross-lagged panel analysis is structural equation modelling and is widely used in longitudinal data analysis of a set of variables (Kuiper & Ryan, 2018). It is recognized as a valid assessment for the longitudinal effects (regression) that the variables have on each other, over and above the stability and influence of cross-sectional associations (autoregressive) between them (von Salisch et al., 2017).

In this study, three models were tested. First, a cross-lagged model with autoregressive and cross-lagged paths was specified to determine the unadjusted relationships between insomnia symptoms and depression (Figure 6.1 Model 1). Second, COVID-19 anxiety was added as a covariate to assess the impact of pandemic related anxiety on the relationships between insomnia symptoms and depression (Figure 6.1 Model 2). Third, sex (0 = males, 1 = females) and age (measured in years) were added as additional covariates (Figure 6. 1 Model 3) to determine if the relationship between depression and insomnia were influenced by these demographic variables.

These models were compared using two relative fit indices, the Akaike Information Criteria (AIC) and the Bayesian Information Criteria (BIC). The model with the lowest value is considered to be statistically superior. Overall fit of the model to the sample data was assessed using multiple indices including the chi-square, the Comparative Fit Index (CFI), the Tucker-Lewis index (TLI), the Root Mean Square Error of Approximation (RMSEA) and the Standardized Root Mean Square Residual (SRMR). Standard recommendations were followed to assess model fit where a non-significant chi-square value, CFI and TLI values >0.90, and RMSEA and SRMR values <0.08 indicate acceptable fit.

Notably, Model 1 was a saturated model therefore fit indices are reported for models 2 and 3 only. Full information maximum likelihood estimation, widely recognized as an effective method for unbiased parameter estimates and standard errors for randomly missing data in structural equation modelling (Schafer & Graham, 2002; Widaman, 2006), was used to estimate these models and to manage missing data from non-responders at Time 2. Thus, all analyses are based on the available data at Time 1.

6.3 Results

6.3.1 Demographics of study sample

There were 1032 participants at Time 1. Of these, 388 (recontact rate =37.6%) responded to the call to participate at Time 2 (N=1100). The rest of the participants at Time 2 were either new recruits or had participated in prior waves of data collection but not Time 1. Time 1 participants who responded at Time 2, when compared to the non-responders, were significantly more likely to be male (χ^2 (1, *n* = 1029) = 6.37, *p* =0.01), older (*t* (1030) = 10.48, *p*< 0.001), and reported higher COVID-19 anxiety (*t* (832) = 2.69, *p*=0.007) but lower depression symptoms (*t* (896) =-4.52, *p*<0.001). The responders and non-responders did not differ significantly in terms of their insomnia symptoms.

The mean age of participants at Time 1 was 44.86 years (± 15.74) and 52% of them were females. 30% of the participants at Time 1met the criteria for a diagnosis of insomnia and 26% reported symptoms endorsing a depression disorder. Insomnia symptoms correlated strongly with depression symptoms at both time points (r=-0.555, *p*<0.001 at Time 1 and r=-0.610, *p*<0.001 at Time 2; Table 6.2). COVID-19 anxiety had weak correlations with insomnia symptoms (r=-0.259, *p*<0.001) and depression symptoms (r=0.253, *p*<0.001) at Time 1. Age demonstrated a weak correlation with insomnia symptoms (r=0.175, *p*<0.001) and a correlation of medium strength with depression (r=-0.367, *p*<0.001). There was a weak correlation between COVID-19 anxiety and age (r=0.097, *p*=<0.001).

	Time 1 (n=1032)	Recontact (n=344)	Non-recontact (n=644)
Age (*mean, std. dev)*	44.86 (15.74)	51.15 (14.61)	41.07 (15.19)
Age groups (%)			
18-24	11	4	16
25-34	19	12	24
35-44	21	18	22
45-54	16	18	15
55-65	20	28	15
> 65	13	20	9
Sex (% females)	52	47	55
Time 1 insomnia	21.06 (0.25) 30%	21.63 (0.42) 29%	20.72(0.311) 31%
Time 1 depression	6.22 (0.19) 26%	5.13 (0.29) 22%	6.87(0.25) 28%
Time 1 COVID-19 anxiety	61.10 (0.83)	63.95 (1.33)	59.39(1.06)

Table 6.1 Demographics, and prevalence of insomnia, depression and COVID-19 anxiety

Values presented here for insomnia symptoms, depression symptoms and COVID-19 anxiety are means with standard error of means in parenthesis. % presented for insomnia and depression symptoms refer to participants meeting the cut-off scores for possible insomnia disorder and depression disorder at Time 1. Time 1 participants who responded

	T1 Insomnia	T1 Depression	T2 Insomnia	T2 Depression	T1 COVID-19 Anxiety	T1 Age
T1 Depression	-.555**					
T2 Insomnia	.786**	-.539**				
T2 Depression	-.466**	.684**	-.610**			
T1 COVID-19 Anxiety	-.259**	.253**	-.252**	.159**		
Age	.175**	-.367**	.254**	-.397**	.097**	
Sex	-0.022	0.012	0.019	-0.082	-0.002	0.001

Table 6.2 Correlations (Pearson)

*Correlation is significant at $p<0.001$ (2-tailed).

6.3.2 Cross-lagged path analysis

Model 1 showed that insomnia symptoms at Time 1 significantly predicted Time 2 depression symptoms (Figure 6.1 Model 1; ß=-0.115, $p<0.05$) and depression symptoms at Time 1 were significant predictors of Time 2 insomnia symptoms (ß=-0.163, $p<0.001$). Time 1 insomnia symptoms were highly predictive of insomnia symptoms at Time 2 (ß=0.691, $p< 0.001$), and Time 1 depression symptoms were highly predictive of Time 2 depression symptoms (ß=0.652, $p< 0.001$). Insomnia and depression symptoms correlated significantly at both Time 1 (r=-0.555, $p< 0.001$) and Time 2 (r=-0.416, $p<0.001$). The model accounted for 63% variance in insomnia symptoms and 52% of the variance in depression symptoms at Time 2.

Model 2 incorporated COVID-19 anxiety as a covariate and the model fit statistics were χ^2_2 =1.795, $p=0.407$, RMSEA=0.000 (CI=0.000 to 0.060), SRMR=0.008, TLI =1.000, CFI =1.000. The BIC and AIC decreased substantially from model 1 to model 2 (BIC=-77.051 and AIC=-86.93) after COVID-19 anxiety was included in the model. Covid-19 anxiety had a significant but weak impact on insomnia (ß= -0.259, $p<0.001$) and depression (ß=0.253, $p<0.001$) at Time1, but the cross-lagged associations between insomnia and depression symptoms were unchanged compared to model 1 (Figure 6.1 Model 2).

The BIC and AIC decreased substantially from model 2 to model 3 (BIC = -159.929 and AIC = -179.686) when age and sex were additionally controlled for, suggesting inclusion of COVID-19 anxiety, age and sex improved model fit. Model 3 provided acceptable fit to the sample data (χ^2_6 =17.367, $p<0.05$; RMSEA=0.043, CI =0.020 to 0.067; SRMR=0.034; TLI =0.975 and CFI =0.992). COVID-19 anxiety had a moderate predictive effect on insomnia symptoms (ß=-0.278, $p<0.001$) and depression symptoms (ß=0.292, $p<0.001$) at Time 1. Age had a significant effect on Time 1 insomnia symptoms (ß=0.202, $p<0.001$) and Time 1 depression symptoms (ß=-0.396, $p<0.001$); younger participants reported more insomnia and depression symptoms. There were no associations between sex and Time 1 insomnia symptoms (ß=-0.023, $p<0.433$) and Time 1 depression symptoms (ß=0.013, $p=0.631$). Age and COVID-19 anxiety together accounted for a variance of 11% in insomnia symptoms and 22% in depression symptoms at Time 1. There was no change in the autoregressive effects, the cross-lagged associations and variance at Time 2.

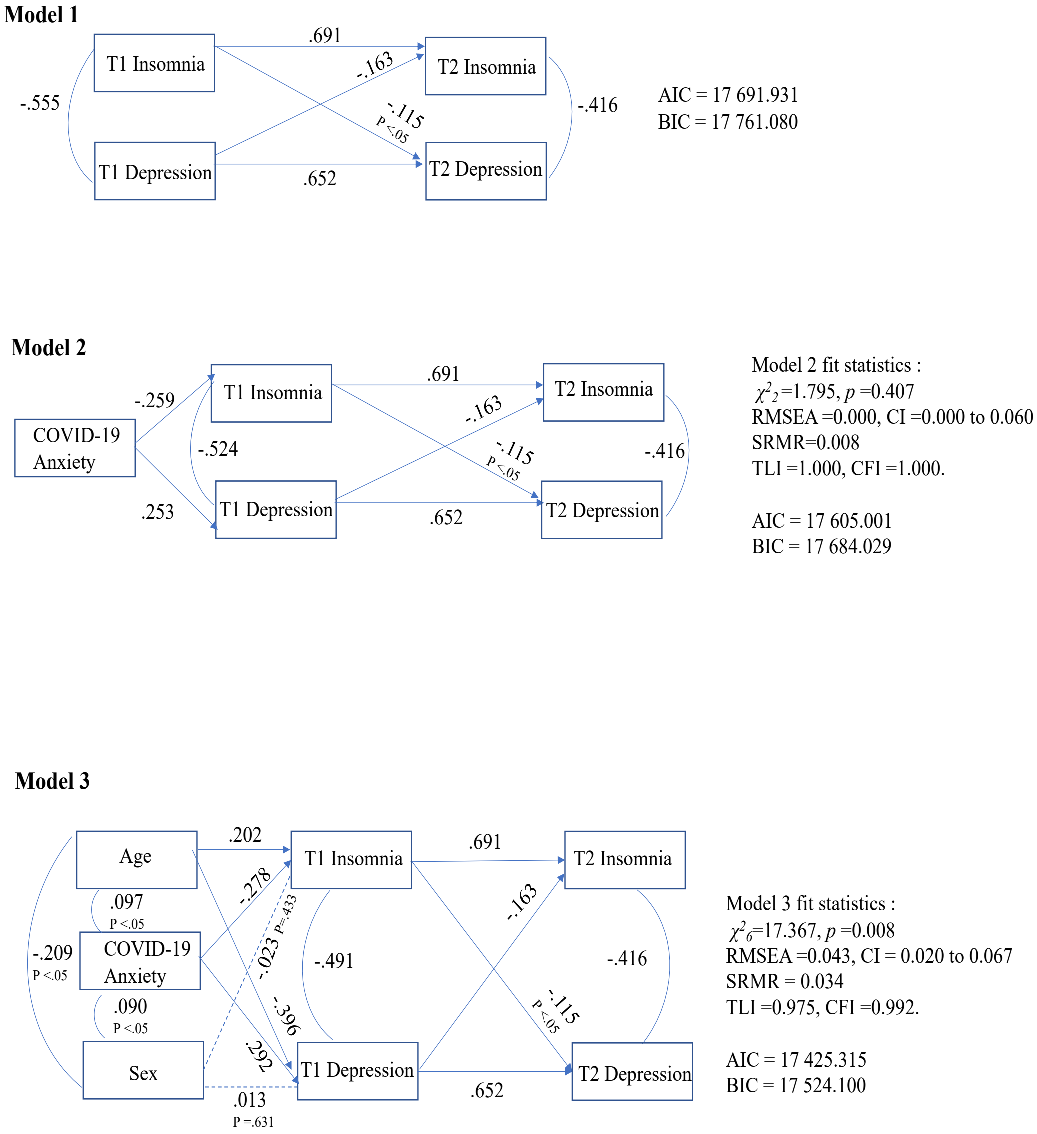

Figure 6.1
Covid-19 anxiety had a significant but small impact on insomnia symptoms and depression at Time 1. The cross-lagged association and correlation were unchanged at Time 2. The AIC and BIC reduced (AIC = -86.93 and BIC = - 77.051). The AIC and BIC reduced from Model 2 to Model 3 (AIC = -179.686 and BIC = - 159.929) when further controlling for age and sex at Time 1, suggesting including COVID-19 , age and sex as covariates improved the model.

***Note**:
All significant paths and correlations are solid arrows and were significant at p<0.001 unless otherwise specified.

Lower scores on the SCI refer to more insomnia symptoms. Higher scores on the PHQ-9 and COVID-19 anxiety question denote more depression and anxiety. Sex was coded as 0 for male and 1 for females.

Negative coefficients to insomnia from (or from insomnia to) depression and anxiety indicate i) more depression symptoms associated with more insomnia symptoms and ii) higher COVID-19 anxiety associated with more insomnia symptoms.

Positive coefficient from age to insomnia indicates older participants reported better sleep and negative coefficient from age to depression indicates younger participants reported more depression.

6.4 Discussion

The goal of this study was to understand the longitudinal relationship between insomnia symptoms and depression symptoms during the first year of the COVID-19 pandemic in Ireland. The findings indicate insomnia and depression symptoms at the early stages of the pandemic predicted themselves and each other approximately 12 months later. Another goal was to explore the impact of COVID-19 anxiety, sex and age on the longitudinal relationship between sleep and depression. Higher COVID-19 anxiety and age had a significant effect on insomnia and depression symptoms at Time 1, but this effect did not alter the longitudinal association between insomnia and depression symptoms at Time 2.

Younger participants in this sample reported significantly more insomnia symptoms and more depression symptoms. There were no significant associations between sex and depression and insomnia. There is evidence that different age groups and males and females experience insomnia and depression symptoms differentially (Buysse et al., 2008; Ohayon, 2002), and individual differences and sensitivity to chronic stress are believed to be key factors in the onset of insomnia and depression during stressful life events (Pillai et al., 2014). In the context of the current pandemic, young adults have been reported to experience heightened mental health distress than other groups (Banks & Xu, 2020). This may explain the significant association with age observed in this study. The results of the current study concur with existing studies on the variable impact of the pandemic on different groups and highlight the vulnerability of specific groups for insomnia and depression during the pandemic.

While COVID-19 anxiety and age had significant effects on insomnia symptoms and depression, the predictive longitudinal association between insomnia symptoms and depression held even when controlled for these variables. Furthermore, insomnia and depression symptoms were reasonably stable and had strong effects on themselves across the two assessment time points. Considering that these effects were controlled, the reciprocal relationship observed might not be trivial. Insomnia symptoms and depression appear to have differential temporal relationship with age and COVID-19 anxiety, and with each other. The data provides evidence that insomnia and depression are mutually dependent constructs sharing a dependent relationship with COVID-19 anxiety and at a concurrent assessment time point, but their predictive relationship on each other and on themselves at a later time point appears to be fairly robust and independent of these confounding variables.

There is strong evidence of the close ties between insomnia and depression during the early days of the pandemic from current cross-sectional studies. However, as the pandemic shows signs of becoming endemic, longitudinal studies such as this may be needed to map the trajectory of symptoms of depression and insomnia over time. This cross-lagged analysis identifies a bidirectional risk, suggesting an equal consideration of risk assessments and intervention for both insomnia symptoms and depression symptoms.

A 2019 Lancet Global Burden of Diseases report places depression in the top ten diseases driving disability burden, and epidemiology of insomnia shows insomnia symptoms are common in the general population (Ohayon, 2002) suggesting both depression and insomnia were public health concerns even before the pandemic. The onset and persistence of depression and insomnia during the COVID-19 pandemic might be an added burden to the already costly ongoing public health crisis. However, the results of this study suggest an opportunity for prevention of such burden via timely identification and treatment of insomnia and depression symptoms for prevention and management.

6.4.1 Limitations

There are caveats to the interpretation and applications of the results from the current study. Firstly, this study did not distinguish between prepandemic and pandemic onset insomnia and depression symptoms. Maeklim et al., 2021, for example, found individuals who developed insomnia during the pandemic reported significantly higher depression and anxiety than those with prepandemic insomnia or no insomnia. In another study, Kocevska et al., 2020 reported a third of their participants with prepandemic clinical insomnia reported better sleep quality during the pandemic but that prepandemic good sleepers reported poor sleep quality. Subgroup analyses of pre- and post-pandemic onset insomnia and depression might provide a clearer indication of the true impact of COVID-19 anxiety on onset of symptoms, and the role COVID-19 anxiety had on the persistence and longitudinal impact insomnia and depression symptoms had on themselves and on each other over time.

Additionally, it has been reported that natural daylight exposure significantly decreased during the pandemic when people started working from home (Korman et al., 2022). Daylight is an important zeitgeber for the synchronization of internal sleep-wake rhythms with the external environment. As daylight is also believed to affect mood, and light is used as a therapeutic agent in the treatment of depression and mood disorders (Wirz-Justice et al., 2005), reduced consumption of natural daylight could be a factor in the incidence of depression and mood difficulties observed during the pandemic. The nature of restrictions imposed in different countries during the pandemic varied considerably and there may have been stricter rules at the start of the pandemic. Thus, daylight exposure, physical activity levels and sleep may have been affected differentially at different times during the pandemic which may have had an impact on mood as well.

Another limitation is namely in terms of the sample demographics, missing data and the methodology used. While the maximum likelihood method used in the analysis is widely regarded as the best available method for handling missing data, it may not eliminate all limitations and bias. Caution is needed in generalizing the findings as there were important significant differences in age and sex between the recontacts and non-recontacts from Time 1 to Time 2. A recent review estimates the median age for onset for mental health disorders (which includes depression and other mood disorders) is in young adulthood (Somni et al., 2021). While at Time 1 there was suggestion that younger people experienced more insomnia and depression symptoms, the recontacts at Time 2 were predominately older. The recontacts at Time 2 had significantly lower depression symptoms but higher COVID-19 anxiety as anticipated (as the virus at the start of the pandemic had more adverse effects for older people). Thus, the findings might not represent the experiences of younger people and those who had more depression symptoms at the start of the pandemic or those with lower pandemic related anxiety.

Another consideration is that the cross-lagged panel modelling is a discrete time analysis, meaning the results are specific to the time-interval between the assessment points (Kuiper & Ryan, 2018). Thus, the longitudinal effects found here of insomnia symptoms and depression from this two-wave analysis are specific to the (approximately) 12 months between the two-waves assessed. The results may not translate to circumstances where more waves or a different time interval between assessment are used, and potentially different strengths of predictive association may be found on a shorter or longer time intervals.

6.5 Conclusion

The present study found insomnia and depression symptoms demonstrated strong concurrent morbidity as well as a significant longitudinal predictive relationship during the first year of the pandemic in Ireland. Insomnia symptoms and depression predicted themselves and each other even when sex, age and COVID-19 anxiety were controlled for. There was cross-sectional evidence for higher COVID-19 anxiety and younger age associating with insomnia and depression symptoms. The results suggest young adults may be particularly vulnerable to depression and insomnia symptoms during the pandemic. As the pandemic shows signs of becoming endemic, identifying the long-term bidirectional risk insomnia and depression present on each other might shed light on the aetiology and persistence of both disorders during the pandemic, and have implications in terms of public health measures targeting prevention and management.

Chapter 7

Exploring the associations between intraindividual behavioural traits and social jetlag

Abstract

Intraindividual behavioural factors may influence bedtime decisions. Dismissing future consequences of present behaviours (delaying bedtime to enjoy leisure activities), discounting of distant rewards (discounting the long-term benefits of regular sleep-wake timings) and dysfunctional beliefs about sleep could add to late sleep-wake timings, circadian misalignment and social jetlag. This study explored the relationships between chronobiological sleep parameters (social jetlag, midsleep timings, sleep duration), insomnia symptoms and temporal consideration of consequences, temporal discounting of future rewards and dysfunctional beliefs about sleep. 120 participants (mean age=23.86 (SD=8.05); 76% females) were included in the study. There were no significant associations between social jetlag, sleep duration, midsleep timings on workdays, and the intraindividual factors. Late midsleep timings on work-free days (late chronotype) associated with stronger dysfunctional beliefs about sleep (r=0.195, p=0.037). However, the association was weak. There was no association between chronotype and temporal consideration of consequences and temporal discounting. Lower ratings of sleep quality (indicative of insomnia symptoms) associated with more dysfunctional beliefs (rho=-0.568, p<0.001) and steeper discounting of future rewards (rho=-0.221, p=0.016). The current results do not provide evidence of associations between social jetlag and intraindividual traits. The results suggest that social jetlag and midsleep timings may be distinct sleep parameters, and that factors that associate with insomnia symptoms may have differential impact on chronobiological sleep parameters.

7.1 Introduction

Late chronotype is associated with difficulties with self-regulation (Milfont & Schwarzenthal, 2014). Research further suggests that social jetlag is associated with impulsivity, and that individuals with immediate time orientation and late chronotypes engage in riskier behaviours compared to their more future oriented counterparts or those with early chronotypes (McGowan et al., 2017; Milfont & Schwarzenthal 2014). Thus, intraindividual traits could play a role in late sleep-wake timings and ultimately social jetlag, as individuals with late chronotypes may find making healthy choices around bedtime harder.

Bedtime procrastination could be a behavioural factor associated with late chronotypes and sleep variability between workdays and work-free days. Kroese et al., 2014 defined bedtime procrastination as going to bed later then intended, when there are no reasonable external factors for delaying bedtime. Bedtime procrastination is viewed as the gap between the good intension of going to bed early to get sufficient sleep and the actual behaviour deviating from that intention.

Studies have demonstrated that bedtime procrastination is significantly associated with less hours of sleep, late waketime and even late dinnertime (Kadzikowska-Wrzosek 2018; Kroese et al., 2014; Kuhnel et al., 2018; Magalhaes et al., 2020). However, it is unclear how behavioural factors (such as bedtime procrastination) associate with biological (such as the circadian and homeostatic regulation) determinants of sleep-wake timings?

Two studies examined this question. Kadzikowska-Wrzosek (2018), showed that bedtime procrastination was associated with low self-control and late chronotypes. Kuhnel et al. (2018) showed that late chronotypes reported more bedtime procrastination on workdays and that the tendency to procrastinate declined over the course of the week. They argued that the delay in getting to bed early might not be a behavioural trait but is rather the biological inability to fall asleep early (not feeling sleepy enough to go to bed). From a chronobiological perspective, the intervening hours between intended (or the required bedtime to get sufficient sleep based on required waketime the next morning) bedtime and actual bedtime could be in the period of circadian peak for alertness where sleepiness is low and there is no homeostatic or circadian push for sleep.

At the outset, Kroese et al.'s behavioural perspective and Kuhnel et al.'s counterproposal of biological deficiency could not both be true at the same time. Theoretically, intraindividual traits and biological factors need not be mutually exclusive but could be interdependent determinants of sleep-wake timings. The role of light in entraining internal sleep-wake rhythms and the behaviours that determine exposure to light could be the link how behavioural and biological factors interact to determine sleep-wake timings.

Chung et al. (2020), in a study investigating bedtime procrastination found that a majority of the participants in the study (total sample comprised of 61% females, mean age =22) who scored high on a bedtime procrastination measure reported a significantly later bedtime, a later waketime and presented with late chronotype. More significantly, the study reported that those who engaged in bedtime procrastination spent more time using media over a 24-hour period and spent almost an hour more on smartphones just 3 hours before their bedtime than those who did not procrastinate.

Recall figure 1.12 from chapter 1. The internal rhythms that determine behavioural outputs such as eating and sleeping, are entrained and synchronized via external light-dark cycles. This process may be interrupted by the use of electronic devices and light at night. The use of electronic devices and light at night may be linked to behavioural factors such as a disregard for the impact of the present behaviour (using light emitting devices just before bedtime) and a discounting of the benefits of an early bedtime. This could trigger or exacerbate the cycle of delayed sleep onset and irregular sleep across work and work-free days. This chapter explores three intraindividual traits that could potentially impact on bedtime decisions.

Consideration of future consequences (CFC) has been widely studied in health sciences, especially in relation to the long-term consequences of smoking (Adam, 2012) and in relation to dietary habits (Joireman et al., 2012; Piko & Brassai, 2009). Studies have demonstrated that individuals who considered the future consequences of their present behaviours engaged in health promoting behaviours (Joireman et al., 2012, Murphy et al., 2018). For example, those scoring high on CFC (indicative of a greater regard for future consequences of present behaviours) are more likely to exercise (Joireman et al., 2012) and to engage in healthy dietary behaviours (Joireman et al., 2012; Piko & Brassai, 2009).

There is a temporal element to the consequences of a behaviour, the immediate consequence of the behaviour and the future consequence. 24-hour availability of relatively affordable media content on streaming platforms present such temporal choices and dilemma in bedtime decisions. The consequences of the choices and the attainment of rewards from the choices are critical in decision-making (Vanderveldt et al., 2016). Delays to the attainment of a reward could alter its value and potentially sway decisions against it (Vanderveldt et al., 2016).

Delaying bedtime on work-free days, for example in order to watch a late-night movie, may not result in immediate undesirable consequences as waketime the next day will likely be later. The consequences of staying up late and sleeping longer on work-free days may result in difficulty in getting to sleep earlier and waking up earlier on workdays. The implications of bedtime and waketime decisions on work-free days might not be fully appreciated (or understood) at the time of the decision-making or when weighed against the immediate gratification of enjoying a movie. The immediate behaviour is more tangible than the distant (and obscure) health benefits of going to bed early. Thus, the future benefit may be discounted in favour of the immediate gratification (Milfont & Schwarzenthal, 2014). The devaluing of a reward because of the delay to its attainment is called temporal discounting and could be another behavioural factor linked to late sleep-wake timings.

Temporal discounting is often assessed in laboratory experiments with monetary rewards, involving a choice between rewards of varying amounts and degrees of delay to attainment. While larger rewards are generally favoured over smaller rewards, the delay to attainment of the larger reward could sway preference toward the immediate smaller reward (Van den Bos & McClure, 2013). For example, choosing to receive €100 now over €120 three months later. The 3-month delay in attainment diminishes the value of €120.

Research has linked temporal discounting with poor self-control and an inability to delay gratification (Jones et al., 2018). When an individual is presented with choices, self-control and inhibition are key factors (Madden & Bickel, 2010) especially when the rewards (the benefit of sufficient and regular sleep-wake timings) are not immediately available. Discounting of future adverse outcomes are associated with unhealthy behaviours (Story et al., 2014). Studies conducted with clinical and at-risk populations appear to suggest that substance use and unsafe sexual activities are linked to steeper temporal discounting (Białaszek et al., 2017; Madden & Bickel, 2010; Washio et al., 2011). The study by Lee et al. (2017) highlighted that substance use and greater discounting were associated with criminal behaviours in young adults. Another study (Jones et al., 2018) revealed steeper sexual delay discounting, defined as impulsive decisions in favour of unsafe sex, predicted risky sexual behaviours among males.

Healthy bedtime decisions may require more foresight, effort and patience as bedtime decisions involve balancing the future benefits of regular sleep with immediate gratification from pleasurable activities that sleep may displace (social contact, watching TV and engaging in social media). This could mean that late chronotypes, who are associated with impulsivity and low self-regulation skills, are susceptible to poor bedtime decisions, irregular sleep and by extension higher social jetlag. Surprisingly, temporal consideration of consequences (CFC) and temporal discounting in relation to sleep-wake timings and social jetlag have not been explored extensively. Apart from one study (Peters et al., 2005) that reported an association between higher CFC scores and regular bedtimes, little is known of the influence of CFC and temporal discounting on midsleep timings and social jetlag.

The third intraindividual factor with potential link to sleep-wake timings and social jetlag explored in this chapter is dysfunctional beliefs about sleep. Some examples of dysfunctional beliefs include having unrealistic expectations for sleep duration (for example, “I must get 8 hours of sleep to feel refreshed and function well the next day”). Studies have highlighted that stronger endorsement of dysfunctional beliefs about sleep have been associated with poor sleep quality and insomnia symptoms (Dautovich et al., 2021; Jin et al., 2018; Morin et al., 2007).

Dysfunctional beliefs about sleep are primarily studied in relation to insomnia and sleep quality. Sleep disruptive beliefs are linked to triggering and sustaining insomnia (Morin et al., 2007). In a review, Schwartz and Carney (2012) proposed that maladaptive beliefs about sleep could be one of several factors perpetuating insomnia, and that targeting these dysfunctional beliefs in cognitive behaviour therapy may help alleviate insomnia symptoms. Morin et al. (2007) found a small correlation between time in bed and dysfunctional beliefs, but little else is known about dysfunctional beliefs and sleep-wake timings.

The current study explored if social jetlag and midsleep timings are associated with temporal consideration of consequences, temporal discounting and dysfunctional beliefs about sleep. The hypotheses of the study are 1) a greater consideration for immediate consequences 2) steeper discounting of future rewards and 3) stronger endorsements of dysfunctional beliefs about sleep would associate with late midsleep timings on work and work-free days, and with social jetlag. Additionally, the study explored the association between these factors and sleep quality/insomnia symptoms.

7.2 Methods

7.2.1 Recruitment and data collection

Participants were recruited between January 2018 and March 2020 (before the onset of the pandemic in Ireland). Adults above 18 years of age and residing in Ireland were included. Participants were mostly students at the university and were not shift workers. Participants were recruited through personal contacts, social media posts and recruitment flyers around campus. Ethical approval was granted by the Research Ethics Committee of Maynooth University and informed consent was indicated by all participants whose data was included in the analysis. Survey questionnaires were administered on-line, via the Qualtrics survey platform (www.qualtrics.com).

7.2.2 Measures

The Munich chronotype questionnaire (MCTQ) was used to assess midsleep timings and social jetlag. Social jetlag was calculated as the absolute difference between midsleep timings on workdays and work-free days. Sleep corrected midsleep timings on work-free days (MSFsc) was used to estimate chronotype for participants who had longer sleep duration on work-free days (MSFsc=MSF– [SDf-SDweek)/2]; Roenneberg & Merrow, 2007). Participants with missing information on the MCTQ, such as alarm clock use or number of working days, were excluded from the analysis. 120 participants with complete MCTQ responses were eligible for inclusion in the current study.

The Sleep Condition Indicator (SCI) was used as a measure of sleep quality and insomnia symptoms. The SCI is a self-report scale, designed to facilitate diagnosis of insomnia based on the DSM-5 threshold criteria for insomnia disorder (Espie et al. 2014). The eight items on the SCI are rated on a five-point Likert scale from zero to four, with possible total scores between zero and 32. Higher scores reflect better sleep and a score of 16 or less is indicative of possible insomnia. The internal reliability of the SCI in this study (α = .87) was excellent.

The 16-item Dysfunctional Beliefs About Sleep questionnaire (DBAS-16) was used to assess beliefs about sleep. The original 30-item DBAS scale was developed to assess individual attitudes and beliefs about sleep that may be disruptive to good sleep health (Morin et al., 1993). The DBAS-16 was developed to encourage wide-spread use of the instrument in clinical settings (Morin et al., 2007). The scale has 16 statements and is divided into four subscales. The four subscales are grouped according to statements assessing 1) daytime consequences of disrupted sleep or insomnia, 2) worries or helplessness about control over sleep problems, 3) expectations for sleep in terms of number of hours per night and sleep loss and 4) the use of medication as a solution for sleep troubles.

Each of the 16 statements on the scale are rated on a Likert scale from 0 (strongly disagree) to 10 (strongly agree), with the ratings denoting the degree with which each statement or belief is endorsed. Selecting a number higher up the scale (for example, 8, 9 or 10) indicates a strong dysfunctional belief or a disruptive attitude that may interfere with good sleep. The scores on all the items are added and averaged to obtain a total scale score. The subscale scores are calculated similarly. Higher scores indicate more dysfunctional beliefs and attitudes. The internal reliability of the DBAS-16 in this study (α =0.86) was excellent.

The 14-item Consideration of Future Consequences (CFC) scale was used in this study. The original CFC scale contained 12 items (Strathman et al., 1994). The original 12-item CFC scale conceptualized time orientation as unidimensional. In recognition that time orientation and consideration of consequences of behaviours are not static or polar opposites, that individuals could consider both future and immediate consequences of their actions, the scale was reorganized as a two-factor scale (Joireman et al., 2012).

Two additional items that specifically assessed future consequences were added to form a scale with two subscales: seven items assessing immediate/present orientation and seven items assessing future orientation (Joireman et al., 2012). The statements in the scale are not specific to sleep behaviours. An example of a statement in the future orientation subscale is “I am willing to sacrifice my immediate happiness or well-being in order to achieve future outcomes”. An example of a statement on the present/immediate subscale is “I think that sacrificing now is usually unnecessary since future outcomes can be dealt with at a later time”. The 14 statements on the scales are rated on a Likert scale ranging from strongly disagree to strongly agree. Higher scores on the future subscale indicate higher consideration for future consequences. Higher scores on the present subscale indicate higher consideration for immediate consequences. The internal reliability of the CFC-14 in this study (α =0.90) was excellent.

The 27-item Kirby Monetary Choice Questionnaire (KMCQ) was used to measure delayed discounting (Kirby et al., 1999). The KMCQ assesses temporal discounting via choices between lower, and immediate, or higher, and delayed, monetary rewards. Delay or temporal discounting is often used in behavioural economics research. Participants were asked whether they would prefer smaller monetary rewards immediately versus larger monetary rewards in the future. The questions include varying immediate and delayed monetary reward values along with varying duration of delay.

Responses are recorded as binary variables (0, 1) for immediate and delayed choices. Scores were entered into an excel automated scorer (Kaplan et al., 2016) to obtain overall k values. k values refer to the discounting rate with an equation of $V=A/(1+kD)$ (Mazur 1987). Gray et al, (2016) explain that the V in the equation refers to present value of the reward, A is the reward, D is the delay in obtaining the reward, and k is the discounting rate. The higher the discounting rate (the k value) the higher the discounting of larger but delayed rewards (Gray et al., 2016). In other words, larger k values indicate higher preference for immediate rewards and steeper discounting of future rewards. The internal reliability of the KMCQ in this study (α = 0.91) was excellent.

7.2.3 Statistical analyses

Analyses were conducted on SPSS. Independent-sample *t*-test or the Mann-Whitney U test were conducted to assess differences in the mean scores of male and female participants. Sex and age were not used as control variables in the analyses below, as there were no significant differences between females and males in the mean scores on the scales and sleep variables. There were no significant correlations between age and the scores on the scales as well. Correlation between social jetlag, midsleep timings and scores on the KMCQ, the CFC scale and the DBAS scale were assessed via Pearson's r or Spearman's rho, depending on the normality of the distribution of social jetlag and midsleep timings. $p<0.05$ was taken as indicating a statistically significant effect.

7.3 Results

7.3.1 Demographics of study sample

The descriptive statistics of midsleep timings, social jetlag, sleep duration, and scores on the KMCQ, the CFC scale and the DBAS scale are shown in Table 7.1. 120 participants were included in the current study. Mean age of total sample was 23.86 (SD=8.05). 76% of the total sample were females. Social jetlag was 1hr 26mins (SE=0.09), midsleep timing on work-free days was 05:05 (SE=0.13) and midsleep timing on workdays was 04:09 (SE=013). Sleep duration on workdays was 7h 11mins (SE=0.12) and sleep duration on work-free days was 8h 27mins. Mean score on the CFC future subscale was 34.37 (SE=0.68) and the CFC present subscale was 25.58 (SE=0.82; mean total score on the CFC scale was 64.79, SE=1.39). Mean score on the DBAS scale was 5.22 (SE=0.15) and the overall K value on the KMCQ was -2.15 (SE=0.06). There were no significant differences between females and males in terms of mean age, social jetlag, midsleep timings, sleep duration and the scores on the KMCQ, the CFC scale and the DBAS scale.

7.3.2 Associations between behavioural traits, and social jetlag and midsleep timings

There were no statistically significant associations between social jetlag and future consideration of consequences (CFCf, rho=-0.014, *p*=0.875) and immediate consideration of consequences (CFCi, rho=-0.017, *p*=0.858). Social jetlag did not associate with temporal discounting (KMCQ, rho=-0.107, *p*=0.243) and dysfunctional beliefs (DBAS, rho=0.000, *p*=0.996) either.

There was a small association between midsleep timings on work-free days(chronotype) and dysfunctional beliefs about sleep (r=0.195, *p*=0.037; Figure 7.1). Late chronotype associated with higher scores on the DBAS scale (higher scores correspond to greater dysfunctional beliefs about sleep). There were no associations between chronotype and temporal consideration of consequences (CFCf, r =-0.120, *p*=0.191; CFCi, r=0.121, *p*=0.187) and temporal discounting (KMCQ, r=0.081, *p*=0.377). There were no associations between midsleep timings on workdays and the behavioural variables (CFCf, rho=-0.139, *p*=0.131; CFCi, rho=0.166, *p*=0.071; KMCQ, rho=0.144, *p*=0.116; and DBAS, rho=0.102, *p*=0.278).

Sleep duration on workdays did not associate with the behavioural variables (CFCf, rho=0.043, *p*=0.643; CFCi, rho=0.024, *p*=0.796; KMCQ, rho=0.008, *p*=0.934; DBAS, rho=-0.009, *p*=0.921). There were no associations between sleep duration on work-free days and the behavioural variables either (CFCf, r=0.048, *p*=0.600; CFCi, r=0.072, *p*=0.436; KMCQ, r= -0.042, *p*=0.652; DBAS, r= -0.040, *p*=0.674).

	Total sample	Males	Females
Age (*mean, std. dev)*	23.86 (SD=8.05)	23.97 (SD=8.82)	23.82 (SD=7.84)
Age groups (%)			
18-24	77.5	-	-
25-34	11.7	-	-
35-44	6.7	-	-
45-54	3.3	-	-
55-64	.8	-	-
Sex (% females)	76%	-	-
Social jetlag	1hour 26 mins (0.09)	1hour 29 mins (0.22)	1 hour 26 mins (0.09)
Midsleep workday	04:09 (0.13)	04:05 (0.22)	04:10 (0.15)
Midsleep work-free day	05:05 (0.13)	05:11 (0.25)	05:03 (0.15)
Sleep duration workday	7 hours 11 mins(0.12)	7 hours 0 mins (0.24)	7 hours 14 mins (0.14)
Sleep duration work-free day	8 hours 27 mins (0.14)	8 hours 06 mins (0.26)	8 hours 34 mins (0.16)
Sleep quality (SCI)	20.05 (0.69)	19.66 (1.44)	20.18 (0.80)
Dysfunctional beliefs (DBAS)	5.22 (0.151)	4.98 (0.28)	5.30 (0.18)
Consideration of consequences CFC Total	64.79 (1.39)	63.52 (2.81)	65.20 (1.60)
Consideration of consequences CFC future subscale	34.37 (0.68)	34.03 (1.36)	34.47 (0.79)
Consideration of consequences CFC immediate subscale	25.58 (0.82)	26.52 (1.68)	25.27 (0.94)
Temporal discounting Overall K (KMCQ)	-2.15 (0.06)	-2.15 (0.14)	-2.15 (0.07)

Table 7.1 Sample demographics, sleep parameters and scores on the scales
120 participants were included in the current study. There were no statistically significant differences between females and males in terms of mean age, social jetlag, midsleep timings, sleep duration and the scores on the KMCQ, the CFC scale and the DBAS scale.

7.3.3 Associations between behavioural traits and insomnia

There was a significant association between the scores on the SCI and the scores on the DBAS scale. Lower ratings of sleep quality (indicative of insomnia symptoms) associated with more dysfunctional beliefs (rho= -0.568, *p*<0.001; Figure 7.1). There was an association between temporal discounting and insomnia symptoms too. Lower ratings of sleep quality/ insomnia symptoms) associated with steeper discounting on the KMCQ (rho= -0.221, *p*=0.016; Figure 7.1). Sleep quality did not associate with temporal consideration of consequences (CFCf, rho =0.030, *p*=0.745; CFCi, rho=-0.058, *p*=0.533).

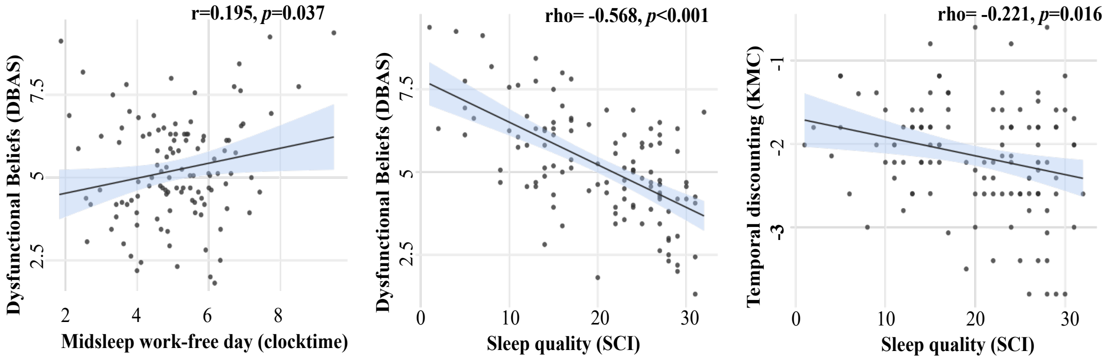

Figure 7.1 Associations between the DBAS scale, the KMCQ, and chronotype and sleep quality. There was a small but significant association between midsleep timings on work-free days and dysfunctional beliefs about sleep. Late chronotype associated with higher scores on the DABS (higher scores correspond to greater dysfunctional beliefs and attitudes about sleep). There was a significant association between scores on the SCI and scores on the DABS. Lower ratings of sleep quality (indicative of insomnia symptoms) associated with more dysfunctional beliefs Lower ratings of sleep quality (insomnia symptoms) associated with steeper discounting on the KMCQ.

7.4 Discussion

The goal of this study was to explore the relationships between social jetlag and intraindividual traits. The hypothesis of the study was that more present temporal orientation (dismissive of future consequences), steeper temporal discounting (favouring smaller immediate rewards at the expense of bigger future benefits) and stronger dysfunctional beliefs about sleep will associate with late chronotype and higher social jetlag. The current results did not validate the hypotheses of the study. The results do not demonstrate a relationship between social jetlag, sleep duration, midsleep timings on workdays and the intraindividual factors assessed in this study. Midsleep timing on work-free days did not associate with temporal consideration of consequences and temporal discounting. Late chronotype associated with stronger endorsement of dysfunctional beliefs about sleep, but this association was weak.

In line with prior studies (Espie, 2002; Harvey et al., 2002; Morin et al., 2007), there was an association between sleep quality/insomnia symptoms and dysfunctional beliefs; stronger dysfunctional beliefs about sleep associated with poor sleep quality ratings and insomnia symptoms. The DBAS scale was designed to assess sleep-disruptive cognitions and sleep quality in insomnia patients and has been used with the general population as well. The scale has been found to be a reliable tool for differentiating good and poor sleepers across both younger and older adults (Carney et al., 2006; Morin et al., 1993). More recently, Dautovich et al. (2021) demonstrated that greater dysfunctional beliefs predicted poor sleep health. Jin et al.(2018) similarly found that dysfunctional beliefs associated with poor sleep quality in an university student sample.

The study by Dautovich et al. (2021) cited above assessed sleep health via the RU-SATED scale (Buysse, 2014). This scale assesses key sleep indicators such as regularity, satisfaction, timing, duration, efficiency and daytime alertness. While the analysis in the study demonstrated a predictive relationship between sleep health (total score of the RU-SATED scale) and dysfunctional beliefs, it is unclear how well each of the subcomponents of the RU-SATED scale (sleep satisfaction versus sleep regularity versus sleep duration) individually associated with dysfunctional beliefs. Dautovich et al.(2021) assessed the mediating role of dysfunctional sleep beliefs in the relationship between perfectionism and sleep health. The final structural equation model did not include the sleep expectation subscale of the DBAS and excluded sleep timing, sleep efficiency and daytime alertness subscales on the RU-SATED scale to improve model fit (these variables had low effect sizes).

The RU-SATED scale is not psychometrically validated (Buysse, 2014). The questions on sleep duration ("Do you sleep between 6 and 8 hours per day?) and sleep regularity ("Are you asleep between 2:00am and 4:00am?") on the scale are assessed via a statement and ratings from 0 (rarely/never) to 2 (often/always). The scale is a general measure of sleep health and is different to the MCTQ or actigraphy/polysomnography assessments of sleep duration and timings. It would nonetheless be interesting to probe the association found in the Dautovich et al. (2021) study to assess which subscale of the sleep health measure had a bigger influence on the association with dysfunctional beliefs.

The association between chronobiological sleep parameters and dysfunctional beliefs is thus not clearly established from the prior studies discussed above. Morin et al. (2007)'s study provided evidence for a possible association between dysfunctional beliefs and sleep duration. They reported a correlation between total time in bed and the daytime consequences and the sleep expectations subscales of the DBAS scale. Their result suggests that longer time spent in bed (not necessarily longer sleep duration) associated with more dysfunctional expectations for sleep. This is particularly relevant to the current discussion. Strong beliefs about needing 8 or more hours of sleep every night and strong beliefs about compensating perceived sleep loss may result in longer time spent in bed. This could perhaps explain the association between late chronotype and DBAS in this sample. The association was however weak. The role that dysfunctional beliefs may play in determining sleep-wake timings remains unclear.

It is somewhat surprising that the CFC scale did not associate with social jetlag and midsleep timings. Prior studies have demonstrated a close link between temporal consideration of consequences and health behaviours. Going to bed early to get sufficient amount of sleep and maintaining a regular sleep schedule can be considered as a form of health behaviour with temporal consequences similar to exercising (short-term cost of energy for long-term cardiovascular benefits) and healthy diet (avoiding unhealthy but tasty food in the present for prevention of obesity and diabetes in the future). Consideration of immediate consequences has been associated with smoking (Adams, 2012) and greater alcohol consumption (Churchill et al., 2016). Consideration of future consequences, on the other hand, have been associated with healthy eating (Gick, 2014) and exercising (Joireman et al., 2012). However, temporal consideration of consequences did not associate with any of the sleep parameters including sleep quality/insomnia symptoms in this sample.

Higher consideration for future benefits may be linked to the value of the benefits and the trade-offs or costs to achieving that benefit in the present (Orji et al., 2012). Sleep health behaviours may differ from other health behaviours in terms of the awareness and perceptions of the consequences of present behaviours on future negative health consequences. For example, there may be greater awareness of the link between obesity, diabetes, exercise and diet. The consequences of present dietary habits may be assessed in terms of the extreme negative trade-off of a chronic and debilitating disease. Such a link might not be immediately evident with sleep health behaviours. For example, the consequences of using electronic devices before bed (present behaviour) on internal rhythms and of circadian misalignment's role in adverse health outcomes (future consequences) might not be obvious to the general population. The current study is however limited in its capacity to assess the awareness of chronobiology and circadian science in the general population. It is also limited in its ability to assess the mechanisms through which temporal consideration of consequences may influence sleep-wake timings. Public health messages and policies could highlight the importance of regular sleep-wake timings and create greater awareness of chronobiology and adverse health outcomes associated with circadian misalignment.

7.4.1 Limitations and future directions

A number of caveats apply to the interpretation of the results of this study. Firstly, the sample used in this study is a fairly homogenous student sample. The variations in sleep-wake timings and social jetlag usually expected in the general population (for example, in a sample of older adults with family/occupational commitments or in a more female-male balanced sample) are not represented in this sample. Further discussions on specific results in this sample, for example the association between chronotype and dysfunctional beliefs, are limited.

Secondly, the use of a scale intended for a clinical population (the DBAS scale and insomnia) and scales without specific reference to sleep-wake timings (CFC scale and the KMCQ) may have affected the results. The design of the initial DBAS scale was based on the experiences of patients with insomnia disorder (Morin et al., 2007). The statements on the scale refer to the cause of insomnia or consequences of insomnia on daytime functioning. It is unlikely that self-reported chronobiological sleep variables may have influenced the results. The MCTQ derived variables have been validated and found to have high correlation with objective measures of circadian phase markers of sleep parameters obtained from objective measures, such as actigraphy measures (Santisteban et al., 2018). Moreover, Morin et al. (2007) used polysomnography derived sleep variables and found no significant correlation between dysfunctional beliefs and chronobiological variables either (expect for time in bed; refer to discussion above). It is likely that the scales' sensitivity and specificity for sleep quality/ insomnia symptoms and other health behaviours are strong, but their ability to associate with chronobiological sleep parameters is unclear.

Future experimental studies could assess other intraindividual factors, such as self-regulation and bedtime procrastination, not examined in this study. Future studies could assess delays in bedtime after the onset of sleepiness (using biological indicators such as melatonin) as well as assess environmental light exposure, work and school start timings and intraindividual factors that influence such delays. Such studies may shed more light on a possible relationship between intraindividual traits and sleep-wake timings. Further, they may assess the role of intraindividual traits in determining sleep-wake timings relative to, and in concert with, biological, environmental and societal factors.

7.5 Conclusion

The hypotheses with regards to midsleep timings on workdays and social jetlag were not validated. An association between dysfunctional beliefs and insomnia symptoms was detected. The results suggest that social jetlag and midsleep timings may be distinct sleep parameters with differential relationships with factors that associate with sleep quality or insomnia symptoms.

Chapter 8

General discussion and conclusion

8.1 Summary and general discussion of key findings

8.1.1 Societal determinants of sleep-wake timings and social jetlag

Marked changes in sleep-wake timings on workdays during the COVID-19 pandemic, and the subsequent reduction in social jetlag (chapter 4) are key findings reported in this thesis. Overall, the results discussed in this thesis suggest that socially imposed timings do negatively impact social jetlag. A substantial reduction in social jetlag was observed from the shift to later sleep-wake timings on workdays. As such, allowing sleep on workdays to align closer to the biologically determined sleep-wake propensity on work-free days may be key to better sleep health.

Current research on the effects of school start timing on adolescent sleep provide additional evidence for this. Delaying school start time by an hour, from 8am to 9am, was linked to longer sleep, better sustained attention throughout the day and improved academic performance (Alfonsi et al., 2020). A systematic review found that changes to school start timings of between 25-60 minutes resulted in an increase of 25-77 minutes in total sleep time during school nights (Minges et al., 2016). A study conducted during the pandemic highlighted that sleep opportunity increased with later school start time and that students with online instructions slept longer than those who attended in-person classes (Meltzer et al., 2020). The findings from the Meltzer et al. (2020) study corroborates those presented in this thesis, namely, that working from home resulted in later sleep end timings.

It appears that commute timings and work/school start timings may play a significant role in waketimes on workdays. The removal of commuting time and later work/school start timings may facilitate later sleep end timings and subsequently facilitate a reduction in social jetlag. It is encouraging that even modest changes to start time (of under an hour difference) may result in reduction of daytime sleepiness (Minges et al., 2015), a promising implication should working from home become the norm post-pandemic. A study reported that 74% of participants (of 575 total) experienced working from home positively and that burn-out rates during the pandemic were lower than prepandemic rates (Hoffman et al., 2020). This further highlights the benefits, and widespread acceptance, of working from home.

The results of chapter 3 are surprising from a chronobiological perspective. Contrary to circadian science and chronobiological understandings, the results presented here show that daylight saving time was experienced positively, and standard time was experienced negatively. The preference for daylight saving time as a permanent time alternative is not the best option due to the evidence linking daylight saving time to adverse health and occupational outcomes (Fritz et al., 2020; Manfredini et al., 2018). The results of the current research highlight the challenges to implementing changes to socially imposed timings, and this may not be specific to the biannual clock switching. Changes to school start timings, for example, have met with challenges. Teacher or administrator resistance and the spill-on effects of school end time on extracurricular activities are some of the challenges identified with implementation of late school start time (Fitzpatrick et al., 2020). One study found teachers favoured late start timings, but this was determined by the teachers' sleep characteristics (those who had misaligned sleep themselves, and perhaps greater empathy for sleep loss) and their awareness of students' struggles during early classes (Albrecht et al., 2021).

Similarly, it is currently unclear if working from home or flexible work schedules would be adopted post-pandemic. While working from home was generally favoured, negative experiences of working from home have also been reported. Negative experiences are primarily related to child-care or family commitments and technology connectivity issues (Hoffman et al., 2020). Lunde et al. (2022) highlighted a dearth of research, and the current knowledge gap, in understanding the full impact of working from home on human health. This may hinder implementation of changes to work schedules.

Considering public opinion is important for general compliance with policy changes (Blume and Schabus, 2020) and may be significant barriers to translating science into society-wide policy. However, educating parents, teachers and major stakeholders, via collaboration with healthcare professionals, was found to facilitate better understanding and acceptance of such policies (Fitpatrick et al., 2020). This offers hope that in due time an appropriate permanent time and flexible work options would be adopted, which may in turn facilitate a reduction in social jetlag.

8.1.2 Intraindividual determinants of sleep-wake timings and social jetlag

There were no associations between social jetlag, sleep duration, midsleep timings on workdays, and temporal consideration of consequences, temporal discounting and dysfunctional beliefs (chapter 7). The results are somewhat surprising given that consideration of future consequences is associated with other health behaviours such as substance use and diet (Churchill et al., 2016; Gick, 2014). It is further surprising as dysfunctional beliefs about sleep is associated with insomnia (Schwartz and Carney, 2012). The findings raise two interesting points for consideration. Firstly, bedtime and waketime behaviours may differ from other health behaviours, such as smoking and diet, in terms of the awareness of the consequences of present behaviours on future negative health consequences. For example, there may be greater awareness of the link between smoking and cancer, but the link between variable sleep timings and the long-term implications of circadian misalignment on health might not be apparent to the general population.

Secondly, biological (circadian and homeostatic push for sleep) and societal (work/school start timings) factors may be primary determinants of when an individual falls asleep and wakes up. The delay in getting to bed early might not be due to behavioural traits but could be due to the biological inability to fall asleep early on workdays (not feeling sleepy enough to go to bed). The results however need to be considered cautiously in view of the small sample size and study design.

The role of intraindividual behavioural factors warrant further examination beyond what is covered in this thesis as prior research links behavioural factors to bedtime procrastination (Kamphorst et al., 2018; Nauts et al., 2019) and late chronotypes (Kadzikowska-Wrzosek, 2018; Kuhnel et al., 2018). Research further suggests that late chronotype and social jetlag may be associated with intraindividual traits, such as low self-regulation and greater preference for immediate gratification (Milfont and Schwarzenthal, 2014), that may play a role in bedtime decisions. Thus, individuals with later chronotypes are more likely to find it find it harder to resist the temptations of electronic devices and struggle to make healthy choices around bedtime.

The lack of empirical evidence from the data presented here for the influence of behavioural factors on social jetlag notwithstanding, theoretically, biological and societal factors and intraindividual traits could be interdependent determinants of sleep-wake timings. Societal influences (socially imposed timings) and intraindividual traits (self-regulation, time orientations, beliefs) may interact with environmental elements (daylight exposure and light at night) to effect biology (circadian rhythms and homeostasis) that ultimately determines sleep-wake timings.

8.1.3 The association between insomnia and social jetlag

Sleep quality is an important sleep parameter that is widely investigated in sleep research. The results of the current research suggest that social jetlag and midsleep timings may be indicators of poor sleep quality. This is in line with other studies that have reported an association between late chronotype and poor sleep quality (Walsh et al., 2022). Brandao et al. (2021) demonstrated that both increases and decreases in social jetlag observed during the pandemic associated with more insomnia symptoms. In the current research, a reduction in social jetlag did not correspond to better sleep quality (chapter 4). This result suggests that reducing or eliminating social jetlag may not necessarily improve sleep quality. However, in contrast to the Brandao et al. (2021) study, the findings of the current research did not report an association between social jetlag and insomnia symptoms (chapter 5). Furthermore, chronotype did not associate with insomnia as well.

This could be sample specific as other studies have shown an association between late chronotype and insomnia (Li et al., 2018). Prior research suggest that insomnia may be a significant risk for night-to-night sleep variability (Buysse et al., 2010). As sleep variability may be a significant risk for social jetlag, further research in assessing the relationship between social jetlag and insomnia is warranted. The directionality of the relationship, and the mediating/moderating role of sleep variability or chronotype in this relationship may be interesting points for further research.

Social jetlag did not associate with depression and anxiety in this current research. However, there were associations between midsleep timings and depression and anxiety. This might not be surprising as prior research has been varied in reporting an association between psychological distress and these chronobiological sleep parameters. Knapen et al., (2018) for example reported no significant difference in levels of social jetlag between patients with depression and healthy controls, while Levandovski et al (2011) found an association between higher social jetlag and more depression symptoms. In the current research, depression and anxiety associated significantly with insomnia, which suggests that factors that influence or associate with insomnia and sleep quality may not necessarily impact social jetlag. This suggests a differential relationship between psychological distress and key sleep parameters.

Insomnia symptoms had a strong association with depression and anxiety in the current study in line with studies that have highlighted a strong link between insomnia and psychological distress during the pandemic (Kocevska et al., 2020; Kokou-Kpolou et al., 2020; Meaklim et al., 2021). As stress is associated with sleep disturbances and insomnia onset (Pillay et al., 2014), it is perhaps not unusual that almost a third of the participants endorsed insomnia symptoms on a survey conducted during a stressful global phenomenon with fatalities and when Ireland had been either between restrictions or under strict restrictions for many months. The correlations observed between insomnia symptoms and psychological distress during the pandemic suggests the strong relationship between insomnia and psychological distress in prepandemic studies (Alvaro et al., 2013; Baglioni et al 2011; Hertenstein et al., 2019) is observed in the context of the pandemic as well.

While short-term sleep disturbances due to acute stress are to be expected, prolonged sleep troubles could have long term consequences, especially since this results and other research are showing high correlation between sleep disturbances and psychological distress. Serious consequences of sleep troubles were stressed by a study that showed that insomnia severity was linked to higher suicidal ideation during the pandemic (Killgore et al., 2020). Treating insomnia and sleep disturbances could be a vital first line of response as studies have shown that insomnia treatment that improved sleep onset and maintenance of sleep was associated with a reduction in depressive mood symptoms (Cunningham & Shapiro, 2018).

The importance of recognizing sleep disturbances as early warning symptoms for serious psychological distress is becoming clearer with more research conducted during the pandemic. Early identification and treatment of distress via sleep could potentially alleviate poor mood and anxiety and reduce stress to avoid debilitating consequences such as self-harm or suicide.

8.1.4 The association between chronotype and social jetlag

The relationship between social jetlag and chronotype is central to the discussion on the multifactorial determinants of social jetlag presented above. The association between chronotype and social cues (caregiver responsibility in chapter 5) further reflects the importance of not just work/school start timings but the importance of other social cues such as family responsibilities on chronotype. As discussed in chapter 1, social factors are recognized as zeitgebers and it is believed that social cues may influence internal rhythms via sleep-wake cycles (Mistlberger & Skene, 2004). Family commitments and living arrangements may provide the behavioural structure for entraining sleep-wake rhythms to a 24-hour period (Campbell 1984). The potential for social cues and familial demands to exert positive effect on sleep-wake rhythms was demonstrated by a recent study by The AMHSI research team (2021).

AMHSI et al. (2021) analyzed 3787 stay-at-home participants during the pandemic. This study highlights several key observations about human sleep-wake behaviours. Firstly, the study identified that social and economic circumstances played a key role for sleep-wake timings under self-determined sleep conditions. The study reported that 16% of the participants (n=617) displayed desynchronized rhythms (defined as unfixed rest-activity rhythms which were at odds with the natural light-dark cycles) at the end of the stay-at-home period. They observed that these participants were predominately older and males, and that the meal timings and the nocturnal sleep of these desynchronized individuals became unfixed over the course of the study period. Daytime napping was cited as a potential reason for delays in night-time sleep.

On the other hand, participants (77%) who reported engagement with physical activities and chores around the house during the stay-at-home period did not display desynchronized sleep-wake patterns. These participants shifted their night-time sleep by an hour, but the social activities and chores may have had a positive effect in keeping their rhythms less variable and may have served as anchors preventing the rhythms from desynchronizing.

The second key observation from the study was that a significant percentage of participants shifted towards late chronotype during the pandemic, with a shift in bedtime of about an hour. This is similar to the findings in chapter 4, namely, that those working from home reported approximately an hour shift in their bedtime during workdays. This may suggest that under normal circumstances (prepandemic) a vast majority were forced to live against their internal body clock. It could also mean that sleep-wake timings adapted to a flexible schedule in the absence of social and occupational demands.

AMHSI et al. (2021) caution against alarm over the observation of desynchronized rhythms during the stay-at-home period. The desynchrony observed in that study may be an extreme response applicable only to a small group of individuals. However, the long-term implications of the shifts in sleep-wake timings observed during the pandemic is currently unclear from cross-sectional studies. There are currently indications of both positive and adverse effects on other behavioural outputs that may be tied to sleep-wake cycles and circadian rhythms, such as meal timings. Studies conducted during the pandemic have shown significant correlation between midsleep timings, working from home and timings of meals (Benedict et al., 2021; Bazzani et al., 2020), suggesting meal timings may be intrinsically connected to the changes in sleep-wake timings during the pandemic.

Benedict et al. (2021) reported that the first meal of the day shifted by 23 minutes during the pandemic, and they found a significantly shorter eating window (period of time when meals are consumed over the course of the day). They found longer fasting periods between the last meal and the first meal the next day. Shorter eating window and longer fasting periods may have metabolic benefits. For example, Wilkinson et al., (2020) found time-restricted feeding (to a 10-hour window) resulted in weight loss and lower blood pressure. It appears later sleep-wake timings may have beneficial effects on other circadian outputs.

However, in another study, Bazzani et al., (2020) reported that late chronotypes delayed their meal timings on both workdays and work-free days during the pandemic. They found people who worked from home had their first meals later than people who were not working from home. A recent scoping review found that late chronotype may be associated with unhealthy dietary habits such as consuming food high in sugar content and lower intake of vegetables and fruits (Mazri et al., 2021). Additionally, the review found late chronotypes tend to skip breakfast and consume food late at night compared to morning chronotypes. Furthermore, irregular meal timings have also been associated with subjective depressed mood and feeling anxious (Tahara et al., 2021).

This may suggest the potential adverse effects of late sleep-wake timings and consequent late meal timings.

There is currently no evidence that the shifts in sleep-wake timings observed during the pandemic may translate into long-term manifestations of late chronotypes. However, the long-term effects of the pandemic are yet to be determined. More research on the long-term effects of the pandemic induced social and travel restrictions on human health is needed (Lunde et al., 2022), and the effects of the pandemic on chronobiological sleep-wake timings and feeding parameters may yet to be fully understood.

It may be best to view the reduction in social jetlag during the pandemic, that was at the expense of late sleep-wake timings, with cautious optimism. Shifting sleep-wake timings on workdays to later timings is one way to reduce social jetlag. Since sleep on work-free days or chronotype is an associate of social jetlag, another way to reduce social jetlag would be through the entraining of late clocks to advance to earlier timings. Several research groups have recently demonstrated that the idea of advancing late clocks through light interventions is not just a theoretical proposal but actually achievable.

Stothard et al., 2017 studied the effects of environmental light on sleep-wake rhythms in a week-long camping study. Participants were exposed to only natural daylight, and campfires and moonlight at night. This study reported that sleep start timings advanced by about 2.5 hours under the natural lighting conditions. The study showed that it may be possible to prevent the circadian phase shifts back and forth between work and work-free days by phase advancing and resetting internal rhythms for earlier sleep onset timings. Weekend camping trips might not be feasible for everyone. It might not be practical to completely remove indoor artificial light as well.

Facer-Childs et al. (2019) demonstrated that there may be a another more practical way to achieve effects similar to the Stothard study. In a randomized control trial, Facer-Childs et al., investigated the effects of fixed (and earlier) sleep-wake timings and meal timings. The intervention instruction given to the participants included sleeping and waking 2-3 hours earlier than usual, and to keep to a regular (+/- 15-30 minutes) sleep-wake timings across the week. Participants were also asked to eat breakfast after waking up and to keep meal timings fixed. The study reported that individuals with late chronotypes were able to advance their sleep-wake timings by about 2 hours.

Both studies have demonstrated that it is possible to phase advance late clocks. They have further demonstrated that such shifts may be achieved via practical and cost effective means such as sleep hygiene education and practices. These studies show how remarkably sensitive and adaptive the human circadian system is to the external environment and highlight hope that chronotype, a significant risk factor for social jetlag, may be a modifiable construct.

8.2 Limitations and future directions

There are limitations to the studies presented in this thesis that warrant a cautious interpretation of the results. The limitation discussed here are the general limitations across all studies. Limitations specific to each study are discussed in detail in the respective chapters. Firstly, the samples used were either convenience samples recruited via social media posts or recruited by a research recruitment company. The samples in chapters 5 and 6 were nationally representative, with a balanced sex ratio. However, the other samples were primarily students and females, and are not nationally representative. The results of this thesis may not be generalized due to the fairly homogenous student participants (chapters 2 and 7) or predominately older participants (chapters 3-6). Prepandemic samples and samples collected during the pandemic differed in terms of age and sex compositions. Thus, comparisons (chapter 5) were limited to qualitative descriptions, and statistical significance was not reported.

Secondly, cross-sectional study designs, correlational analysis and self-report measures may have affected the results. Like mentioned in chapter 7, the MCTQ derived variables have been validated and found to have high correlation with objective measures (such as actigraphy measures) of chronobiological sleep parameters. However, the specificity of the questions in some of the questionnaires in assessing the key variables of the studies were at times ambiguous. Furthermore, socially desirable responding and recall bias cannot be ruled out. For example, it is unclear if participants in chapter 3 may have associated the experience of daylight saving time with the experience of the summer months rather than the clock switching itself. Prepandemic sleep timings referenced in chapter 4 were retrospective reporting, and there may be recall bias.

The results presented here may be specific to the geographical location, and political and socioeconomic circumstances of Ireland. Studies conducted in different jurisdictions and in different latitudes reported results similar to the ones presented in chapter 3 (favouring daylight saving time over standard time). However, there is a possibility that the geographical position and latitude of Ireland may have influenced the results in chapter 3.

Similarly, changes in sleep-wake timings on workdays and reduction in social jetlag were not specific to Ireland but were observed globally. However, there may be specific circumstances that are unique to Ireland during the pandemic that is likely to have affected the results in chapters 4-6. The political and socioeconomic situation in Ireland may be different to other countries and the nature of the lockdown and the experience of the lockdown may have been different as well. Ireland had been under various levels of lockdown since late March 2020 (refer to figure 1.13 in chapter 1). This situates the findings presented in chapters 4-6, and the findings may be specific to Ireland and not generalizable to other countries.

The findings from the current research point to potential future research. Firstly, the studies in the research were not prospective, understandably due to the sudden and unexpected onset of the pandemic. Moving forward, planned experimental research could assess if working from home might result in phase delays in internal rhythms. The correlation between working from home, late sleep-wake timings and late meal timings suggested by other studies could be expanded to assess longitudinal bidirectional relationships between sleep and meal timings for those working from home.

Secondly, the current research relied on cross-sectional anonymous online surveys. Future research could include actigraphy assessment of sleep-wake timings. Assessing the impact of working from home for specific populations, such as patients with sleep disorders, obesity and diabetes or cardiovascular disorders, might help elucidate the clinical impact of the shifts in sleep-wake timings and reduction in social jetlag. Furthermore, the impact of the shifts in sleep-wake timings (and meal timings) on metabolites and other biomarkers could be assessed as well.

Finally, this research referred to sleep variability between work and work-free days. In real world settings, there could be night-to-night variability in sleep-wake timings. Future research could focus on assessing variability in sleep-wake timings across the week. Future research could also assess onset of sleepiness (via melatonin, body temperature and/or cortisol) and the time interval between melatonin onset and bedtime. Also, factors associated with variability in sleep-wake timings and delays in bedtime after melatonin onset (societal vs behavioural vs familial) could be examined.

8.3 Conclusion

The current research set out to examine the societal and intraindividual behavioural determinants of sleep-wake timings and social jetlag. The evidence from the data presented in this thesis unequivocally demonstrate the stress that socially imposed timings place on sleep-wake timings and social jetlag. There was no evidence of an association between social jetlag, chronotype and intraindividual traits in the current research. Reducing social jetlag via later sleep-wake timings on workdays may be one option to improve sleep health. However, reduction in social jetlag did not improve sleep quality. Other social, demographic and health factors may influence overall sleep quality. The current research suggests that public opinion and preferences may be different to scientific recommendations. Public education on sleep regularity and circadian misalignment via dissemination of research to the general public may help facilitate a discussion and possibly a chronobiologically sound solution to the widespread problem of social jetlag in modern society.

References

Adams, J. (2012). Consideration of immediate and future consequences, smoking status, and body mass index. *Health Psychology, 31*(2), 260-263. https://doi.org/10.1037/a0025790

Adan, A., Archer, S. N., Hidalgo, M. P., Di Milia, L., Natale, V., & Randler, C. (2012). Circadian typology: a comprehensive review. *Chronobiology International*, 29(9), 1153–1175. https://doi.org/ 10.3109/07420528.2012.719971

Akram, U., Stevenson, J. C., Gardani, M., Akram, A., & Allen, S. (2019). Psychopathy and chronotype disposition: the mediating role of depression. *Heliyon*, *5*(11), e02894. https://doi.org/10.1016/j.heliyon.2019.e02894

Akiyama, T., Katsumura, T., Nakagome, S., Lee, S. I., Joh, K., Soejima, H., Fujimoto, K., Kimura, R., Ishida, H., Hanihara, T., Yasukouchi, A., Satta, Y., Higuchi, S., & Oota, H. (2017). An ancestral haplotype of the human PERIOD2 gene associates with reduced sensitivity to light-induced melatonin suppression. *PloS One*, *12*(6), e0178373. https://doi.org/10.1371/journal.pone.0178373

Albrecht, J. N., Werner, H., Yaw, M. L., Jenni, O. G., & Huber, R. (2021). Teachers' preference for later school start times. *Journal of Sleep Research*, e13534. https://doi.org/10.1111/jsr.13534

Alfonsi, V., Palmizio, R., Rubino, A., Scarpelli, S., Gorgoni, M., D'Atri, A., Pazzaglia, M., Ferrara, M., Giuliano, S., & De Gennaro, L. (2020). The Association Between School Start Time and Sleep Duration, Sustained Attention, and Academic Performance. *Nature and Science of Sleep*, *12*, 1161–1172. https://doi.org/10.2147/NSS.S273875

Alimoradi, Z., Broström, A., Tsang, H., Griffiths, M. D., Haghayegh, S., Ohayon, M. M., Lin, C. Y., & Pakpour, A. H. (2021). Sleep problems during COVID-19 pandemic and its' association to psychological distress: A systematic review and meta-analysis. *E Clinical Medicine*, *36*, 100916. https://doi.org/10.1016/j.eclinm.2021.100916

Alvaro, P. K., Roberts, R. M., & Harris, J. K. (2013). A Systematic Review Assessing Bidirectionality between Sleep Disturbances, Anxiety, and Depression. *Sleep*, *36*(7), 1059–1068. https://doi.org/10.5665/sleep.2810

Al-Rawi, N., Madkour, M., Jahrami, H., Salahat, D., Alhasan, F., BaHammam, A., & Al-Islam Faris, M. (2020). Effect of diurnal intermittent fasting during Ramadan on ghrelin, leptin, melatonin, and cortisol levels among overweight and obese subjects: A prospective observational study. *PloS One*, *15*(8), e0237922. https://doi.org/10.1371/journal.pone.0237922

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Washington, DC: Author.

AMHSI Research Team, Milken Research Team, Roitblat, Y., Burger, J., Vaiman, M., Nehuliaieva, L., Buchris, N., & Shterenshis, M. (2021). Owls and larks do not exist: COVID-19 quarantine sleep habits. *Sleep Medicine*, *77*, 177–183. https://doi.org/10.1016/j.sleep.2020.09.003

Anderson, E. L., Richmond, R. C., Jones, S. E., Hemani, G., Wade, K. H., Dashti, H. S., Lane, J. M., Wang, H., Saxena, R., Brumpton, B., Korologou-Linden, R., Nielsen, J. B., Åsvold, B. O., Abecasis, G., Coulthard, E., Kyle, S. D., Beaumont, R. N., Tyrrell, J., Frayling, T. M., Munafò, M. R., … Davey Smith, G. (2021). Is disrupted sleep a risk factor for Alzheimer's disease? Evidence from a two-sample Mendelian randomization analysis. *International Journal of Epidemiology*, *50*(3), 817–828. https://doi.org/10.1093/ije/dyaa183

Andrews, S. J., Fulton-Howard, B., O'Reilly, P., Marcora, E., Goate, A. M., & collaborators of the Alzheimer's Disease Genetics Consortium (2021). Causal Associations Between Modifiable Risk Factors and the Alzheimer's Phenome. *Annals of Neurology*, *89*(1), 54–65. https://doi.org/10.1002/ana.25918

Arendt, J., & Skene, D. J. (2005). Melatonin as a chronobiotic. *Sleep Medicine Reviews*, *9*(1), 25–39. https://doi.org/10.1016/j.smrv.2004.05.002

Aschoff, J., Fatranská, M., Giedke, H., Doerr, P., Stamm, D., & Wisser, H. (1971). Human circadian rhythms in continuous darkness: entrainment by social cues. *Science (New York, N.Y.)*, *171*(3967), 213–215. https://doi.org/10.1126/science.171.3967.213

Baehr, E. K., Eastman, C. I., Revelle, W., Olson, S. H., Wolfe, L. F., & Zee, P. C. (2003). Circadian phase-shifting effects of nocturnal exercise in older compared with young adults. *American journal of physiology. Regulatory, Integrative and Comparative Physiology*, *284*(6), R1542–R1550. https://doi.org/10.1152/ajpregu.00761.2002

Balbo, M., Leproult, R., & Van Cauter, E. (2010). Impact of sleep and its disturbances on hypothalamo-pituitary-adrenal axis activity. *International Journal of Endocrinology*, *2010*, 759234. https://doi.org/10.1155/2010/759234

Baglioni, C., Battagliese, G., Feige, B., Spiegelhalder, K., Nissen, C., Voderholzer, U., Lombardo, C., & Riemann, D. (2011). Insomnia as a predictor of depression: a meta-analytic evaluation of longitudinal epidemiological studies. *Journal of Affective Disorders*, *135*(1-3), 10–19. https://doi.org/10.1016/j.jad.2011.01.011

Banks, J., & Xu, X. (2020). The mental health effects of the first two months of lockdown during the COVID-19 pandemic in the UK. *Fiscal Studies*, *41*(3), 685-708. https://doi.org/10.1111/1475-5890.12239

Bazzani, A., Marantonio, S., Andreozzi, G., Lorenzoni, V., Bruno, S., Cruz-Sanabria, F., d'Ascanio, P., Turchetti, G., & Faraguna, U. (2022). Late chronotypes, late mealtimes. Chrononutrition and sleep habits during the COVID-19 lockdown in Italy. *Appetite*, *172*, 105951. https://doi.org/10.1016/j.appet.2022.105951

Benedict, C., Brandão, L., Merikanto, I., Partinen, M., Bjorvatn, B., & Cedernaes, J. (2021). Meal and sleep timing before and during the COVID-19 Pandemic: A cross-sectional anonymous survey study from Sweden. *Clocks & Sleep*, *3*(2), 251–258. https://doi.org/10.3390/clockssleep3020015

Białaszek, W., Marcowski, P., & Cox, D. J. (2017). Differences in delay, but not probability discounting, in current smokers, e-cigarette users, and never smokers. *The Psychological Record*, 67(2), 223–230. https://doi.org/10.1007/s40732-017-0244-1.

Bjorvatn, B., Pallesen, S., Saxvig, I. W., & Waage, S. (2021). Daylight saving time preferences in Norway: Do individual chronotype and home address' latitude and longitude matter?. *Chronobiology International,* 38(10), 1449-1459. https://doi.org/10.1080/07420528.2021.1931278

Blume, C., & Schabus, M. (2020). Perspective: Daylight saving time-an advocacy for a balanced view and against fanning fear. *Clocks & Sleep*, *2*(1), 19–25. https://doi.org/10.3390/clockssleep2010003

Blume, C., Schmidt, M. H., & Cajochen, C. (2020). Effects of the COVID-19 lockdown on human sleep and rest-activity rhythms. *Current Biology : CB*, *30*(14), R795–R797. https://doi.org/10.1016/j.cub.2020.06.021

Bonaccorsi, G., Pierri, F., Cinelli, M., Flori, A., Galeazzi, A., Porcelli, F., Schmidt, A. L., Valensise, C. M., Scala, A., Quattrociocchi, W., & Pammolli, F. (2020). Economic and social consequences of human mobility restrictions under COVID-19. *Proceedings of the National Academy of Sciences of the United States of America*, *117*(27), 15530–15535. https://doi.org/10.1073/pnas.2007658117

Borbély, A. A. (1982). A two process model of sleep regulation. *Human neurobiology*, *1*(3), 195-204.

Borbély, A. A., & Achermann, P. (1999). Sleep homeostasis and models of sleep regulation. *Journal of Biological Rhythms*, *14*(6), 557–568. https://doi.org/10.1177/074873099129000894.

Borbely, A. A., Daan, S., Wirz-Justice, A., & Deboer, T. (2016). The two- process model of sleep regulation: A reappraisal. *Journal of Sleep Research*, 25(2), 131–143. https://doi.org/10.1111/jsr.12371.

Borisenkov, M. F., Perminova, E. V., & Kosova, A. L. (2010). Chronotype, sleep length, and school achievement of 11- to 23-year-old students in northen Russia. *Chronobiology International*, *27*(6), 1259–1270. https://doi.org/10.3109/07420528.2010.487624

Borisenkov, M. F., Tserne, T. A., Panev, A. S., Kuznetsova, E. S., Petrova, N. B., Timonin, V. D., ... & Kasyanova, O. N. (2017). Seven-year survey of sleep timing in Russian children and adolescents: chronic 1-h forward transition of social clock is associated with increased social jetlag and winter pattern of mood seasonality. *Biological Rhythm Research*, *48*(1), 3-12. https://doi.org/10.1080/09291016.2016.1223778

Brandão, L., Martikainen, T., Merikanto, I., Holzinger, B., Morin, C. M., Espie, C. A., Bolstad, C. J., Leger, D., Chung, F., Plazzi, G., Dauvilliers, Y., Matsui, K., De Gennaro, L., Sieminski, M., Nadorff, M. R., Chan, N. Y., Wing, Y. K., Mota-Rolim, S. A., Inoue, Y., Partinen, M., … Cedernaes, J. (2021). Social Jetlag Changes During the COVID-19 Pandemic as a Predictor of Insomnia - A Multi-National Survey Study. *Nature and Science of Sleep*, *13*, 1711–1722. https://doi.org/10.2147/NSS.S327365

Brooks, S. K., Webster, R. K., Smith, L. E., Woodland, L., Wessely, S., Greenberg, N., & Rubin, G. J. (2020). The psychological impact of quarantine and how to reduce it: Rapid review of the evidence. *Lancet*, *395*(10227), 912–920. https://doi.org/10.1016/S0140-6736(20)30460-8

Buysse, D. J., Reynolds, C. F., 3rd, Monk, T. H., Berman, S. R., & Kupfer, D. J. (1989). The Pittsburgh Sleep Quality Index: A new instrument for psychiatric practice and research. *Psychiatry Research*, *28*(2), 193–213. https://doi.org/10.1016/01651781(89)90047-4

Buysse, D. J., Angst, J., Gamma, A., Ajdacic, V., Eich, D., & Rössler, W. (2008). Prevalence, course, and comorbidity of insomnia and depression in young adults. *Sleep*, *31*(4), 473–480. https://doi.org/10.1093/sleep/31.4.473

Buysse, D. J., Cheng, Y., Germain, A., Moul, D. E., Franzen, P. L., Fletcher, M., & Monk, T. H. (2010). Night-to-night sleep variability in older adults with and without chronic insomnia. *Sleep Medicine*, *11*(1), 56–64. https://doi.org/10.1016/j.sleep.2009.02.010

Buysse D. J. (2014). Sleep health: Can we define it? Does it matter?. *Sleep*, *37*(1), 9–17. https://doi.org/10.5665/sleep.329

Campbell S. S. (1984). Duration and placement of sleep in a "disentrained" environment. *Psychophysiology*, *21*(1), 106–113. https://doi.org/10.1111/j.1469-8986.1984.tb02327.x

Canteras, N. S., Ribeiro-Barbosa, É. R., Goto, M., Cipolla-Neto, J., & Swanson, L. W. (2011). The retinohypothalamic tract: Comparison of axonal projection patterns from four major targets. *Brain Research Reviews*, *65*(2), 150-183.

Carney, C. E., & Edinger, J. D. (2006). Identifying critical beliefs about sleep in primary insomnia. *Sleep*, *29*(4), 444–453. https://doi.org/10.1093/sleep/29.3.342

Carskadon, M. A., Mindell, J. A., & Drake, C. (2006). Sleep in America poll: Teens. Washington, DC: National Sleep Foundation.

Carskadon M. A. (2011). Sleep in adolescents: the perfect storm. *Pediatric clinics of North America*, *58*(3), 637–647. https://doi.org/10.1016/j.pcl.2011.03.003

Carvalho, F. G., Hidalgo, M. P., & Levandovski, R. (2014). Differences in circadian patterns between rural and urban populations: an epidemiological study in countryside. *Chronobiology International*, *31*(3), 442–449. https://doi.org/10.3109/07420528.2013.846350

Cespedes Feliciano, E. M., Rifas-Shiman, S. L., Quante, M., Redline, S., Oken, E., & Taveras, E. M. (2019). Chronotype, social jet lag, and cardiometabolic risk factors in early adolescence. *JAMA Pediatrics*, *173*(11), 1049–1057. https://doi.org/10.1001/jamapediatrics.2019.3089

Chang, S. J., & Jang, S. J. (2019). Social jetlag and quality of life among nursing students: A cross-sectional study. *Journal of Advanced Nursing*, *75*(7), 1418–1426. https://doi.org/10.1111/jan.13857

Chellappa, S. L., Gordijn, M. C. M., & Cajochen, C. (2011). Can light make us bright? Effects of light on cognition and sleep. *Progress in Brain Research*, 190, 119-133. https://doi.org/ 10.1016/B978-0-444-53817-8.00007-4.

Chellappa, S. L., Morris, C. J., & Scheer, F. (2018). Daily circadian misalignment impairs human cognitive performance task-dependently. *Scientific Reports*, *8*(1), 3041. https://doi.org/10.1038/s41598-018-20707-4

Choi, S. J., Joo, E. Y., & Hong, S. B. (2016). Sleep-wake pattern, chronotype and seizures in patients with epilepsy. *Epilepsy Research*, *120*, 19–24. https://doi.org/10.1016/j.eplepsyres.2015.11.010

Chung, S. J., An, H., & Suh, S. (2020). What do people do before going to bed? A study of bedtime procrastination using time use surveys. *Sleep*, *43*(4), zsz267. https://doi.org/10.1093/sleep/zsz267

Churchill, S., Pavey, L., Jessop, D., & Sparks, P. (2016). Persuading people to drink less alcohol: The role of message framing, temporal focus and autonomy. *Alcohol and Alcoholism*, *51*(6), 727-733. https://doi.org/10.1093/alcalc/agw033

Cipolla-Neto, J., Skorupa, A. L., Ribeiro-Barbosa, E. R., Bartol, I., Mota, S. R., Afeche, S. C., Delagrange, P., Guardiola-Lemaitre, B., & Canteras, N. S. (1999). The role of the retrochiasmatic area in the control of pineal metabolism. *Neuroendocrinology*, *69*(2), 97–104. https://doi.org/10.1159/000054407

Cipolla-Neto, J., & Amaral, F. (2018). Melatonin as a hormone: New physiological and clinical insights. *Endocrine Reviews*, *39*(6), 990–1028. https://doi.org/10.1210/er.2018-00084

Cohen, J. (1988). Statistical Power Analysis for the Behavioral Sciences; Erlbaum: Hillsdale, MI, USA.

Committee on Science (2001) Energy conservation potential of extended and double daylight saving time. http://commdocs.house.gov/committees/science/hsy73325.000/hsy73325_0.HTM

Cullell, N., Cárcel-Márquez, J., Gallego-Fábrega, C., Muiño, E., Lluciá-Carol, L., Lledós, M., Amaut, K., Krupinski, J., & Fernández-Cadenas, I. (2021). Sleep/wake cycle alterations as a cause of neurodegenerative diseases: A Mendelian randomization study. *Neurobiology of Aging*, *106*, 320.e1–320.e12. https://doi.org/10.1016/j.neurobiolaging.2021.05.008

Cunningham, J., & Shapiro, C. M. (2018). Cognitive behavioural therapy for insomnia (CBT-I) to treat depression: A systematic review. *Journal of Psychosomatic Research*, *106*, 1 12. https://doi.org/10.1016/j.jpsychores.2017.12.012

Dautovich, N. D., Reid, M. P., Sabet, S. M., Ghose, S. M., & Dzierzewski, J. M. (2021). Practice does not make perfect: The tireless pursuit of achieving perfect sleep. *International Journal of Environmental Research and Public Health*, *18*(16), 8523. https://doi.org/10.3390/ijerph18168523

de la Iglesia, H. O., Fernández-Duque, E., Golombek, D. A., Lanza, N., Duffy, J. F., Czeisler, C. A., & Valeggia, C. R. (2015). Access to electric light is associated with shorter sleep duration in a traditionally hunter-gatherer community. *Journal of Biological Rhythms*, *30*(4), 342–350. https://doi.org/10.1177/0748730415590702

de Zwart, B. J., Beulens, J., Elders, P., & Rutters, F. (2018). Pilot data on the association between social jetlag and obesity-related characteristics in Dutch adolescents over one year. *Sleep Medicine*, *47*, 32–35. https://doi.org/10.1016/j.sleep.2018.03.024

Deboer T. (2018). Sleep homeostasis and the circadian clock: Do the circadian pacemaker and the sleep homeostat influence each other's functioning? *Neurobiology of Sleep and Circadian Rhythms*, *5*, 68–77. https://doi.org/10.1016/j.nbscr.2018.02.003

Dijk, D. J., & Archer, S. N. (2009). Circadian and homeostatic regulation of human sleep and cognitive performance and its modulation by PERIOD3. *Sleep Medicine Clinics*, *4*(2), 111–125. https://doi.org/10.1016/j.jsmc.2009.02.001

Duffy, J. F., & Wright, K. P., Jr (2005). Entrainment of the human circadian system by light. *Journal of Biological Rhythms*, *20*(4), 326–338. https://doi.org/10.1177/0748730405277983

Elmore, S. K., Betrus, P. A., & Burr, R. (1994). Light, social zeitgebers, and the sleep-wake cycle in the entrainment of human circadian rhythms. *Research in Nursing & Health*, *17*(6), 471–478. https://doi.org/10.1002/nur.4770170610

Espie C. A. (2002). Insomnia: Conceptual issues in the development, persistence, and treatment of sleep disorder in adults. *Annual Review of Psychology*, *53*, 215–243. https://doi.org/10.1146/annurev.psych.53.100901.135243

Espie, C. A., Kyle, S. D., Hames, P., Gardani, M., Fleming, L., & Cape, J. (2014). The Sleep Condition Indicator: A clinical screening tool to evaluate insomnia disorder. *BMJ Open*, *4*(3), e004183. https://doi.org/10.1136/bmjopen-2013-004183

Evans, D. S., Snitker, S., Wu, S. H., Mody, A., Njajou, O. T., Perlis, M. L., Gehrman, P. R., Shuldiner, A. R., & Hsueh, W. C. (2011). Habitual sleep/wake patterns in the Old Order Amish: Heritability and association with non-genetic factors. *Sleep*, *34*(5), 661-669. https://doi.org/10.1093/sleep/34.5.661

Evans J., & Silver R. (2015) The suprachiasmatic nucleus and the circadian timekeeping system of the body. In: Pfaff D., Volkow N. (eds) Neuroscience in the 21st Century. Springer, New York.
https://doi.org/10.1007/978-1-4614-6434-1_66-3

Facer-Childs, E. R., Middleton, B., Skene, D. J., & Bagshaw, A. P. (2019). Resetting the late timing of 'night owls' has a positive impact on mental health and performance. *Sleep Medicine*, *60*, 236–247. https://doi.org/10.1016/j.sleep.2019.05.001

Fan, M., Sun, D., Zhou, T., Heianza, Y., Lv, J., Li, L., & Qi, L. (2020). Sleep patterns, genetic susceptibility, and incident cardiovascular disease: A prospective study of 385 292 UK biobank participants. *European Heart Journal*, *41*(11), 1182–1189. https://doi.org/10.1093/eurheartj/ehz849

Fernandez-Mendoza, J., & Vgontzas, A. N. (2013). Insomnia and its impact on physical and mental health. *Current Psychiatry Reports*, *15*(12), 418. https://doi.org/10.1007/s11920-013-0418-8

Fischer, D., Lombardi, D. A., Marucci-Wellman, H., & Roenneberg, T. (2017). Chronotypes in the US–influence of age and sex. *PLoS One*, 12(6), e0178782. https://doi.org/10.1093/sleepj/zsx050.157.

Fitzpatrick, J. M., Silva, G. E., & Vana, K. D. (2020). Perceived barriers and facilitating factors in implementing delayed school start times to improve adolescent sleep patterns. *The Journal of School Health*. https://doi.org/10.1111/josh.12983

Fogteloo, A. J., Pijl, H., Roelfsema, F., Frölich, M., & Meinders, A. E. (2004). Impact of meal timing and frequency on the twenty-four-hour leptin rhythm. *Hormone Research*, *62*(2), 71–78. https://doi.org/10.1159/000079326

Ford, D. E., & Kamerow, D. B. (1989). Epidemiologic study of sleep disturbances and psychiatric disorders. An opportunity for prevention?. *JAMA*, *262*(11), 1479–1484. https://doi.org/10.1001/jama.262.11.1479

Foster, R. G., & Wulff, K. (2005). The rhythm of rest and excess. *Nature Reviews. Neuroscience*, *6*(5), 407–414. https://doi.org/10.1038/nrn1670

Foster, R. G., & Roenneberg, T. (2008). Human responses to the geophysical daily, annual and lunar cycles. *Current Biology*, 18(17), R784–R794. https://doi.org/10.1016/j.cub.2008.07.003

Foster, R.G., & Kreitzman, L. (2017). Circadian rhythms: A very short introduction. Oxford University Press.

Fritz, J., VoPham, T., Wright, K. P., Jr, & Vetter, C. (2020). A chronobiological evaluation of the acute effects of daylight saving time on traffic accident risk. *Current Biology : CB*, *30*(4), 729–735.e2. https://doi.org/10.1016/j.cub.2019.12.045

Gadie, A., Shafto, M., Leng, Y., Kievit, R. A., & Cam-CAN (2017). How are age-related differences in sleep quality associated with health outcomes? An epidemiological investigation in a UK cohort of 2406 adults. *BMJ Open*, *7*(7), e014920. https://doi.org/10.1136/bmjopen-2016-014920

Ghotbi, N., Pilz, L. K., Winnebeck, E. C., Vetter, C., Zerbini, G., Lenssen, D., Frighetto, G., Salamanca, M., Costa, R., Montagnese, S., & Roenneberg, T. (2020). The µMCTQ: An ultra-short version of the Munich ChronoType Questionnaire. *Journal of Biological Rhythms*, *35*(1), 98–110. https://doi.org/10.1177/0748730419886986

Gick, M. (2014). An exploration of interactions between conscientiousness and consideration of future consequences on healthy eating. *Personality and Individual Differences*, *66*, 181-187. https://doi.org/10.1016/j.paid.2014.03.020

Gooley, J. J., Chamberlain, K., Smith, K. A., Khalsa, S. B., Rajaratnam, S. M., Van Reen, E., Zeitzer, J. M., Czeisler, C. A., & Lockley, S. W. (2011). Exposure to room light before bedtime suppresses melatonin onset and shortens melatonin duration in humans. *The Journal of Clinical Endocrinology and Metabolism*, *96*(3), E463–E472. https://doi.org/10.1210/jc.2010-2098

Government of Ireland, Department of Health. (n.d). From https://www.gov.ie/en/publication/cf9b0d-newpublic-health-measures-effective-now-to-prevent-further-spreado/?referrer=/en/publication/539d23-stay-athome-the-latest public-health-measures-to-prevent-the-spread/

Granados-Fuentes, D., Prolo, L. M., Abraham, U., & Herzog, E. D. (2004). The suprachiasmatic nucleus entrains, but does not sustain, circadian rhythmicity in the olfactory bulb. *Journal of Neuroscience*, 24(3), 615–619. https:/doi.org/10.1523/JNEUROSCI.400203.2004.

Gray, J. C., Amlung, M. T., Palmer, A. A., & MacKillop, J. (2016). Syntax for calculation of discounting indices from the monetary choice questionnaire and probability discounting questionnaire. *Journal of the Experimental Analysis of Behavior*, *106*(2), 156–163. https://doi.org/10.1002/jeab.221

Gu, F., Xu, S., Devesa, S. S., Zhang, F., Klerman, E. B., Graubard, B. I., & Caporaso, N. E. (2017). Longitude position in a time zone and cancer risk in the United States. *Cancer Epidemiology, Biomarkers & Prevention : A publication of the American Association for Cancer Research, cosponsored by the American Society of Preventive Oncology*, *26*(8), 1306–1311. https://doi.org/10.1158/1055-9965.EPI-16-1029

Hadjidemetriou, G. M., Sasidharan, M., Kouyialis, G., & Parlikad, A. K. (2020). The impact of government measures and human mobility trend on COVID-19 related deaths in the UK. *Transportation Research Interdisciplinary Perspectives*, *6*, 100167. https://doi.org/10.1016/j.trip.2020.100167

Harvey A. G. (2002). A cognitive model of insomnia. *Behaviour Research and Therapy*, *40*(8), 869–893. https://doi.org/10.1016/s0005-7967(01)00061-4

Haugland, B., Hysing, M., & Sivertsen, B. (2020). The burden of care: A national survey on the prevalence, demographic characteristics and health problems among young adult carers attending higher education in Norway. *Frontiers in Psychology*, *10*, 2859. https://doi.org/10.3389/fpsyg.2019.02859

Häusler, N., Marques-Vidal, P., Haba-Rubio, J., & Heinzer, R. (2020). Association between actigraphy-based sleep duration variability and cardiovascular risk factors - results of a population-based study. *Sleep Medicine*, *66*, 286–290. https://doi.org/10.1016/j.sleep.2019.02.008

Haynie, D. L., Lewin, D., Luk, J. W., Lipsky, L. M., O'Brien, F., Iannotti, R. J., Liu, D., & Simons-Morton, B. G. (2018). Beyond sleep duration: Bidirectional associations among chronotype, social jetlag, and drinking behaviors in a longitudinal sample of US high School students. *Sleep*, *41*(2), zsx202. https://doi.org/10.1093/sleep/zsx202

Henderson, S., Brady, E. M., & Robertson, N. (2019). Associations between social jetlag and mental health in young people: A systematic review. *Chronobiology International*, *36*(10), 1316–1333. https://doi.org/10.1080/07420528.2019.1636813

Hertenstein, E., Feige, B., Gmeiner, T., Kienzler, C., Spiegelhalder, K., Johann, A., Jansson-Fröjmark, M., Palagini, L., Rücker, G., Riemann, D., & Baglioni, C. (2019). Insomnia as a predictor of mental disorders: A systematic review and meta-analysis. *Sleep Medicine Reviews*, *43*, 96–105. https://doi.org/10.1016/j.smrv.2018.10.006

Higgins, S., Stoner, L., Black, K., Wong, J. E., Quigg, R., Meredith-Jones, K., & Skidmore, P. M. (2021). Social jetlag is associated with obesity-related outcomes in 9-11-year-old children, independent of other sleep characteristics. *Sleep Medicine*, *84*, 294–302. https://doi.org/10.1016/j.sleep.2021.06.014

Hirshkowitz, M., Whiton, K., Albert, S. M., Alessi, C., Bruni, O., DonCarlos, L., Hazen, N., Herman, J., Katz, E. S., Kheirandish-Gozal, L., Neubauer, D. N., O'Donnell, A. E., Ohayon, M., Peever, J., Rawding, R., Sachdeva, R. C., Setters, B., Vitiello, M. V., Ware, J. C., & Adams Hillard, P. J. (2015). National Sleep Foundation's sleep time duration recommendations: Methodology and results summary. *Sleep Health*, *1*(1), 40–43. https://doi.org/10.1016/j.sleh.2014.12.010

Hoffman, K. E., Garner, D., Koong, A. C., & Woodward, W. A. (2020). Understanding the intersection of working from home and burnout to optimize post-COVID19 work arrangements in radiation oncology. *International Journal of Radiation Oncology, Biology, Physics*, *108*(2), 370–373. https://doi.org/10.1016/j.ijrobp.2020.06.062

Holbein, J. B., Schafer, J. P., & Dickinson, D. L. (2019). Insufficient sleep reduces voting and other prosocial behaviours. *Nature Human Behaviour*, *3*(5), 492–500. https://doi.org/10.1038/s41562-019-0543-4

Horne, J. A., & Ostberg, O. (1976). A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. *International Journal of Chronobiology*, *4*(2), 97–110.

Huang, J., Zuber, V., Matthews, P. M., Elliott, P., Tzoulaki, J., & Dehghan, A. (2020). Sleep, major depressive disorder, and Alzheimer disease: A Mendelian randomization study. *Neurology*, *95*(14), e1963–e1970. https://doi.org/10.1212/WNL.0000000000010463

Hughes, S., Jagannath, A., Hankins, M. W., Foster, R. G., & Peirson, S. N. (2015). Photic regulation of clock systems. *Methods in Enzymology*, 552, 125–143. https://doi.org/10.1016/bs.mie.2014.10.018

Hyland, P., Vallières, F., McBride, O., Murphy, J., Shevlin, M., Bentall, R. P., Butter, S., Hartman, T. K., Karatzias, T., MacLachlan, M., Maguire, R., Power, J. M., Spikol, E., & Daly, M. (2021). Mental health of adults in Ireland during the first year of the COVID-19 pandemic: Results from a nationally representative, longitudinal study. *Psychological Medicine*, 1–3. Advance online publication. https://doi.org/10.1017/S0033291721004360

Irish Department of Justice and Equality (2019) Report of the Interdepartmental Group on EU Proposal to Discontinue Seasonal Clock Changes. http://www.justice.ie/en/JELR/Report_of_the_Interdepartmental_Group_on_EU_Proposal_to_Discontinue_Seasonal_Clock_Changes.pdf/Files/Report_of_the_Interdepartmental_Group_on_EU_Proposal_to_Discontinue_Seasonal_Clock_Changes.pdf.

Islam, Z., Hu, H., Akter, S., Kuwahara, K., Kochi, T., Eguchi, M., Kurotani, K., Nanri, A., Kabe, I., & Mizoue, T. (2020). Social jetlag is associated with an increased likelihood of having depressive symptoms among the Japanese working population: The Furukawa Nutrition and Health Study. *Sleep*, *43*(1), zsz204. https://doi.org/10.1093/sleep/zsz204

Ito, W., Komada, Y., Okajima, I., & Inoue, Y. (2017). Excessive daytime sleepiness in adults with possible attention deficit/hyperactivity disorder (ADHD): A web-based cross sectional study. Sleep Medicine, 32, 4–9. https://doi.org/10.1016/j.sleep.2016.04.008.

Jagannath, A., Taylor, L., Wakaf, Z., Vasudevan, S. R., & Foster, R. G. (2017). The genetics of circadian rhythms, sleep and health. *Human Molecular Genetics*, 26(R2), R128–R138. https://doi.org/10.1093/ hmg/ddx240.

Janati Idrissi, A., Lamkaddem, A., Benouajjit, A., Ben El Bouaazzaoui, M., El Houari, F., Alami, M., Labyad, S., Chahidi, A., Benjelloun, M., Rabhi, S., Kissani, N., Zarhbouch, B., Ouazzani, R., Kadiri, F., Alouane, R., Elbiaze, M., Boujraf, S., El Fakir, S., & Souirti, Z. (2020). Sleep quality and mental health in the context of COVID-19 pandemic and lockdown in Morocco. *Sleep Medicine*, *74*, 248–253. https://doi.org/10.1016/j.sleep.2020.07.045

Jin, L., Zhou, J., Peng, H., Ding, S., & Yuan, H. (2018). Investigation on dysfunctional beliefs and attitudes about sleep in Chinese college students. *Neuropsychiatric Disease and Treatment*, *14*, 1425–1432. https://doi.org/10.2147/NDT.S155722

Johnson, D. A., Meltzer, L. J., Zhang, T., Lu, M., Cassidy-Bushrow, A. E., Stokes-Buzzelli, S., Duffy, E., McKinnon, B., Mahajan, P., Redline, S., & Joseph, C. L. (2018). The influence of psychosocial stressors and socioeconomic status on sleep among caregivers of teenagers with asthma, the Puff City study. *Sleep Health*, *4*(2), 141–146. https://doi.org/10.1016/j.sleh.2017.11.003

Johnson, D. A., Guo, N., & Redline, S. (2020). 0784 Associations of sleep regularity and chronotype with hypertension among African Americans in the Jackson Heart Sleep Study. *Sleep*, *43*, A298. DOI:10.1093/sleep/zsaa056.780

Johnson, E. O., Roth, T., & Breslau, N. (2006). The association of insomnia with anxiety disorders and depression: Exploration of the direction of risk. *Journal of Psychiatric Research*, *40*(8), 700–708. https://doi.org/10.1016/j.jpsychires.2006.07.008

Joireman, J., Shaffer, M. J., Balliet, D., & Strathman, A. (2012). Promotion orientation explains why future-oriented people exercise and eat healthy: Evidence from the two-factor consideration of future consequences-14 scale. *Personality & Social Psychology Bulletin*, *38*(10), 1272–1287. https://doi.org/10.1177/0146167212449362

Jones, J., Guest, J. L., Sullivan, P. S., Sales, J. M., Jenness, S. M., & Kramer, M. R. (2018). The association between monetary and sexual delay discounting and risky sexual behavior in an online sample of men who have sex with men. *AIDS Care*, 1–9. https://doi.org/10.1080/09540121.2018.1427851.

Ju, Y. E., Lucey, B. P., & Holtzman, D. M. (2014). Sleep and Alzheimer disease pathology--a bidirectional relationship. *Nature Reviews. Neurology*, *10*(2), 115–119. https://doi.org/10.1038/nrneurol.2013.269

Jungmann, S. M., & Witthöft, M. (2020). Health anxiety, cyberchondria, and coping in the current COVID-19 pandemic: Which factors are related to coronavirus anxiety? *Journal of Anxiety Disorders*, *73*, 102239. https://doi.org/10.1016/j.janxdis.2020.102239

Kadzikowska-Wrzosek, R. (2018). Self-regulation and bedtime procrastination: The role of self-regulation skills and chronotype. *Personality and Individual Differences*, *128*, 10-15. https://doi.org/10.1016/j.paid.2018.02.015

Kamphorst, B. A., Nauts, S., De Ridder, D., & Anderson, J. H. (2018). Too depleted to turn In: The relevance of end-of-the-day resource depletion for reducing bedtime procrastination. *Frontiers in Psychology*, *9*, 252. https://doi.org/10.3389/fpsyg.2018.00252

Kantermann, T., Juda, M., Merrow, M., & Roenneberg, T. (2007). The human circadian clock's seasonal adjustment is disrupted by daylight saving time. *Current Biology : CB*, *17*(22), 1996–2000. https://doi.org/10.1016/j.cub.2007.10.025

Kaplan, B. A., Amlung, M., Reed, D. D., Jarmolowicz, D. P., McKerchar, T. L., & Lemley, S. M. (2016). Automating scoring of delay discounting for the 21- and 27-item Monetary Choice Questionnaires. *The Behavior Analyst*, *39*(2), 293–304. https://doi.org/10.1007/s40614-016-0070-9

Kelly, R. M., Healy, U., Sreenan, S., McDermott, J. H., & Coogan, A. N. (2018). Clocks in the clinic: Circadian rhythms in health and disease. *Postgraduate Medical Journal*, *94*(1117), 653–658. https://doi.org/10.1136/postgradmedj-2018-135719

Kelly, R. M., Finn, J., Healy, U., Gallen, D., Sreenan, S., McDermott, J. H., & Coogan, A. N. (2020). Greater social jetlag associates with higher HbA1c in adults with type 2 diabetes: A cross sectional study. *Sleep Medicine*, *66*, 1-9.

Kelly, R. M., Healy, U., Sreenan, S., McDermott, J., & Coogan, A. N. (2022). An exploratory study of associations between sleep timing variability and cardiometabolic health in middle-aged adults with type 2 diabetes mellitus. *Chronobiology International*, 1–10. https://doi.org/10.1080/07420528.2021.2005083

Killgore, W., Cloonan, S. A., Taylor, E. C., Fernandez, F., Grandner, M. A., & Dailey, N. S. (2020). Suicidal ideation during the COVID-19 pandemic: The role of insomnia. *Psychiatry Research*, *290*, 113134. https://doi.org/10.1016/j.psychres.2020.113134

Kim, K. M., Han, S. M., Heo, K., Kim, W. J., & Chu, M. K. (2020). Sex differences in the association between chronotype and risk of depression. *Scientific Reports*, *10*(1), 18512. https://doi.org/10.1038/s41598-020-75724-z

Kirby, K. N., Petry, N. M., & Bickel, W. K. (1999). Heroin addicts have higher discount rates for delayed rewards than non-drug-using controls. *Journal of Experimental Psychology. General*, *128*(1), 78–87. https://doi.org/10.1037//0096-3445.128.1.78

Kivelä, L., Papadopoulos, M. R., & Antypa, N. (2018). Chronotype and psychiatric disorders. *Current Sleep Medicine Reports*, *4*(2), 94–103. https://doi.org/10.1007/s40675-018-0113-8

Kocevska, D., Blanken, T. F., Van Someren, E., & Rösler, L. (2020). Sleep quality during the COVID-19 pandemic: Not one size fits all. *Sleep Medicine*, *76*, 86–88. https://doi.org/10.1016/j.sleep.2020.09.029

Kokou-Kpolou, C. K., Megalakaki, O., Laimou, D., & Kousouri, M. (2020). Insomnia during COVID-19 pandemic and lockdown: Prevalence, severity, and associated risk factors in French population. *Psychiatry Research*, *290*, 113128. https://doi.org/10.1016/j.psychres.2020.113128

Konjarski, M., Murray, G., Lee, V. V., & Jackson, M. L. (2018). Reciprocal relationships between daily sleep and mood: A systematic review of naturalistic prospective studies. *Sleep Medicine Reviews*, *42*, 47–58. https://doi.org/10.1016/j.smrv.2018.05.005

Korman, M., Tkachev, V., Reis, C., Komada, Y., Kitamura, S., Gubin, D., Kumar, V., & Roenneberg, T. (2020). COVID-19-mandated social restrictions unveil the impact of social time pressure on sleep and body clock. *Scientific Reports*, *10*(1), 22225. https://doi.org/10.1038/s41598-020-79299-7

Korman, M., Tkachev, V., Reis, C., Komada, Y., Kitamura, S., Gubin, D., Kumar, V., & Roenneberg, T. (2022). Outdoor daylight expsoure and longer sleep promote wellbeing under COVID-19 mandated restrictions. *Journal of Sleep Research*, *31*(2), e13471. https://doi.org/10.1111/jsr.13471

Knapen, S. E., Riemersma-van der Lek, R. F., Antypa, N., Meesters, Y., Penninx, B., & Schoevers, R. A. (2018). Social jetlag and depression status: Results obtained from the Netherlands Study of Depression and Anxiety. *Chronobiology International*, *35*(1), 1 7. https://doi.org/10.1080/07420528.2017.1374966

Kroenke, K., Spitzer, R. L., & Williams, J. B. (2001). The PHQ-9: Validity of a brief depression severity measure. *Journal of General Internal Medicine*, *16*(9), 606–613. https://doi.org/10.1046/j.1525-1497.2001.016009606.x

Kroese, F. M., De Ridder, D. T., Evers, C., & Adriaanse, M. A. (2014). Bedtime procrastination: Introducing a new area of procrastination. *Frontiers in Psychology*, *5*, 611. https://doi.org/10.3389/fpsyg.2014.00611

Kronholm, E., Partonen, T., Laatikainen, T., Peltonen, M., Härmä, M., Hublin, C., Kaprio, J., Aro, A.R., Partinen, M., Fogelholm, M. & Valve, R. (2008). Trends in self-reported sleep duration and insomnia-related symptoms in Finland from 1972 to 2005: A comparative review and re-analysis of Finnish population samples. *Journal of Sleep Research*, *17*(1), pp.54-62. https://doi.org/10.1111/j.1365-2869.2008.00627.x

Kühnel, J., Syrek, C. J., & Dreher, A. (2018). Why don't you go to bed on time? A daily diary study on the relationships between chronotype, self-control resources and the phenomenon of bedtime procrastination. *Frontiers in Psychology*, *9*, 77. https://doi.org/10.3389/fpsyg.2018.00077

Kuiper, R. M., & Ryan, O. (2018). Drawing conclusions from cross-lagged relationships: Re-considering the role of the time-interval. *Structural Equation Modeling: A Multidisciplinary Journal*, *25*(5), 809-823. https://doi.org/10.1080/10705511.2018.1431046

Lades, L. K., Laffan, K., Daly, M., & Delaney, L. (2020). Daily emotional well-being during the COVID-19 pandemic. *British Journal of Health Psychology*, *25*(4), 902–911. https://doi.org/10.1111/bjhp.12450

Lahiri, A., Jha, S. S., Acharya, R., Dey, A., & Chakraborty, A. (2021). Correlates of insomnia among the adults during COVID19 pandemic: Evidence from an online survey in India. *Sleep Medicine*, *77*, 66–73. https://doi.org/10.1016/j.sleep.2020.11.020

Lahti, T. A., Leppämäki, S., Lönnqvist, J., & Partonen, T. (2008). Transitions into and out of daylight saving time compromise sleep and the rest-activity cycles. *BMC Physiology*, *8*, 3. https://doi.org/10.1186/1472-6793-8-3

Larcher, S., Gauchez, A. S., Lablanche, S., Pepin, J. L., Benhamou, P. Y., & Borel, A. L. (2016). Impact of sleep behavior on glycemic control in type 1 diabetes: The role of social jetlag. *European Journal of Endocrinology*, 175(5), 411–419. https://doi.org/10.1530/EJE-16- 0188.

Lee, C. A., Derefinko, K. J., Milich, R., Lynam, D. R., & DeWall, C. N. (2017). Longitudinal and reciprocal relations between delay discounting and crime. *Personality and Individual Differences*, *111*, 193-198. https://doi.org/10.1016/j.paid.2017.02.023

Leone, M. J., Sigman, M., & Golombek, D. A. (2020). Effects of lockdown on human sleep and chronotype during the COVID-19 pandemic. *Current Biology : CB*, *30*(16), R930-R931. https://doi.org/10.1016/j.cub.2020.07.015

Levandovski, R., Dantas, G., Fernandes, L. C., Caumo, W., Torres, I., Roenneberg, T., et al. (2011). Depression scores associate with chronotype and social jetlag in a rural population. *Chronobiology International*, 28(9), 771–778. https://doi.org/10.3109/07420528. 2011.602445.

Li, L., Wu, C., Gan, Y., Qu, X., & Lu, Z. (2016). Insomnia and the risk of depression: A meta-analysis of prospective cohort studies. *BMC Psychiatry*, *16*(1), 375. https://doi.org/10.1186/s12888-016-1075-3

Li, S. X., Chan, N. Y., Man Yu, M. W., Lam, S. P., Zhang, J., Yan Chan, J. W., Li, A. M., & Wing, Y. K. (2018). Eveningness chronotype, insomnia symptoms, and emotional and behavioural problems in adolescents. *Sleep Medicine*, *47*, 93–99. https://doi.org/10.1016/j.sleep.2018.03.025

Lichstein K. L. (2006). Secondary insomnia: A myth dismissed. *Sleep Medicine Reviews*, *10*(1), 3–5. https://doi.org/10.1016/j.smrv.2005.10.001

Liu, S., Li, C., Shi, Z., Wang, X., Zhou, Y., Liu, S., Liu, J., Yu, T., & Ji, Y. (2017). Caregiver burden and prevalence of depression, anxiety and sleep disturbances in Alzheimer's disease caregivers in China. *Journal of Clinical Nursing*, *26*(9-10), 1291–1300. https://doi.org/10.1111/jocn.13601

Liu, T., Pan, B., & Yin, Z. (2020). Pandemic, mobile payment, and household consumption: Micro-evidence from China. *Emerging Markets Finance and Trade*, *56*(10), 2378 2389. https://doi.org/10.1080/1540496X.2020.1788539

Liu, X., Zhang, B., Xu, X., Huang, Z., & Qu, W. (2012). Lesions of suprachiasmatic nucleus modify sleep structure but do not alter the total amount of daily sleep in rats. *Sleep and Biological Rhythms*, 10(4), 293–301. https://doi.org/10.1111/j.1479 8425.2012.00572.x.

Lockley, S. W., Brainard, G. C., & Czeisler, C. A. (2003). High sensitivity of the human circadian melatonin rhythm to resetting by short wavelength light. *The Journal of Clinical Endocrinology and Metabolism*, *88*(9), 4502–4505. https://doi.org/10.1210/jc.2003-030570

Lucey, B. P., & Holtzman, D. M. (2015). How amyloid, sleep and memory connect. *Nature Neuroscience,* 18(7), 933. https://doi.org/ 10.1038/nn.4048.

Lunde, L. K., Fløvik, L., Christensen, J. O., Johannessen, H. A., Finne, L. B., Jørgensen, I. L., Mohr, B., & Vleeshouwers, J. (2022). The relationship between telework from home and employee health: a systematic review. *BMC Public Health*, *22*(1), 47. https://doi.org/10.1186/s12889-021-12481-2

Lunn, R.M., Blask, D.E., Coogan, A.N., Figueiro, M.G., Gorman, M.R., Hall, J.E., Hansen, J., Nelson, R.J., Panda, S., Smolensky, M.H. & Stevens, R.G. (2017). Health consequences of electric lighting practices in the modern world: A report on the National Toxicology Program's workshop on shift work at night, artificial light at night, and circadian disruption. *Science of the Total Environment*, *607*, pp.1073-1084. https:/doi.org/10.1016/j.scitotenv.2017

Madden, G. J., & Bickel, W. K. (2010). Impulsivity: The behavioral and neurological science of discounting. American Psychological Association. https://doi.org/10.1037/12069-000

Magalhães, P., Cruz, V., Teixeira, S., Fuentes, S., & Rosário, P. (2020). An exploratory study on sleep procrastination: Bedtime vs. while-in-bed procrastination. *International Journal of Environmental Research and Public Health*, *17*(16), 5892. https://doi.org/10.3390/ijerph17165892

Makarem, N., Zuraikat, F. M., Aggarwal, B., Jelic, S., & St-Onge, M. P. (2020). Variability in sleep patterns: An emerging risk factor for hypertension. *Current Hypertension Reports*, *22*(2), 19. https://doi.org/10.1007/s11906-020-1025-9

Malhotra R. K. (2018). Neurodegenerative disorders and sleep. *Sleep Medicine Clinics*, *13*(1), 63–70. https://doi.org/10.1016/j.jsmc.2017.09.006

Manfredini, R., Fabbian, F., Cappadona, R., & Modesti, P. A. (2018). Daylight saving time, circadian rhythms, and cardiovascular health. *Internal and Emergency Medicine*, *13*(5), 641–646. https://doi.org/10.1007/s11739-018-1900-4

Mandelkorn, U., Genzer, S., Choshen-Hillel, S., Reiter, J., Meira E Cruz, M., Hochner, H., Kheirandish-Gozal, L., Gozal, D., & Gileles-Hillel, A. (2021). Escalation of sleep disturbances amid the COVID-19 pandemic: A cross-sectional international study. *Journal of Clinical Sleep Medicine : JCSM : Official Publication of the American Academy of Sleep Medicine*, *17*(1), 45–53. https://doi.org/10.5664/jcsm.8800

Manni, R., Cremascoli, R., Perretti, C., De Icco, R., Picascia, M., Ghezzi, C., Cerri, S., Sinforiani, E., & Terzaghi, M. (2019). Evening melatonin timing secretion in real life conditions in patients with Alzheimer disease of mild to moderate severity. *Sleep Medicine*, *63*, 122–126. https://doi.org/10.1016/j.sleep.2019.04.018

Manni, R., Cremascoli, R., De Icco, R., & Terzaghi, M. (2015). Chronotype in patients with epilepsy: A controlled study in 60 subjects with late-onset focal epilepsy. *Epilepsy & Behavior : E&B*, *50*, 1–6. https://doi.org/10.1016/j.yebeh.2015.05.031

Marlowe, F. (2010). *The Hadza: hunter-gatherers of Tanzania* (Vol. 3). Univ of California Press.

Mazri, F. H., Manaf, Z. A., Shahar, S., & Mat Ludin, A. F. (2019). The association between chronotype and dietary pattern among adults: A scoping review. *International Journal of Environmental Research and Public Health*, *17*(1), 68. https://doi.org/10.3390/ijerph17010068

Martín-Olalla J. M. (2019). The long term impact of daylight saving time regulations in daily life at several circles of latitude. *Scientific Reports*, *9*(1), 18466. https://doi.org/10.1038/s41598-019-54990-6

Mazur, J. E. (1987). An adjusting procedure for studying delayed reinforcement. *Quantitative Analyses of Behavior*, *5*, 55-73.

McBride, O., Murphy, J., Shevlin, M., Gibson-Miller, J., Hartman, T. K., Hyland, P., Levita, L., Mason, L., Martinez, A. P., McKay, R., Stocks, T. V., Bennett, K. M., Vallières, F., Karatzias, T., Valiente, C., Vazquez, C., & Bentall, R. P. (2021). Monitoring the psychological, social, and economic impact of the COVID-19 pandemic in the population: Context, design and conduct of the longitudinal COVID-19 psychological research consortium (C19PRC) study. *International Journal of Methods in Psychiatric Research*, *30*(1), e1861. https://doi.org/10.1002/mpr.1861

McGowan, N. M., Brannigan, R., Doyle, D., & Coogan, A. N. (2017). Diurnal preference, circadian phase of entrainment and time perspectives: just what are the relationships? *Personality and Individual Differences*, 112, 79–84. https://doi.org/10.1016/ j.paid.2017.02.051.

McGowan, N. M., Voinescu, B. I., & Coogan, A. N. (2016). Sleep quality, chronotype and social jetlag differentially associate with symptoms of attention deficit hyperactivity disorder in adults. *Chronobiology International*, *33*(10), 1433–1443. https://doi.org/10.1080/07420528.2016.1208214

McMahon, D. M., Burch, J. B., Youngstedt, S. D., Wirth, M. D., Hardin, J. W., Hurley, T. G., Blair, S. N., Hand, G. A., Shook, R. P., Drenowatz, C., Burgess, S., & Hebert, J. R. (2019). Relationships between chronotype, social jetlag, sleep, obesity and blood pressure in healthy young adults. *Chronobiology International*, *36*(4), 493–509. https://doi.org/10.1080/07420528.2018.1563094

Meaklim, H., Junge, M. F., Varma, P., Finck, W. A., & Jackson, M. L. (2021). Pre-existing and post-pandemic insomnia symptoms are associated with high levels of stress, anxiety, and depression globally during the COVID-19 pandemic. *Journal of Clinical Sleep Medicine : JCSM : Official Publication of the American Academy of Sleep Medicine*, *17*(10), 2085–2097. https://doi.org/10.5664/jcsm.9354

Meltzer, L. J., Saletin, J. M., Honaker, S. M., Owens, J. A., Seixas, A., Wahlstrom, K. L., Wolfson, A. R., Wong, P., & Carskadon, M. A. (2021). COVID-19 instructional approaches (in-person, online, hybrid), school start times, and sleep in over 5,000 U.S. adolescents. *Sleep*, *44*(12), zsab180. https://doi.org/10.1093/sleep/zsab180

Merikanto, I., Kortesoja, L., Benedict, C., Chung, F., Cedernaes, J., Espie, C. A., Morin, C. M., Dauvilliers, Y., Partinen, M., De Gennaro, L., Wing, Y. K., Chan, N. Y., Inoue, Y., Matsui, K., Holzinger, B., Plazzi, G., Mota-Rolim, S. A., Leger, D., Penzel, T., & Bjorvatn, B. (2022). Evening-types show highest increase of sleep and mental health problems during the COVID-19 pandemic-multinational study on 19 267 adults. *Sleep*, *45*(2), zsab216. https://doi.org/10.1093/sleep/zsab216

Merrow, M., Spoelstra, K., & Roenneberg, T. (2005). The circadian cycle: Daily rhythms from behaviour to genes: First in the Cycles Review Series. *EMBO Reports*, *6*(10), 930-935. https://doi.org/10.1038/sj.embor.7400541

Milfont, T. L., & Schwarzenthal, M. (2014). Explaining why larks are future-oriented and owls are present-oriented: self-control mediates the chronotype-time perspective relationships. *Chronobiology International*, 31(4), 581–588. https:/doi.org/10.3109/07420528. 2013.876428.

Minges, K. E., & Redeker, N. S. (2016). Delayed school start times and adolescent sleep: A systematic review of the experimental evidence. *Sleep Medicine Reviews*, *28*, 86–95. https://doi.org/10.1016/j.smrv.2015.06.002

Mistlberger, R. E., & Skene, D. J. (2004). Social influences on mammalian circadian rhythms: Animal and human studies. *Biological Reviews of the Cambridge Philosophical Society*, *79*(3), 533–556. https://doi.org/10.1017/s1464793103006353

Mistlberger, R. E., & Skene, D. J. (2005). Nonphotic entrainment in humans? *Journal of Biological Rhythms*, *20*(4), 339–352. https://doi.org/10.1177/0748730405277982

Morin, C. M., Stone, J., Trinkle, D., Mercer, J., & Remsberg, S. (1993). Dysfunctional beliefs and attitudes about sleep among older adults with and without insomnia complaints. *Psychology and Aging*, *8*(3), 463–467. https://doi.org/10.1037//08827974.8.3.463

Morin, C. M., Vallières, A., & Ivers, H. (2007). Dysfunctional beliefs and attitudes about sleep (DBAS): Validation of a brief version (DBAS-16). *Sleep*, *30*(11), 1547–1554. https://doi.org/10.1093/sleep/30.11.1547

Morin, C. M., Bjorvatn, B., Chung, F., Holzinger, B., Partinen, M., Penzel, T., Ivers, H., Wing, Y. K., Chan, N. Y., Merikanto, I., Mota-Rolim, S., Macêdo, T., De Gennaro, L., Léger, D., Dauvilliers, Y., Plazzi, G., Nadorff, M. R., Bolstad, C. J., Sieminski, M., Benedict, C., … Espie, C. A. (2021). Insomnia, anxiety, and depression during the COVID-19 pandemic: An international collaborative study. *Sleep Medicine*, *87*, 38–45. https://doi.org/10.1016/j.sleep.2021.07.035

Murphy, L., & Dockray, S. (2018). The consideration of future consequences and health behaviour: A meta-analysis. *Health Psychology Review*, *12*(4), 357-381. https://doi.org/10.1080/17437199.2018.1489298

Murray, C. J., & Lopez, A. D. (1997). Alternative projections of mortality and disability by cause 1990-2020: Global Burden of Disease Study. *Lancet (London, England)*, *349*(9064), 1498–1504. https://doi.org/10.1016/S0140-6736(96)07492-2

Muthén, L. K., & Muthén, B. (2017). Mplus user's guide: Statistical analysis with latent variables, user's guide. Muthén & Muthén.

Nauts, S., Kamphorst, B. A., Stut, W., De Ridder, D., & Anderson, J. H. (2019). The explanations people give for going to bed late: A qualitative study of the varieties of bedtime procrastination. *Behavioral Sleep Medicine*, *17*(6), 753–762. https://doi.org/10.1080/15402002.2018.1491850

Núñez, P., Perillan, C., Arguelles, J., & Diaz, E. (2019). Comparison of sleep and chronotype between senior and undergraduate university students. *Chronobiology International*, *36*(12), 1626–1637. https://doi.org/10.1080/07420528.2019.1660359

Ohayon M. M. (2002). Epidemiology of insomnia: what we know and what we still need to learn. *Sleep Medicine Reviews*, *6*(2), 97–111. https://doi.org/10.1053/smrv.2002.0186

Oh, C. M., Kim, H. Y., Na, H. K., Cho, K. H., & Chu, M. K. (2019). The effect of anxiety and depression on sleep quality of individuals with high risk for insomnia: A population-based study. *Frontiers in Neurology*, *10*, 849. https://doi.org/10.3389/fneur.2019.00849

Ohayon, M., Wickwire, E. M., Hirshkowitz, M., Albert, S. M., Avidan, A., Daly, F. J., Dauvilliers, Y., Ferri, R., Fung, C., Gozal, D., Hazen, N., Krystal, A., Lichstein, K., Mallampalli, M., Plazzi, G., Rawding, R., Scheer, F. A., Somers, V., & Vitiello, M. V. (2017). National Sleep Foundation's sleep quality recommendations: First report. *Sleep Health*, *3*(1), 6–19. https://doi.org/10.1016/j.sleh.2016.11.006

Ohida, T., Kamal, A. M., Uchiyama, M., Kim, K., Takemura, S., Sone, T., & Ishii, T. (2001). The influence of lifestyle and health status factors on sleep loss among the Japanese general population. *Sleep*, *24*(3), 333–338. https://doi.org/10.1093/sleep/24.3.333

Orji, R., Vassileva, J., & Mandryk, R. (2012). Towards an effective health interventions design: an extension of the health belief model. *Online Journal of Public Health Informatics*, *4*(3), ojphi.v4i3.4321. https://doi.org/10.5210/ojphi.v4i3.4321

Patton, A. P., & Hastings, M. H. (2018). The suprachiasmatic nucleus. *Current Biology : CB*, *28*(15), R816–R822. https://doi.org/10.1016/j.cub.2018.06.052

Pennycook, G., & Rand, D. G. (2020). Who falls for fake news? The roles of bullshit receptivity, overclaiming, familiarity, and analytic thinking. *Journal of Personality*, *88*(2), 185–200. https://doi.org/10.1111/jopy.12476

Peters, B. R., Joireman, J., & Ridgway, R. L. (2005). Individual differences in the consideration of future consequences scale correlate with sleep habits, sleep quality, and GPA in university students. *Psychological Reports*, *96*(3), 817-824. https://doi.org/10.2466/pr0.96.3.817-824

Petrov, M. E., Weng, J., Reid, K. J., Wang, R., Ramos, A. R., Wallace, D. M., Alcantara, C., Cai, J., Perreira, K., Espinoza Giacinto, R. A., Zee, P. C., Sotres-Alvarez, D., & Patel, S. R. (2018). Commuting and sleep: Results from the Hispanic Community Health Study/Study of Latinos Sueño Ancillary Study. *American Journal of Preventive Medicine*, *54*(3), e49–e57. https://doi.org/10.1016/j.amepre.2017.11.006

Pfefferbaum, B., & North, C. S. (2020). Mental Health and the Covid-19 Pandemic. *The New England Journal of Medicine*, *383*(6), 510–512. https://doi.org/10.1056/NEJMp2008017

Phillips, A., Vidafar, P., Burns, A. C., McGlashan, E. M., Anderson, C., Rajaratnam, S., Lockley, S. W., & Cain, S. W. (2019). High sensitivity and interindividual variability in the response of the human circadian system to evening light. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(24), 12019-12024. https://doi.org/10.1073/pnas.1901824116

Pieh, C., Budimir, S., Delgadillo, J., Barkham, M., Fontaine, J., & Probst, T. (2021). Mental health during COVID-19 lockdown in the United Kingdom. *Psychosomatic Medicine*, *83*(4), 328–337. https://doi.org/10.1097/PSY.0000000000000871

Piko, B. F., & Brassai, L. (2009). The role of individual and familial protective factors in adolescents' diet control. *Journal of Health Psychology*, 14, 810-819. doi:10.1177/1359105309338971

Pillai, V., Roth, T., Mullins, H. M., & Drake, C. L. (2014). Moderators and mediators of the relationship between stress and insomnia: stressor chronicity, cognitive intrusion, and coping. *Sleep*, *37*(7), 1199–1208. https://doi.org/10.5665/sleep.3838

Pilcher, J. J., Ginter, D. R., & Sadowsky, B. (1997). Sleep quality versus sleep quantity: relationships between sleep and measures of health, well-being and sleepiness in college students. *Journal of Psychosomatic Research*, *42*(6), 583–596. https://doi.org/10.1016/s0022-3999(97)00004-4

Pilz, L. K., Keller, L. K., Lenssen, D., & Roenneberg, T. (2018). Time to rethink sleep quality: PSQI scores reflect sleep quality on workdays. *Sleep*, *41*(5), 10.1093/sleep/zsy029. https://doi.org/10.1093/sleep/zsy029

Pittendrigh, C. S., & Daan, S. (1976). A functional analysis of circadian pacemakers in nocturnal rodents. *Journal of Comparative Physiology*, *106*(3), 223-252. https://doi.org/10.1007/BF01417856

Pontzer, H., Raichlen, D. A., Wood, B. M., Mabulla, A. Z., Racette, S. B., & Marlowe, F. W. (2012). Hunter-gatherer energetics and human obesity. *PLoS One*, 7(7), e40503. https://doi.org/10.1371/journal. pone.0040503.

Przepiórka, A., Błachnio, A., & Siu, N. Y. (2019). The relationships between self-efficacy, self-control, chronotype, procrastination and sleep problems in young adults. *Chronobiology International*, *36*(8), 1025–1035. https://doi.org/10.1080/07420528.2019.1607370

Putilov, A. A., Poluektov, M. G., & Dorokhov, V. B. (2020). Evening chronotype, late weekend sleep times and social jetlag as possible causes of sleep curtailment after maintaining perennial DST: ain't they as black as they are painted?. *Chronobiology International*, *37*(1), 82–100. https://doi.org/10.1080/07420528.2019.1684937

Putilov A. A. (2021). Sleep during "lockdown" highlighted the need to rethink the concept of weekend catch-up sleep. *Sleep & Breathing*, 1–7. https://doi.org/10.1007/s11325-02102492-z

Rajkumar R. P. (2020). COVID-19 and mental health: A review of the existing literature. *Asian Journal of Psychiatry*, *52*, 102066. https://doi.org/10.1016/j.ajp.2020.102066

Reis, C., Pilz, L. K., Keller, L. K., Paiva, T., & Roenneberg, T. (2020). Social timing influences sleep quality in patients with sleep disorders. *Sleep Medicine*, *71*, 8–17. https://doi.org/10.1016/j.sleep.2020.02.019

Rice, W. L., Mateer, T. J., Reigner, N., Newman, P., Lawhon, B., & Taff, B. D. (2020). Changes in recreational behaviors of outdoor enthusiasts during the COVID-19 pandemic: analysis across urban and rural communities. *Journal of Urban Ecology*, *6*(1), juaa020. https://doi.org/10.1093/jue/juaa020

Riemann, D., & Voderholzer, U. (2003). Primary insomnia: A risk factor to develop depression? *Journal of Affective Disorders*, *76*(1-3), 255–259. https://doi.org/10.1016/s0165-0327(02)00072-1

Riemann, D., Krone, L. B., Wulff, K., & Nissen, C. (2020). Sleep, insomnia, and depression. *Neuropsychopharmacology : Official Publication of the American College of Neuropsychopharmacology*, *45*(1), 74–89. https://doi.org/10.1038/s41386-019-0411-y

Rishi, M. A., Ahmed, O., Barrantes Perez, J. H., Berneking, M., Dombrowsky, J., Flynn-Evans, E. E., Santiago, V., Sullivan, S. S., Upender, R., Yuen, K., Abbasi-Feinberg, F., Aurora, R. N., Carden, K. A., Kirsch, D. B., Kristo, D. A., Malhotra, R. K., Martin, J. L., Olson, E. J., Ramar, K., Rosen, C. L., … Gurubhagavatula, I. (2020). Daylight saving time: an American Academy of Sleep Medicine position statement. *Journal of Clinical Sleep Medicine : JCSM : Official Publication of the American Academy of Sleep Medicine*, *16*(10), 1781–1784. https://doi.org/10.5664/jcsm.8780

Robinson, E., Sutin, A. R., Daly, M., & Jones, A. (2022). A systematic review and meta-analysis of longitudinal cohort studies comparing mental health before versus during the COVID-19 pandemic in 2020. *Journal of Affective Disorders*, *296*, 567–576. https://doi.org/10.1016/j.jad.2021.09.098

Roenneberg, T., Wirz-Justice, A., & Merrow, M. (2003). Life between clocks: Daily temporal patterns of human chronotypes. *Journal of Biological Rhythms*, *18*(1), 80–90. https://doi.org/10.1177/0748730402239679

Roenneberg, T., Kuehnle, T., Pramstaller, P. P., Ricken, J., Havel, M., Guth, A., & Merrow, M. (2004). A marker for the end of adolescence. *Current Biology : CB*, *14*(24), R1038–R1039. https://doi.org/10.1016/j.cub.2004.11.039

Roenneberg, T., & Merrow, M. (2007). Entrainment of the human circadian clock. In Vol. 72. Cold Spring Harbor symposia on quantitative biology (pp. 293–299). Cold Spring Harbor Laboratory Press. https://doi.org/10.1101/sqb.2007.72.043.

Roenneberg, T., Kumar, C. J., & Merrow, M. (2007). The human circadian clock entrains to sun time. *Current Biology : CB*, *17*(2), R44–R45. https://doi.org/10.1016/j.cub.2006.12.011

Roenneberg, T., Allebrandt, K. V., Merrow, M., & Vetter, C. (2012). Social jetlag and obesity. *Current Biology*, 22(10), 939–943. https:// doi.org/10.1016/j.cub.2012.03.038.

Roenneberg, T., Keller, L. K., Fischer, D., Matera, J. L., Vetter, C., & Winnebeck, E. C. (2015). Human activity and rest in situ. In Vol. 552. *Methods in Enzymology* (pp. 257–283). Academic Press. https://doi.org/10.1016/bs.mie.2014.11.028.

Roenneberg, T., & Merrow, M. (2016). The circadian clock and human health. *Current Biology*, 26(10), R432–R443. https://doi.org/ 10.1016/j.cub.2016.04.011.

Roenneberg, T., Pilz, L. K., Zerbini, G., & Winnebeck, E. C. (2019a). Chronotype and social jetlag: a (self-) critical review. *Biology*, *8*(3), 54. https://doi.org/10.3390/biology8030054

Roenneberg, T., Winnebeck, E. C., & Klerman, E. B. (2019b). Daylight saving time and artificial time zones - A battle between biological and social times. *Frontiers in Physiology*, *10*, 944. https://doi.org/10.3389/fphys.2019.00944

Roenneberg, T., Wirz-Justice, A., Skene, D. J., Ancoli-Israel, S., Wright, K. P., Dijk, D. J., Zee, P., Gorman, M. R., Winnebeck, E. C., & Klerman, E. B. (2019c). Why Should We Abolish Daylight Saving Time? *Journal of Biological Rhythms*, *34*(3), 227–230. https://doi.org/10.1177/0748730419854197

Rowe, M. A., McCrae, C. S., Campbell, J. M., Benito, A. P., & Cheng, J. (2008). Sleep pattern differences between older adult dementia caregivers and older adult non-caregivers using objective and subjective measures. *Journal of Clinical Sleep Medicine : JCSM : Official Publication of the American Academy of Sleep Medicine*, *4*(4), 362–369.

Rusu, A., Ciobanu, D., Bala, C., Cerghizan, A., & Roman, G. (2019). Social jetlag, sleep-related parameters, and glycemic control in adults with type 1 diabetes: Results of a cross-sectional study. *Journal of Diabetes*, *11*(5), 394–401. https://doi.org/10.1111/17530407.12867

Sack, R. L., Brandes, R. W., Kendall, A. R., & Lewy, A. J. (2000). Entrainment of free-running circadian rhythms by melatonin in blind people. *New England Journal of Medicine*, 343(15), 1070–1077. https://doi.org/10.1056/NEJM200010123431503.

Sansom, K., Walsh, J., Eastwood, P., Maddison, K., Singh, B., Reynolds, A., ... & McArdle, N. (2021). P124 Chronotype and OSA combine to modify risk of hypertension. *Sleep Advances*, *2*(Supplement_1), A61-A62. https://doi.org/10.1093/sleepadvances/zpab014.165

Santisteban, J. A., Brown, T. G., & Gruber, R. (2018). Association between the Munich Chronotype Questionnaire and wrist actigraphy. *Sleep Disorders*, *2018*, 5646848. https://doi.org/10.1155/2018/5646848

Saper, C. B., Lu, J., Chou, T. C., & Gooley, J. (2005). The hypothalamic integrator for circadian rhythms. *Trends in Neurosciences*, 28, 152–157. https://doi.org/10.1016/j.tins.2004.12.009.

Schafer, J. L., & Graham, J. W. (2002). Missing data: our view of the state of the art. *Psychological Methods*, *7*(2), 147–177. https://doi.org/10.1037/1082-989X.7.2.147

Scheer, F. A., Hilton, M. F., Mantzoros, C. S., & Shea, S. A. (2009). Adverse metabolic and cardiovascular consequences of circadian misalignment. *Proceedings of the National Academy of Sciences of the United States of America*, *106*(11), 4453–4458. https://doi.org/10.1073/pnas.0808180106

Schoeller, D. A., Cella, L. K., Sinha, M. K., & Caro, J. F. (1997). Entrainment of the diurnal rhythm of plasma leptin to meal timing. *The Journal of Clinical Investigation*, *100*(7), 1882–1887. https://doi.org/10.1172/JCI119717

Schredl, M., & Göritz, A. S. (2020). Nightmares, chronotype, ubanicity, and personality: An online study. *Clocks & Sleep*, *2*(3), 390–398. https://doi.org/10.3390/clockssleep2030029

Schwartz, D. R., & Carney, C. E. (2012). Mediators of cognitive-behavioral therapy for insomnia: A review of randomized controlled trials and secondary analysis studies. *Clinical Psychology Review*, *32*(7), 664–675. https://doi.org/10.1016/j.cpr.2012.06.006

Siegel, J. M. (2005). Clues to the functions of mammalian sleep. *Nature*, 437(7063), 1264 1271. https://doi.org/10.1038/nature04285

Skeldon, A. C., Phillips, A. J., & Dijk, D. J. (2017). The effects of self-selected light-dark cycles and social constraints on human sleep and circadian timing: A modeling approach. *Scientific Reports*, *7*, 45158. https://doi.org/10.1038/srep45158

Sládek, M., Kudrnáčová Röschová, M., Adámková, V., Hamplová, D., & Sumová, A. (2020). Chronotype assessment via a large scale socio-demographic survey favours yearlong standard time over daylight saving time in central Europe. *Scientific Reports*, *10*(1), 1419. https://doi.org/10.1038/s41598-020-58413-9

Sletten, T. L., Cappuccio, F. P., Davidson, A. J., Van Cauter, E., Rajaratnam, S., & Scheer, F. (2020). Health consequences of circadian disruption. *Sleep*, *43*(1), zsz194. https://doi.org/10.1093/sleep/zsz194

Solmi, M., Radua, J., Olivola, M., Croce, E., Soardo, L., Salazar de Pablo, G., Il Shin, J., Kirkbride, J. B., Jones, P., Kim, J. H., Kim, J. Y., Carvalho, A. F., Seeman, M. V., Correll, C. U., & Fusar-Poli, P. (2021). Age at onset of mental disorders worldwide: Large-scale meta-analysis of 192 epidemiological studies. *Molecular Psychiatry*, https://doi.org/10.1038/s41380-021-01161-7

Spikol, E., McBride, O., Vallières, F., Butter, S., & Hyland, P. (2021). Tracking the Irish adult population during the first year of the COVID-19 pandemic: A methodological report of the COVID-19 psychological research consortium (C19PRC) study in Ireland. *Acta Psychologica*, *220*, 103416. https://doi.org/10.1016/j.actpsy.2021.103416

Spitzer, R. L., Kroenke, K., Williams, J. B., & Löwe, B. (2006). A brief measure for assessing generalized anxiety disorder: the GAD-7. *Archives of Internal Medicine*, *166*(10), 1092–1097. https://doi.org/10.1001/archinte.166.10.1092

Stephan, F. K., & Zucker, I. (1972). Circadian rhythms in drinking behavior and locomotor activity of rats are eliminated by hypothalamic lesions. *Proceedings of the National Academy of Sciences of the United States of America*, *69*(6), 1583–1586. https://doi.org/10.1073/pnas.69.6.1583

Stoner, L., Beets, M. W., Brazendale, K., Moore, J. B., & Weaver, R. G. (2018). Social jetlag is associated with adiposity in children. *Global Pediatric Health*, *5*, https://doi.org/10.1177/2333794X18816921

Story, G., Vlaev, I., Seymour, B., Darzi, A., & Dolan, R. (2014). Does temporal discounting explain unhealthy behavior? A systematic review and reinforcement learning perspective. *Frontiers in Behavioral Neuroscience*, 8, 76. https://doi.org/10.3389/fnbeh. 2014.00076.

Stothard, E. R., McHill, A. W., Depner, C. M., Birks, B. R., Moehlman, T. M., Ritchie, H. K., Guzzetti, J. R., Chinoy, E. D., LeBourgeois, M. K., Axelsson, J., & Wright, K. P., Jr (2017). Circadian entrainment to the natural light-dark cycle across seasons and the weekend. *Current Biology : CB*, *27*(4), 508–513. https://doi.org/10.1016/j.cub.2016.12.041

Stranges, S., Tigbe, W., Gómez-Olive, F. X., Thorogood, M., & Kandala, N. B. (2012). Sleep problems: An emerging global epidemic? Findings from the INDEPTH WHO-SAGE study among more than 40,000 older adults from 8 countries across Africa and Asia. *Sleep*, 35(8), 1173–1181. https://doi.org/10.5665/sleep.2012.

Strathman, A., Gleicher, F., Boninger, D. S., & Edwards, C. S. (1994). The consideration of future consequences: Weighing immediate and distant outcomes of behavior. *Journal of Personality and Social Psychology*, *66*(4), 742. https://doi.org/10.1037/00223514.66.4.742

Sűdy, Á. R., Ella, K., Bódizs, R., & Káldi, K. (2019). Association of social jetlag with sleep quality and autonomic cardiac control during sleep in young healthy men. *Frontiers in Neuroscience*, 950. https://doi.org/10.3389/fnins.2019.00950

Suikki, T., Maukonen, M., Partonen, T., Jousilahti, P., Kanerva, N., & Männistö, S. (2021). Association between social jet lag, quality of diet and obesity by diurnal preference in Finnish adult population. *Chronobiology International*, *38*(5), 720-731. https://doi.org/10.1080/07420528.2021.1876721

Taha, S., Matheson, K., Cronin, T., & Anisman, H. (2014). Intolerance of uncertainty, appraisals, coping, and anxiety: the case of the 2009 H1N1 pandemic. *British Journal of Health Psychology*, *19*(3), 592–605. https://doi.org/10.1111/bjhp.12058

Tahara, Y., Makino, S., Suiko, T., Nagamori, Y., Iwai, T., Aono, M., & Shibata, S. (2021). Association between irregular meal timing and the mental health of Japanese workers. *Nutrients*, *13*(8), 2775. https://doi.org/10.3390/nu13082775

Tamura, N., Komada, Y., Inoue, Y., & Tanaka, H. (2021). Social jetlag among Japanese adolescents: Association with irritable mood, daytime sleepiness, fatigue, and poor academic performance. *Chronobiology International*, 1–12. https://doi.org/10.1080/07420528.2021.1996388

Taylor, B. J., Bowman, M. A., Brindle, A., Hasler, B. P., Roecklein, K. A., Krafty, R. T., Matthews, K. A., & Hall, M. H. (2020). Evening chronotype, alcohol use disorder severity, and emotion regulation in college students. *Chronobiology International*, *37*(12), 1725–1735. https://doi.org/10.1080/07420528.2020.1800028

The European Commission (2018) Summertime Consultation: 84% want Europe to stop changing the clock.https://ec.europa.eu/transport/themes/summertime/news/2018-08-31-consultation-outcome_en.

The European Parliament (2018) European Parliament resolution of 8 February 2018 on Time Change Arrangements. https://www.europarl.europa.eu/doceo/document/TA-8-2018-0043_EN.html?redirect.

Tonetti, L., Erbacci, A., Fabbri, M., Martoni, M., & Natale, V. (2013). Effects of transitions into and out of daylight saving time on the quality of the sleep/wake cycle: An actigraphic study in healthy university students. *Chronobiology International*, *30*(10), 1218–1222. https://doi.org/10.3109/07420528.2013.812651

Toth Quintilham, M. C., Adamowicz, T., Pereira, E. F., Pedrazzoli, M., & Louzada, F. M. (2014). Does the transition into daylight saving time really cause partial sleep deprivation? *Annals of Human Biology*, *41*(6), 554–560. https://doi.org/10.3109/03014460.2014.897756

Usher, K., Jackson, D., Durkin, J., Gyamfi, N., & Bhullar, N. (2020). Pandemic-related behaviours and psychological outcomes: A rapid literature review to explain COVID-19 behaviours. *International Journal of Mental Health Nursing*, *29*(6), 1018–1034. https://doi.org/10.1111/inm.12790

Valeggia, C. R., Burke, K. M., & Fernandez-Duque, E. (2010). Nutritional status and socioeconomic change among Toba and Wichí populations of the Argentinean Chaco. *Economics and Human Biology*, *8*(1), 100–110. https://doi.org/10.1016/j.ehb.2009.11.001

Vanderveldt, A., Oliveira, L., & Green, L. (2016). Delay discounting: pigeon, rat, human—does it matter?. *Journal of Experimental Psychology: Animal Learning and Cognition*, *42*(2), 141. https://doi.org/10.1037/xan0000097

Van den Berg, J. F., Kivelä, L., & Antypa, N. (2018). Chronotype and depressive symptoms in students: An investigation of possible mechanisms. *Chronobiology International*, *35*(9), 1248–1261. https://doi.org/10.1080/07420528.2018.1470531

Van den Bos, W., & McClure, S. M. (2013). Towards a general model of temporal discounting. *Journal of the Experimental Analysis of Behavior*, *99*(1), 58–73. https://doi.org/10.1002/jeab.6

Van Erum, J., Van Dam, D., & De Deyn, P. P. (2018). Sleep and Alzheimer's disease: A pivotal role for the suprachiasmatic nucleus. *Sleep Medicine Reviews*, *40*, 17–27. https://doi.org/10.1016/j.smrv.2017.07.005

Voitsidis, P., Gliatas, I., Bairachtari, V., Papadopoulou, K., Papageorgiou, G., Parlapani, E., Syngelakis, M., Holeva, V., & Diakogiannis, I. (2020). Insomnia during the COVID-19 pandemic in a Greek population. *Psychiatry Research*, *289*, 113076. https://doi.org/10.1016/j.psychres.2020.113076

von Salisch, M., Denham, S. A., & Koch, T. (2017). Emotion knowledge and attention problems in young children: A cross-lagged panel study on the direction of effects. *Journal of Abnormal Child Psychology*, *45*(1), 45–56. https://doi.org/10.1007/s10802-016-0157-5

Vosko, A. M., Colwell, C. S., & Avidan, A. Y. (2010). Jet lag syndrome: Circadian organization, pathophysiology, and management strategies. *Nature and Science of Sleep*, *2*, 187–198. https://doi.org/10.2147/NSS.S6683

Walsh, N. A., Repa, L. M., & Garland, S. N. (2022). Mindful larks and lonely owls: The relationship between chronotype, mental health, sleep quality, and social support in young adults. *Journal of Sleep Research*, *31*(1), e13442. https://doi.org/10.1111/jsr.13442

Washio, Y., Higgins, S. T., Heil, S. H., McKerchar, T. L., Badger, G. J., Skelly, J. M., et al. (2011). Delay discounting is associated with treatment response among cocaine-dependent outpatients. Experimental and Clinical Psychopharmacology, 19(3), 243–248. https://doi.org/10.1037/a0023617.

Watson N. F. (2019). Time to show leadership on the daylight saving time debate. *Journal of clinical sleep medicine : JCSM : Official Publication of the American Academy of Sleep Medicine*, *15*(6), 815–817. https://doi.org/10.5664/jcsm.7822

West, K. E., Jablonski, M. R., Warfield, B., Cecil, K. S., James, M., Ayers, M. A., et al. (2010). Blue light from light-emitting diodes elicits a dose-dependent suppression of melatonin in humans. *Journal of Applied Physiology*, 110(3), 619–626. https://doi.org/ 10.1152/japplphysiol.01413.2009.

Wever R. A. (1989). Light effects on human circadian rhythms: A review of recent Andechs experiments. *Journal of Biological Rhythms*, *4*(2), 161–185.

Widaman, K. F. (2006). Best practices in quantitative methods for developmentalists: III. Missing data: What to do with or without them. *Monographs of the Society for Research in Child Development*. https://doi.org/10.1111/j.1540-5834.2006.00404.x

Wilkinson, M. J., Manoogian, E., Zadourian, A., Lo, H., Fakhouri, S., Shoghi, A., Wang, X., Fleischer, J. G., Navlakha, S., Panda, S., & Taub, P. R. (2020). Ten-hour time-restricted eating reduces weight, blood pressure, and atherogenic lipids in patients with metabolic syndrome. *Cell Metabolism*, *31*(1), 92–104.e5. https://doi.org/10.1016/j.cmet.2019.11.004

Wirz-Justice, A., Benedetti, F., Berger, M., Lam, R., Martiny, K., Terman, M., & Wu, J. (2005). Chronotherapeutics (light and wake therapy) in affective disorders. *Psychological Medicine*, 35(7), 939–44. https://doi.org/10.1017/s 003329170500437x.

Wittmann, M., Dinich, J., Merrow, M., & Roenneberg, T. (2006). Social jetlag: Misalignment of biological and social time. *Chronobiology International*, 23(1–2), 497–509. https://doi.org/10.1080/07420520 500545979.

Wong, P. M., Hasler, B. P., Kamarck, T. W., Muldoon, M. F., & Manuck, S. B. (2015). Social jetlag, chronotype, and cardiometabolic risk. *The Journal of Clinical Endocrinology & Metabolism*, 100(12), 4612–4620. https://doi.org/10.1210/jc.2015-2923.

World Health Organization. The World health report: 2001: Mental health: New understanding, new hope. Geneva: World Health Organization; 2001.

Worthman, C. M. (2008). After dark: the evolutionary ecology of human sleep. *Evolutionary Medicine and Health*, 291-313.

Wright, K. P., Jr, McHill, A. W., Birks, B. R., Griffin, B. R., Rusterholz, T., & Chinoy, E. D. (2013). Entrainment of the human circadian clock to the natural light-dark cycle. *Current Biology*, *23*(16), 1554–1558. https://doi.org/10.1016/j.cub.2013.06.039

Wright, K. P., Jr, Linton, S. K., Withrow, D., Casiraghi, L., Lanza, S. M., Iglesia, H., Vetter, C., & Depner, C. M. (2020). Sleep in university students prior to and during COVID-19 stay-at-home orders. *Current Biology : CB*, *30*(14), R797–R798. https://doi.org/10.1016/j.cub.2020.06.022

Xiang, Y. T., Yang, Y., Li, W., Zhang, L., Zhang, Q., Cheung, T., & Ng, C. H. (2020). Timely mental health care for the 2019 novel coronavirus outbreak is urgently needed. *The Lancet. Psychiatry*, *7*(3), 228–229. https://doi.org/10.1016/S2215-0366(20)30046-8

Xiao, H., Zhang, Y., Kong, D., Li, S., & Yang, N. (2020). Social Capital and Sleep Quality in Individuals Who Self-Isolated for 14 Days During the Coronavirus Disease 2019 (COVID-19) Outbreak in January 2020 in China. *Medical Science Monitor: International Medical Journal of Experimental and Clinical Research*, *26*, e923921. https://doi.org/10.12659/MSM.923921

Yamanaka, Y., Hashimoto, S., Tanahashi, Y., Nishide, S. Y., Honma, S., & Honma, K. (2010). Physical exercise accelerates reentrainment of human sleep-wake cycle but not of plasma melatonin rhythm to 8-h phase-advanced sleep schedule. *American Journal of Physiology, Regulatory, Integrative and Comparative Physiology*, *298*(3), R681R691. https://doi.org/10.1152/ajpregu.00345.2009

Yetish, G., Kaplan, H., Gurven, M., Wood, B., Pontzer, H., Manger, P. R., Wilson, C., McGregor, R., & Siegel, J. M. (2015). Natural sleep and its seasonal variations in three preindustrial societies. *Current Biology : CB*, *25*(21), 2862–2868. https://doi.org/10.1016/j.cub.2015.09.046

Youngstedt, S. D., Elliott, J. A., & Kripke, D. F. (2019). Human circadian phase-response curves for exercise. *The Journal of Physiology*, *597*(8), 2253–2268. https://doi.org/10.1113/JP276943

Yusuf, S., Joseph, P., Rangarajan, S., Islam, S., Mente, A., Hystad, P., Brauer, M., Kutty, V. R., Gupta, R., Wielgosz, A., AlHabib, K. F., Dans, A., Lopez-Jaramillo, P., Avezum, A., Lanas, F., Oguz, A., Kruger, I. M., Diaz, R., Yusoff, K., Mony, P., … Dagenais, G. (2020). Modifiable risk factors, cardiovascular disease, and mortality in 155 722 individuals from 21 high-income, middle-income, and low-income countries (PURE): A prospective cohort study. *Lancet (London, England)*, *395*(10226), 795–808. https://doi.org/10.1016/S0140-6736(19)32008-2

Zenic, N., Taiar, R., Gilic, B., Blazevic, M., Maric, D., Pojskic, H., & Sekulic, D. (2020). Levels and changes of physical activity in adolescents during the COVID-19 pandemic: Contextualizing urban vs. rural living environment. *Applied Sciences*, *10*(11), 3997. https://doi.org/10.3390/app10113997

Zhang, R., Lahens, N. F., Ballance, H. I., Hughes, M. E., & Hogenesch, J. B. (2014). A circadian gene expression atlas in mammals: Implications for biology and medicine. Proceedings of the National Academy of Sciences of the United States of America, 111(45), 16219–16224. https://doi.org/10.1073/pnas. 1408886111.