Does sleep loss or sleep disturbance affect daily activities of birds?

Simeng Li

A thesis submitted in partial fulfilment of the requirements for
the degree of Master of Science in Biological Sciences
the University of Auckland, 2024

Abstract

Sleep is essential for all organisms, and insufficient sleep can lead to a series of negative consequences. Presently, anthropogenic disturbances such as noise and light pollution are increasingly prevalent, and sleep deprivation as well as disturbances have been shown to affect behavioural and cognitive performances in a variety of animals, including humans. However, few studies have investigated the effects of sleep deprivation and sleep disturbance on the diurnal behaviours of birds following the disturbance.

This study focused on adult common mynas (*Acridotheres tristis*) and investigated the importance of sleep on birds' daily activity. I recorded the active and inactive time of common mynas following a 12-hour sleep deprivation overnight, 6-hour sleep deprivation during either the first or last half of the night, and 12-hour sleep disturbance due to light exposure.

The findings indicate that sleep deprivation from the previous night results in reduced daily activity levels of common mynas, with the 12-hour sleep deprivation having a greater impact than the 6-hour deprivation, and deprivation during the latter half of the night being more significant than during the first half, while the effect of light disturbance was comparatively minor. Future research could incorporate electrophysiological methods to further explore the consequences of long-term sleep loss in different avian species.

Acknowledgments

Crossing hemisphere for the first time to embark on a new chapter of learning and personal growth in the unfamiliar country of New Zealand, I look back on this journey now coming to an end with a great deal of gratitude in my heart. I would like to extend my deepest thanks to those who have provided unlimited support, encouragement, and companionship throughout this journey.

First and foremost, I must express my profound and sincere gratitude to my wonderful advisor, Dr. Kristal Cain, and Dr. Juliane Gaviraghi Mussoi, who has been like a co-advisor to me. You have not only guided my academic journey with your extensive professional knowledge and profound insights but have also extended a hand of care in my life. I am grateful for your patience and kindness. When I struggled to express my ideas in poor oral English, you always listened with empathy, slowed down your speech and responded clearly, ensuring I understood your meaning and provided timely, helpful feedback. And thank you for giving me the freedom to choose my research topic, and I'm sure that you were also sleep-deprived during the sleep deprivation experiments on common mynas, dedicating immense effort to this interesting and meaningful project. Studying avian ecology has been an incredibly interesting thing. I am fortunate to have chosen this field, which is far from dull, and I am delighted to observe and learn about the various lovely birds in nature that many people might overlook. I am also thankful for your meticulous guidance in data processing and thesis writing, especially regarding R programming, which initially intimidated me due to lack of practical experience. With Juli's patient, step-by-step teaching, I found that using R was not as daunting as I had feared. Indeed, the hardest part is often just getting started. Many thanks to you and every member of Kristal's and Margaret's dynamic, vibrant laboratory team from around the world for your friendly care.

And I want to thank my parents, thanks for your care and encouragement over the years. It is your unconditional love and support that have given me the strength. In every stage of my growth, you have always been my strongest backing, giving me the courage to meet challenges, overcome difficulties, pursue my dream, and come to New Zealand to study. I also wish to thank my best friends in China, friends and classmates who study abroad together. Your assistance and companionship helped me through the loneliest days and made my life outside of academics richer

and more colourful. Finally, I would like to thank myself for making that resolute choice three years ago. Despite the anxiety of facing an unknown life, I still bravely walked this path to come to now. When I first arrived in New Zealand, it all seemed not real, and now, as I am about to leave, I marvel at how quickly time has passed. I am glad for having experienced all of this, for witnessing different cultures, learning new knowledge, seeing diverse landscapes, creating unforgettable memories, and, most importantly, for shaping a stronger version of myself.

Table of Contents

1 Introduction

1.1 Sleep in animals

The definition of sleep is based on behavioural and electrophysiological criteria, where the behavioural criteria are manifested as: spontaneous maintenance of a specific posture with a preference for location during periods of quiescence; an elevated behavioural response threshold to arousing stimuli, with the capability to rapidly return to wakefulness upon sufficiently strong stimuli; sleep homeostasis, indicated by an increased propensity for sleep following deprivation requiring deeper and longer recovery sleep periods; and it is typically associated with the organism's internal circadian clock, though it can also function independently on a physiological level (Campbell & Tobler, 1984; Piéron, 1913; Zimmerman et al., 2008). The electrophysiological criteria of sleep needs to be determined by electroencephalogram, electromyography and electrooophthalmogram. Different sleep stages, such as slow wave sleep (SWS) and rapid eye movement (REM) sleep, can be distinguished by measuring different states of brain activity, eye movement and muscle tension (Aserinsky & Kleitman, 2003; Jaggard et al., 2021; Paul-Antoine & Anthony, 2015).

Sleep is a fundamental requirement for sustaining life processes, playing a critical role in the physical health, growth and development, physiological restoration, brain function regulation, and the modulation of circadian rhythms across various biological entities (Alhola & Polo-Kantola, 2007; Aly & Moscovitch, 2010; Beyaert et al., 2012; Klinzing et al., 2019; Vorster & Born, 2015; Xie et al., 2013). Within the animal kingdom, sleep exhibits notable diversity and complexity (Rattenborg & Ungurean, 2023). As animals have evolved, sleep patterns and mechanisms have undergone significant changes and adaptations, reflecting the importance of sleep in physiology and species survival (Blumberg et al., 2020; Paul-Antoine & Anthony, 2015; Rattenborg & Martinez-Gonzalez, 2015; Siegel, 2022). Despite the apparent universal need for sleep among all animals, the form, duration, and patterns of sleep display remarkable variability depending on the species, environmental conditions, and habitual behaviours (Campbell & Tobler, 1984; Peever & Fuller, 2017; Rattenborg et al., 2022).

In evolutionarily older taxa, the resting or quiescent state of arthropods such as insects is usually similar to sleep, it is typically combined with periods of activity (Hendricks et al., 2000; Shaw et al., 2000). Studies have indicated that the roundworm (*Caenorhabditis elegans*) exhibits sleep-like behavioural traits during the lethargus phase of larval development and the adult stage under conditions of satiety (Cassada & Russell, 1975; Maycock et al., 2008). Bees, flies, butterflies, and other such organisms display periods of behavioural quiescence with stereotypic postures, requiring more intense external stimuli to be awakened to a state of alertness, and this regulation occurs independently of the biological clock, maintaining homeostasis (Campbell & Tobler, 1984; Hendricks et al., 2000; Rau & Rau, 1916; Shaw et al., 2000; Siegel, 2008). Some studies have shown that fruit flies and bees exhibit alternation between deep and light sleep during prolonged periods of inactivity (van Alphen et al., 2013; Zwaka et al., 2015). As a model organism for understanding sleep functions, the fruit fly (*Drosophila melanogaster*) has been demonstrated to have two stages during sleep, active and quiet sleep, which function similarly to those in mammals (Stanhope et al., 2020; Van De Poll & van Swinderen, 2021; Yap et al., 2017). Recent research has discovered that the jumping spider (*Evarcha arcuata,* Salticidae) also displays a state akin to rapid eye movement sleep during nocturnal rest, including periodic retinal movements, limb twitching, and characteristic leg curling behaviours (Roßler et al., 2022).

Aquatic animals, such as fish, often exhibit short periods of inactivity akin to sleep, which can be defined as behavioural sleep. During this state, metabolic processes are slowed, and vigilance is reduced (Campbell & Tobler, 1984; Dutfield, 2023; Siegel, 2008). The resting characteristics among different fish species vary significantly. For instance, the parrotfish (*Chlorurus*) swims to the seabed rocks after sunset, where glands located posterior to the gills secrete mucus to form a cocoon that protects it from potential harm while sleeping (Dutfield, 2023). The zebrafish, serving as a primary model for fish sleep research, has been observed to exhibit sleep characteristics similar to those of mammals, including reversible states of quiescence, increased arousal thresholds, preference for specific resting locations, regulation by circadian rhythms, and evidence of homeostatic rebound following sleep deprivation (Yokogawa et al., 2007; Zhdanova et al., 2001). Recent research employing fluorescence-based polysomnography (fPSG) techniques on zebrafish has, for the first time, recorded and analyzed neuronal activity in their dorsal pallium, along with continuous monitoring of the whole brain, muscle, heartbeat, and eye movements, uncovering two primary types of their sleep: Slow Bursting Sleep (SBS) and Propagating Wave Sleep (PWS). The SBS mode is similar to the Non-Rapid Eye Movement/Slow Wave Sleep (NREM/SWS) in mammals, characterized by slow synchronous oscillations of neuronal discharges in the brain, low muscle tonicity, and slow heartbeats. Meanwhile, the PWS mode shares similarities with Rapid Eye Movement Sleep (REM/PS), including specific neural network activities within the brain, wake-like activity in the dorsal part of the telencephalon, complete muscle relaxation, and irregular heart rates (Leung et al., 2019). Similarly, sleep in marine invertebrates such as octopuses exhibits two phases: quiet sleep and active sleep (Medeiros et al., 2021). During active sleep, despite its short duration, octopuses display a variety of dynamic skin patterns, accelerated eye movements, and electrophysiological recordings indicate that local field potential (LFP) activities in the brain resemble wakefulness, similar to the REM sleep state in mammals. During quiet sleep, electrophysiology shows less activity in these brain areas, but they are found to have characteristic brain waves similar to those in NREM sleep, and the skin is uniformly pale, the pupils are constricted into thin slits (Pophale et al., 2023). Cuttlefish have also been found to have similar sleep states (Frank et al., 2012).

Most amphibians and reptiles exhibit behavioural characteristics of sleep, a specific immobile position with a reduced heart and respiratory rate, alongside a higher arousal threshold and decreased electroencephalographic (EEG) frequency (Paul-Antoine & Anthony, 2015). However, some reptile species can enter a prolonged low-metabolic resting state during darkness and cold, known as dormancy, and this particular state exhibits behavioural traits similar to those of sleep, but with a slow-wave sleep rebound after dormancy, suggesting that there is a functional difference between sleep and dormancy (Rial et al., 2010). Currently, there is no evidence of rapid eye movement (REM) sleep in amphibians, and it is controversial whether reptiles experience REM sleep (Frank, 2013; Paul-Antoine & Anthony, 2015; Siegel, 2008).

In species with homeothermy, sleep patterns are more complex. Mammals possess Rapid Eye Movement (REM) and Non-Rapid Eye Movement (NREM) sleep phases (Rattenborg et al., 2011). Sleep patterns vary significantly across species, from the smallest mammals (bats) to the largest (blue whales). The short-nosed fruit bat (*Cynopterus sphinx*) predominantly sleeps during the day, with fewer but longer cycle of NREM and REM sleep, whereas the sleep of the dawn fruit bat (*Eonycteris spelaea*) is more evenly distributed between day and night (Zhao et al., 2010). Some marine mammals can be half-asleep and half-awake while swimming, while remaining asleep and alert at the same time (Lyamin et al., 2017; Yokogawa et al., 2007). For example, northern fur seals (*Callorhinus ursinus*) exhibit REM sleep and slow-wave sleep (SWS) on land similar to terrestrial mammals, but in water, they primarily engage in unihemispheric slow-wave sleep (USWS), with one side eye open and keeping rest while the other eye closed but the brain awake to maintain necessary physiological activity and alertness (Lyamin et al., 2018; Lyamin et al., 2017). It is noteworthy that seals do not exhibit the rebound in REM and SWS sleep that is typical in terrestrial mammals following sleep deprivation (Siegel, 2022). Moreover, dolphins and certain whale species demonstrate only unihemispheric slow waves during sleep, with no observed indications of REM sleep (Lyamin et al., 2006; Siegel, 2022).

In summary, sleep, as a universal physiological phenomenon, has evolved alongside nervous systems and brains, from the simplest forms of quiescence to the complex stages of REM and NREM sleep. Various ecological factors, including habitat type, seasonal climate, food resources, and the pressure of being preyed, influence animals' lifestyles and physiological needs to varying extents, thereby shaping their diverse sleep patterns (Siegel, 2022). These varied sleep patterns not only reflect the specific lifestyles and physiological needs of different animals but also reveal the crucial role of sleep in sustaining fundamental life processes.

1.2 Sleep in birds

Birds and mammals alike share two types of sleep, namely Rapid Eye Movement (REM) sleep and Non-Rapid Eye Movement (NREM) sleep - also known as Slow-Wave Sleep (SWS), with each sleep cycle comprising alternating periods of these two stages (Campbell & Tobler, 1984; Rattenborg et al., 2019; Rattenborg & Martinez-Gonzalez, 2015). The electroencephalogram (EEG) of rapid eye movement (REM) sleep shows high-frequency, low-amplitude features similar to those of the waking state, and differs from the waking state in that muscle tone is reduced to a minimum level and the eyes move rapidly back and forth, usually in association with dreaming (Martinez Gonzalez et al., 2008; Rattenborg et al., 2000; Rattenborg et al., 2009; Tobler & Borbély, 1988). EEG recordings during NREM sleep, on the other hand, exhibit high amplitude, slow waves (0.5-4.5Hz) (Lesku et al., 2019; Rattenborg et al., 2000; Rattenborg et al., 2009; Tobler & Borbély, 1988). During this stage, brain temperature decreases, skeletal muscles relax, eye movements typically remain relatively quiescent, and heart rate and respiration tend to be more regular (Lesku et al., 2019; Rattenborg et al., 2009).

However, birds exhibit some differences in REM sleep brain activity compared to mammals (Rattenborg et al., 2011). While most mammals show active brain activity in both hemispheres during REM sleep, birds can have one hemisphere remain awake while the other exhibits slow-wave sleep activity, a unique electrophysiological state known as unihemispheric slow-wave sleep (USWS) (Rattenborg et al., 2000; Rattenborg et al., 2008; Szymczak et al., 1996). Some species, capable of flying for consecutive days without landing, adapt their sleep patterns based on environmental changes, employing unihemispheric sleep (closing only the corresponding eye) or even entering sleep simultaneously in both brain hemispheres for brief periods to sustain prolonged flights (Rattenborg, 2017; Rattenborg et al., 2019; Rattenborg et al., 2016). This behaviour bears a resemblance to some aquatic mammals such as cetaceans, dolphins, and several seal species, which can alternately keep both halves of the brain in the sleeping and awake state (Kendall-Bar et al., 2019; Lyamin et al., 2017; Mukhametov, 1987; Oleg et al., 2008). When exposed to unsafe environments, birds tend to utilize unihemispheric sleep more frequently to remain vigilant to their surroundings, mitigating the conflict between sleep and potential threats (Rattenborg et al., 2000; Rattenborg et al., 1999a, 1999b; Rattenborg et al., 2016). Furthermore, unlike mammals, where slow-wave sleep can last for several minutes to tens of minutes, birds may experience hundreds of microsleeps throughout the day, with rapid eye movement sleep durations typically lasting no more than 10 seconds and always involving both brain hemispheres (Aulsebrook et al., 2016; Libourel et al., 2023; Rattenborg, 2017).

1.3 Effects of sleep deprivation on birds

Sleep interruption is a common occurrence, with an extensive body of research documenting the potential adverse effects of sleep deprivation on humans and some other mammals. For example, one study of healthy young adults who were restricted to 67% of their habitual sleep duration for seven consecutive nights (averaging 4.98 hours per night) resulted in a cumulative decline in measures of neurobehavioural alertness at wakefulness, including subjective sleepiness, emotional state, and psychomotor alertness, and recovery of these losses appeared to require two full nights of sleep (Dinges et al., 1997). Surprisingly, following sleep deprivation experiments, young adults exhibited poorer cognitive memory (Alhola & Polo-Kantola, 2007; Smulders et al., 1997) and lower vigilance (Philip et al., 2004; Stenuit & Kerkhofs, 2005) compared to sleep deprived older adults .

Amidi noted in the review that sleep disorders are prevalent among patients with neurodegenerative diseases (such as Parkinson's disease) as well as in those with non-neurodegenerative diseases (such as cancer and mood disorders), and are associated with poorer cognitive functions (Amidi et al., 2023). According to the research of Banks and Dinges, when nightly sleep duration is restricted to less than 7 hours, it will not only result in obvious impairment to an individual's neurobehavioural and physiological functions, but also may lead to decreased attention, slower memory processing speed, reduced cognitive capacity, and diminished mood (Banks & Dinges, 2007). Harrison and Horne have pointed out that sleep deprivation impairs the ability of the prefrontal cortex (PFC) to perform tasks, affecting high-level decision making in emergency situations (Harrison & Horne, 2000). The study by Tucker et al. suggests that sleep deprivation has differential effects on various components of cognitive processing. They discovered that core executive functions, such as working memory and resistance to interference, were not significantly impaired and that some executive functions even showed improvement. This finding challenges the prevalent view that executive functions are particularly vulnerable to sleep deprivation (Tucker et al., 2010). Killgore, in his review, pointed out that the impact of sleep deprivation on cognitive functions is complex and differentiated, encompassing declines in global vigilance and attention, the extent to which specific cognitive functions depend on emotional processing networks, and whether cognitive processes can be compensated for by related brain regions. Thus, maintaining adequate sleep is crucial for our physiological, emotional, and cognitive functions (Killgore, 2010).

Rechtschaffen and colleagues have experimentally confirmed that total sleep deprivation (TSD) and paradoxical sleep deprivation (PSD, i.e., deprivation of REM sleep phase) can induce a series of biological responses in rats, including death, weight loss, debilitated appearance, and skin lesions (Rechtschaffen & Bergmann, 2002). Mullington et al. reported in their review that sleep insufficiency increases the risk of developing heart disease by altering cardiovascular risk factors such as blood pressure, glucose metabolism, hormonal regulation, and inflammation (Mullington et al., 2009). A study involving 12 normal-weight male subjects, subjected to one night of total sleep deprivation and one night of normal sleep, found that although blood glucose levels remained unchanged, total sleep deprivation increased the response of the right anterior cingulate cortex to images of food compared to normal sleep, indicating that acute sleep deprivation enhances subjective appetite (Benedict et al., 2012).

The impacts of sleep deprivation have predominantly been examined in male subjects, with limited consideration for sex-specific effects. However, there is evidence suggesting that the response to sleep deprivation may exhibit sexual dimorphism. Electroencephalogram (EEG) displays and reaction times indicate that sleep deprivation affects women less severely than men. Yet, men can return to their pre-deprivation state after a single night of recovery sleep, while women may require more sleep for recovery (Corsi-Cabrera et al., 2003). According to research by Andersen et al. on rats, following a 4-day paradoxical sleep deprivation period, male and female rats exhibited different recovery patterns during the nocturnal recovery, especially in terms of sleep efficiency and the rate of recovery of paradoxical sleep (rapid eye movement sleep), with females recovering faster than males at certain stages (Andersen et al., 2008). Tobler et al., by implanting electrodes in the cortical and hippocampal areas of rabbits, found that sleep deprivation led to an extension of NREM sleep duration and a brief increase in REM sleep. The EEG changes in the hippocampus have a similar response pattern to that of the cerebral cortex in sleep regulation, consistent with observations in other mammals (Tobler et al., 1990).

In short, there is ample scientific evidence that sleep is crucial for our physiological, emotional, and cognitive functions, including learning abilities, memory, attention, verbal communication skills, decision-making abilities, and more, and that it is fundamentally guarantee for maintaining our normal circadian rhythms. Further, data suggests that in some contexts, there are sex-specific responses to different types of sleep distruptions.

Sleep restriction comes in two different forms. For the purposes of this thesis, I will refer to them as sleep deprivation – when the bird is kept from sleeping at all for extended periods of time (Orzeł-Gryglewska, 2010); and sleep disturbance/disruptions – when the bird regular sleep pattern is disturbed but they bird is not kept awake for long stretches of time. In sleep deprivation, the brain is still fully awake and the body responsive. In disturbance, the animal does reach sleep states, but the sleep pattern may be disturbed – with different ration of NREM and REM, or lighter sleep, or more frequent arousal (Connelly et al., 2020).

To date, there is little data on the effects of sleep disruption or deprivation in birds. Some studies suggest that birds can adapt to the lack of sleep. For instance, birds that breed in the polar regions, are sometimes awake for very long stretches of time. The polygamous pectoral sandpipers (*Calidris melanotos*) face a multitude of challenges during the breeding season, including territorial disputes with rival males, courtship and mating with receptive females, threats from unknown predators, and the constant need to forage for sustenance to maintain their energy. In response to these demands, they have to sacrifice significant amounts of sleep to increase their possibility of breeding more offspring (Lesku et al., 2012). Some males stay awake for as much as 14 days without any sleep, and when they do sleep, they sleep more deeply. Similarly, though less extremely, temperate blue tits (*Cyanistes caeruleus*) experience sleep deprivation during the breeding season or months with long sunlight hours. They also may cope with this change by adjusting the depth of their sleep (Steinmeyer et al., 2010).

Studies have shown that birds also exhibit compensatory responses to sleep deprivation, restoring physical fitness and brain function by increasing the amount of sleep or changing the depth of sleep. Chinstrap penguins (*Pygoscelis antarcticus*) in Antarctica, after staying in the sea for over 20 hours, usually spend the first few hours upon returning to land recovering sleep. And when exposed to continuous disturbances from egg predators like the brown skua (*Stercorarius antarcticus*) and attacks from other penguins during nesting, they manage to accumulate nearly 11 hours of sleep through thousands of microsleeps, each lasting only 4 seconds, as a way to adapt to the need to remain vigilant in their external environment (Libourel et al., 2023). Birds engaged in long-distance flights can have brief periods of sleep while gliding, but this duration is far from sufficient to compensate for their lost sleep. Great frigatebirds (*Fregata minor*) can fly over oceans for months without landing (Weimerskirch et al., 2016), and their sleep intensity reaches its peak shortly after returning to land, then gradually decreases to baseline (Rattenborg, 2017; Rattenborg et al., 2016). There are also some nocturnal migratory passerine birds, such as Swainson's thrush *(Catharus* *ustulatus*) and the White-Crowned Sparrow (*Zonotrichia leucophrys gambelii*), that remain migratory restlessness at night, despite being kept in laboratory captivity. These birds experience significantly reduced night-time sleep, but supplement with more sleep during the day (Fuchs et al., 2006; Fuchs et al., 2009; Peter et al., 2000; Rattenborg et al., 2004). For 11-day-old chicks deprived of 8 hours of sleep by forced exercise, the duration of sleep episodes in the recovery period was increased but did not differ from the total nighttime sleep duration of control chicks. Notably, the duration of eye closure in the left and right eyes during unihemispheric sleep exhibits significant disparities, possibly related to hemisphere dominance shifts during chick development (Bobbo et al., 2002; Bobbo et al., 2008). However, Domestic chickens (*Gallus domesticus*) between 20 and 23 weeks of age, after being deprived of 14 hours of sleep during the day though artificially employing visual and auditory stimulus disturbances, showed decreased alertness at night and chose to sleep more by closing both eyes to make up for the lack of sleep (Boerema et al., 2003). Similarly, pigeons (*Columba livia*) forced to stay awake under laboratory conditions exhibited a significant increase in REM sleep duration (Tobler & Borbély, 1988). Studies show pigeons compensate for sleep loss by increasing slow-wave activity (SWA), with SWA initially increasing then decreasing during the nighttime recovery sleep period, and transitions between SWS and REM sleep becoming more frequent (Martinez Gonzalez et al., 2008; Tobler & Borbély, 1988).

However, though many birds seem to be resilient to sleep loss, sleep deprivation can inflict potentially long-term negative effects on birds. Irregular sleep patterns may negatively affect the physiological health and reproductive cycles of birds, leading to alterations in various aspects of normal behaviour (de Jong et al., 2016). Moreover, sleep is crucial for maintaining normal immune system function and memory consolidation, and disturbances in sleep can result in decreased immune system function and cognitive abilities (de Jong et al., 2016). Australian magpies (*Cracticus tibicen*) subjected to sleep deprivation experienced significant negative effects, manifested as a decrease in motivation due to fatigue, reduced cognitive abilities and behavioural flexibility, and changes in song output, specifically singing for longer durations but producing fewer songs, with alterations also observed in the peak timing of singing. The effects from full night of sleep deprivation were more severe than that from half-night deprivation, and some effects persisted even after a full night of recovery sleep (Johnsson et al., 2022). Similarly, after experiencing sleep deprivation, common mynas (*Acridotheres tristis*) showed reduced song output and complexity, while call output increased, and spectral parameters of calls changed, resulting in longer calls, with lower frequencies and a narrower frequency range. Moreover, longer duration of sleep deprivation had a greater impact on the vocal performance of the common myna, with a more significant reduction in song output after 12 hours of sleep deprivation compared to 6 hours, yet the duration of singing became longer (Gaviraghi Mussoi, 2023).

Sleep is crucial for the health and survival of birds; however, bird sleep can be disrupted by a multitude of factors. Among them, natural factors including weather changes, seasonal transitions, instability of food resources, intraspecific competition, and the threat of predators may all impact avian sleep (Da Silva & Kempenaers, 2017; Fuchs et al., 2006; Libourel et al., 2023; Lima et al., 2005). In addition, with the acceleration of urbanization, anthropogenic disturbances have become significant factors affecting bird sleep. These include habitat destruction, noise and light interference, etc., particularly light pollution, which is now prevalent in modern society, has emerged as an important topic in the research of disturbances to bird sleep (Da Silva et al., 2014; Dominoni et al., 2013; Nordt & Klenke, 2013).

1.4 Effects of sleep disturbances (lights) on birds

The impact of artificial lighting on avian sleep in the natural world is an increasingly concerned environmental issue, particularly in urban and suburban areas where light from streetlamps and buildings disrupts the natural sleep cycles of birds (Da Silva et al., 2016; Nordt & Klenke, 2013). Avian biological clocks are closely linked to daylight cycles (Dominoni et al., 2014; Giebultowicz, 2004; Gwinner & Brandstatter, 2001; Hasan, 2010), and excessive nocturnal lighting can interfere with the normal secretion of melatonin (de Jong et al., 2016), potentially leading to dysregulation of the biological clock, affecting their sleep patterns and duration (Da Silva & Kempenaers, 2017; de Jong et al., 2016; Leopold & Eynon, 1961; Russart & Nelson, 2018; Wright, 1912). The total sleep time of common mynas subjected to night-time light disturbance decreased by 40.3% compared to baseline period, and the time period of their night-time sleep tendency also changed, which had the greatest impact on sleep in the morning and evening, and the impact on sleep in the middle of the night was relatively small (Gaviraghi Mussoi, 2023). A study monitoring the nocturnal activity of great tits (*Parus major*) at a field site found that individuals living under white light were more restless and vigilant, exhibited higher activity levels, and had a higher likelihood of disease infection, with deleterious effects on avian health (Ouyang et al., 2017). When circadian rhythms are altered in laboratory environments, domestic pigeons (*Columba livia*) continue to be predominantly biased towards sleeping in the dark phase, leading to more fragmented sleep and a reduction in overall sleep time (Aulsebrook et al., 2020; Rattenborg et al., 2005). Indian house crows (*Corvus splendens*) exposed to constant light for 24 hours also reduced their rest time, resulting in decreased learning and cognitive abilities during subsequent daytime tests (Taufique et al., 2018; Taufique & Kumar, 2016). In summary, increasing evidence suggests that lighting disturbance alters avian sleep patterns, cognitive performance and biological rhythms.

Light pollution may cause birds to engage in activities such as singing and foraging at abnormal times (Da Silva et al., 2016; Hutchinson, 2002; Kacelnik, 1979; Leveau, 2020; Nordt & Klenke, 2013; Sanders et al., 2021; Stracey et al., 2014), which may affect their energy balance and social structures. For instance, some studies have shown that urban birds begin their dawn song earlier and cease calling later than their suburban birds due to the influence of anthropogenic light or traffic noise at night (Da Silva et al., 2014; Da Silva et al., 2016; Dominoni et al., 2014; Dominoni et al., 2013; Kempenaers et al., 2010; Marín Gómez, 2022; Miller, 2006; Nordt & Klenke, 2013). Surveys in mid-latitude regions found that anthropogenic night lighting leads to earlier dawn songs in passerine birds (Da Silva & Kempenaers, 2017). In contrast, a survey of dawn song times of five common songbird species in three regions of Europe (northern Finland, 65°N; southern Germany, 48°N; and southern Spain, 37°N), where different latitudes lead to different lighting conditions, found that the earliest singing species such as European robins (*Erithacus rubecula*) and common blackbirds (*Turdus merula*), sang earlier at dawn with a natural increase in nighttime brightness in Finland, but anthropogenic nighttime lighting did not further affect their singing times (Da Silva & Kempenaers, 2017). However, later singing species such as great tits (*Parus major*), blue tits (*Cyanistes caeruleus*) and chaffinches (*Fringilla coelebs*) showed similar dawn song times to sunrise throughout the season and at all latitudes were affected by anthropogenic night lighting (Da Silva & Kempenaers, 2017).

Light at night is not solely negative, however. The continuous presence of artificial light at night enables birds to forage with better visibility in the dark, and insects attracted to the light sources provide readily available food resources for insectivorous birds (Frank, 1988; Leveau, 2020; Negro et al., 2000). In an investigation of the effects of light pollution on the foraging behaviour of the Northern Mockingbird (*Mimus polyglottos*), researchers found that the higher the average light level around the nest after sunset, the longer the average time that the birds continued to feed their chicks (Stracey et al., 2014). Similarly, the feral pigeon (*Columba livia f. domestica*), a common feral pigeon in urban areas, also increases its foraging activities under the influence of nighttime artificial light (Leveau, 2020).

In addition, persistent light pollution may affect the breeding cycles and strategies of birds (Dominoni & Partecke, 2015; Kempenaers et al., 2010). Diurnally active birds often rely on changes in light intensity around specific moments of the day such as sunrise and sunset to time breeding activities (e.g., singing), and fine-tune this response by taking into account surrounding environmental and social factors (Da Silva et al., 2014; Davidson & Menaker, 2003; Foote et al., 2011). The variation in natural light cycles is closely linked to avian internal biological clocks (Davidson & Menaker, 2003; Gwinner, 1986; Wikelski et al., 2008), with increasing day length stimulating the release of hormone, leading to the development and maturation of avian gonads in preparation for the breeding season (Dawson et al., 2001; Lambrechts et al., 1997). Male birds usually start singing at dawn to declare territorial ownership (Amrhein et al., 2004; Amrhein & Erne, 2006; Foote et al., 2011; Marín Gómez, 2022; Sexton et al., 2007; Slagsvold et al., 1994; Staicer et al., 2020), attract females (Kempenaers et al., 1997; Moller, 1991; Slagsvold et al., 1994), protect their mates (Moller, 1991), or stimulate their reproductive development (MACE, 1987; Sexton et al., 2007; Staicer et al., 2020; Welling et al., 1995).

However, under the interference of artificial light, the gonadal development and reproductive cycle of birds will be affected to some extent (Lambrechts et al., 1997). Female blue tits *(Cyanistes caeruleus*) living under the influence of street lighting have been observed to start laying eggs earlier in the breeding season, potentially due to enhanced lighting affecting their biological clocks and reproductive cycles, leading to early reproductive activities (Kempenaers et al., 2010). Similarly, captive blue tits raised in captivity after being captured and exposed to a sudden increase in artificial light also laid eggs earlier (Lambrechts et al., 1997). Laboratory studies have shown that male

European blackbirds (*Turdus merula*) even exposed to low-intensity light at night develop their reproductive systems a month earlier than normal control groups (Dominoni et al., 2013). A field research study has also found that both male and female gonads of urban European blackbirds (*Turdus merula*) living in the wild have advanced growth compared with their forest counterparts (Partecke et al., 2005). Some studies have suggested that under conditions of artificially increased nocturnal lighting, some songbirds begin their dawn singing earlier (Da Silva et al., 2014; Kempenaers et al., 2010; Miller, 2006; Nordt & Klenke, 2013), and males that sing earlier are more likely to attract females and occupy high-quality breeding territories, gaining a competitive advantage during the breeding season and significantly affecting individual reproductive success (Kempenaers et al., 2010; Poesel et al., 2006; Slagsvold et al., 1994). In summary, lighting has significant impacts on the timing and success rates of breeding in many bird species, with excessive artificial light potentially leading to earlier or delayed breeding seasons (Kempenaers et al., 2010), thereby affecting the survival rates of chicks and the health of entire populations. Notably, increased visibility at night provides birds with more opportunities for foraging and mating, which could potentially enhance their productivity to some extent (Miller, 2006).

For migratory birds, anthropogenic light sources can lead to navigational confusion (Rich & Longcore, 2006; Van Doren et al., 2017). Many birds rely on the stars and the moon, or magnetic compass, to determine direction (Fransson et al., 2001; Hiscock et al., 2016; Mouritsen et al., 2016; Stapput et al., 2008). However, the widespread light pollution in urban areas can severely disrupt these natural navigational cues (Muheim et al., 2016; Poot et al., 2008; Wiltschko et al., 1993), leading to disorientation or deviations in migration routes, resulting in delayed migration and excessive depletion of energy reserves (Rich & Longcore, 2006). In addition, nighttime light sources not only attract birds and cause them to change their direction (Cochran & Graber, 1958; Day et al., 2015), but also leads to collisions with urban architectural structures such as windows and glass facades (Cusa et al., 2015; Nemes et al., 2023), maritime vessels (Fischer et al., 2021; Merkel & Johansen, 2011; Ryan et al., 2021) and aircraft (Doppler et al., 2015), or even grounding (Heswall et al., 2022), resulting in massive mortality. The impact of light pollution on the survival of migratory birds has become a far-reaching issue for a long time.

Birds play a vital role in ecosystems, such as pollination, seed dispersal, and pest control. The behavioural patterns changes caused by light pollution may trigger cascading effects on entire ecosystems, impacting other species and the overall ecological balance. Overall, the impact of anthropogenic lighting on birds are multifaceted and involve encompassing various aspects from behaviour to physiology. Not only does it can disrupt their sleep cycles and daily behaviour patterns, affect physiological health, but it may also interfere with migration routes and even leading to wider ecosystem changes. With the acceleration of urbanization and the intensification of light pollution issues, it becomes increasingly important to conduct in-depth studies and focus on the impact of light pollution on birds and the entire ecosystem.

1.5 Assumptions and objectives

Together, the available research has shown that sleep deprivation and sleep disturbance adversely affect avian cognitive performance, memory consolidation, developmental learning, vocal communication, lifestyle habits, breeding and brooding (Gaviraghi Mussoi, 2023; Jackson et al., 2008; Johnsson et al., 2022; Kempenaers et al., 2010; Lambrechts et al., 1997; Mussoi et al., 2022; Rattenborg et al., 2011; Taufique et al., 2018; Taufique & Kumar, 2016). However, few studies have distinctly assessed the independent impacts of different levels of nocturnal sleep deprivation (human disturbance) and sleep disturbance (light interference) on the daytime activity levels of the same species of birds. Therefore, it is unclear to what extent birds engage in compensatory resting behaviour when their sleep is disturbed.

To begin addressing this larger question, I examine the daytime activity levels of 13 captive common mynas (*Acridotheres tristis*) after four experiments with different levels and types of sleep disruptions. Each experiment was divided into two days: a baseline day (after a normal night of sleep) and a treatment day (after a night of sleep deprivation: 12h or First6h or Last6h; or sleep disturbance: 12h of light). I predict that the after reductions in nocturnal sleep, common mynas would be less active during the day and unable to fully engage in normal behavioural performance, furthermore that longer periods of sleep deprivation and more invasive disturbances at night would cause more sleep fragmentation during the day. Through our experimental tests, we aim to provide further empirical insights into how birds' daily behaviour is affected by nocturnal sleep deprivation and sleep disruption, to facilitate a deeper understanding of the consequences of sleep loss.

2 Materials and Methods

2.1 Study species and housing

Common myna (*Acridotheres tristis*) is a medium-sized bird belonging to the starling family, Sturnidae, within the order Passeriformes, measuring 24-25 centimeters in length and averaging 125 grams in weight (Craig et al., 1998). The iris is brown or reddish-brown, with yellow bare skin around the eyes, and their beaks, legs, and feet are also yellow. The plumage is primarily brownish, with the head, neck, and upper chest being glossy black. The lower tail feathers, tail tip, and the base of the primary feathers are white, and during flight, conspicuous white wing patches are visible (Craig et al., 1998; Wilson, 2013).

Figure1.1. Photograph of a common myna (*Acridotheres tristis*). Photo by Simeng Li.

Common myna, originally native to India, has now been introduced worldwide (to regions like South Africa, the Americas, and the Pacific area) (Ewart et al., 2019; Long, 1981; Smith et al., 2020). It was introduced to New Zealand in the 1860s, mainly to reduce the population of pests in agricultural areas (Beesley et al., 2023; Heather et al., 2015). However, due to its extensive diet and strong adaptability, not only consuming a variety of insects, fruits and seeds of plants but also competing with other birds for food and nesting sites, killing young birds, destroying eggs, and displacing small mammals, their introduction has concurrently reduced local biodiversity (Craig et al., 1998; Rogers et al., 2021; Tindall et al., 2007; Wilson, 1975). Common Myna are monogamous, re-partnering only upon the death of a mate (Wilson, 1973). There is no significant sexual dimorphism in appearance between males and females, although females are reported to be slightly smaller than males, usually necessitating genetic sex determination for accurate identification (Ali & Ripley, 1972). The species is widely distributed and common in New Zealand, often inhabiting urban environments. They are social birds, typically living in groups in the wild. Within New Zealand, and other parts of the world, they are commensal with humans, and thus commonly exposed to urban noise, light and disturbance. These factors have led to the possibility that they are likely to be affected by sleep disturbances, making them suitable subjects for studying the impact of sleep disorders on daily behaviour.

In September 2020, 13 wild adult Common Mynas (*Acridotheres tristis*) were captured in the Auckland region of New Zealand using PeeGee traps baited with dog food pellets. Genetic sex determination revealed that 6 of them were females, and 7 were males. These birds were placed in a temperature-controlled (23°C ± 1°C) restricted-access laboratory at the University of Auckland. To facilitate identification, each bird was weighed and equipped with different-coloured tags. The laboratory was equipped with Sylvania 58w Gro-lux lights, simulating a 12-hour light and 12-hour dark cycle (lights-off at 1800h). Additionally, four security cameras (Wisenet 20M IR Flat VDome 5MP 2.8MM lens) were installed on the ceiling of the laboratory to record their behaviour.

The birds were placed in individual cages (103 x 45 x 60 cm) that allowed for auditory and visual contact between them. Each cage was equipped with two perches and provided unrestricted access to water and food. They were fed a daily diet of dog food pellets, supplemented with fruits or mealworms at least twice a week. Prior to conducting these experiments, there was a 5-month acclimation period for the birds within the laboratory environment due to COVID-19-related delays.

2.2 Experimental design

To investigate the impact of sleep deprivation or sleep disruption (light exposure) on the daily activities of the mynas, we conducted four experiments: (1) Full-night sleep deprivation (12SD; 18:00h-06:00h), (2) Early night sleep deprivation (6SD; 18:00h-24:00h), (3) Late night sleep deprivation (6SD; 00:00h-06:00h), and (4) Full-night light disturbance (12SD; 18:00h-06:00h). Each experiment was conducted over two days: the first night (Baseline), no disturbance to the birds; the second night the birds were kept had their sleep disrupted (Sleep Deprivation/Disturbance) for the half of the night (6SD) the entire night (12SD). These experiments were performed in March and April 2021, with a two-week interval between them to ensure complete recovery of the bird subjects.

During the sleep deprivation experiment, we employed gentle measures to ensure that common mynas remained awake. Although the room was kept dark, two people were present, moving around the room continuously. In most cases, the presence and activity of people was sufficient to keep the birds awake. However, if the birds persisted in attempting to sleep, further intervention measures were employed to provide visual and auditory stimulation. This included more frequent walking back and forth, approaching the bird cages, or gently tapping the cages and making slight noise disturbances. If the birds continued to exhibit clear signs of rest, such as closing their eyelids, tucking their heads under wings, or remaining still for over 30 seconds, laboratory staff would gently touch them.

During the light disturbance experiment, the laboratory light source (Sylvania 58w Gro-lux lights) remained on throughout the night (18:00h-06:00h). Our experimental subjects were exposed to the same light environment without any shaded or dark areas, and there were no instances of human interference during the experiment.

2.3 Video data processing

The cameras in the room recorded the behaviour of all the common mynas. For two days of each experiment, from the onset of the light (06:00) to its cessation (18:00), I observed the birds behaviour. To facilitate analysis and determine if there were time of day effects, the day was broken into 30 minutes chunks. I recorded behaviour for the first five minutes of each half hour of video, recording the behaviour of each myna as either active or not active. Active behaviours include activities such as foraging, drinking, walking, jumping, flying, alertness, bowing, preening, calling and singing. Inactive behaviours included resting and sleeping. Postures indicative of resting and sleeping included standing on one or both legs on a perch without movement, sitting with one or both eyes closed, tucking the head into feathers, or remaining motionless at the bottom of the cage, among others.

2.4 Genetic sex identification

We employed a genetic sexing method to accurately determine the sex of the experimental subjects. Details provide in Gavarghi Mussoi 2023 and provided here only briefly (Gaviraghi Mussoi, 2023). We collected blood samples and stored until analysis. We extracted DNA from the blood samples using a specific DNA extraction kit, following the manufacturer's instructions. Using PCR we amplified sex-specific genetic marker and separated and visualized PCR products through gel electrophoresis. Due to the differences in the target gene sequences between females and males, they exhibited different band patterns on the electrophoresis gel; females displayed two bands of different sizes (representing genes on the Z and W chromosomes), while males showed only one band size (representing genes on the Z chromosome), thus enabling the differentiation of the sex of the experimental birds.

Through these steps, we successfully determined that the experimental group consisted of 6 female and 7 male common mynas, providing crucial foundational information for subsequent behavioural studies.

2.5 Statistical analysis

I conducted all statistical analyses using the R programming software v4.2.0 (R Development Core Team, 2021). Prior to the analyses, I checked the normality of the variables and applied statistical transformations when necessary. Due to the non-linear relationship between the dependent variable and time, I converted the recorded time periods into seconds and calculated the proportion of active versus inactive time within each five-minute.

I used descriptive statistics and plotting to present the daytime behavioural changes of the common mynas following different experiments. I utilized generalized linear models to test the differences between the baseline and various treatments, using the proportion of activity every five minutes as the dependent variable, with different treatments, time, and their interactions as fixed effects, and bird ID as a random effect.

I also compared different treatments (12SD, Last6SD, First6SD, 12LightSD) in the four experiments with the average of the four baselines to examine the significant differences in the impact of different treatments on bird activity levels, by using a linear mixed model with the proportion of the time the bird was active as the dependent variable, the interaction between treatment and time as fixed effects, and bird ID as a random effect.

To investigate whether sex had an influential role in this experiment, I separately generated scatter plots and linear regression graphs comparing the activity level proportions of male and female birds in the Baseline group for different experiments using the ggplot package. I also applied linear mixed models with the bird activity Prop as the dependent variable, the interactions between Treatment, time, and sex as fixed effects, and bird ID as a random effect.

Furthermore, I used the drop1 function to compare the Akaike Information Criterion (AIC) of the models, removing non-significant interaction terms, and refitted a simplified linear mixed model.

To visualise the effect of sleep deprivation or disturbance on daytime activity levels, I employed the ggplot package in R to create boxplots showing the difference between active and inactive time proportions for each experiment.

To explore how the proportion of active time varied over time under different treatment conditions, I created separate datasets for each experiment and used the ggplot package to generate scatter and linear regression graphs showing the interaction effects between different Treatments and time on the birds' daytime activity levels the following day. To compare the effect of the treatments, I average the baselines together and then examined all activity levels together in one model.

To visualise the effect of sex in on response to sleep treatments, I separately generated scatter plots and linear regression graphs comparing the activity level proportions of male and female birds in the Baseline group for different experiments using the ggplot package.

2.6 Ethical statement

Trapping, housing and experiments were approved by the University of Auckland Animal Ethics Committee (Approval No. AEC2557).

3 Result

3.1 Sleep deprivation alters daytime behavioural activity

3.1.1 Full night sleep deprivation

When deprived of sleep for an entire night (12SD), compared to after normal sleep, common mynas exhibited a significant increase in inactivity during the subsequent day, with an average increase of 18.22%. The baseline group's average daytime activity was significantly higher than their average inactivity, but after 12 hours of nocturnal sleep deprivation, the average daytime activity slightly decreased below the average inactivity level (Figure 3.1).

Sleep deprivation for 12 hours had a significant negative impact on daytime activity levels (p<0.001), with birds spending more time resting following sleep deprivation treatment compared to the control group (Table 3.1). There was a significant interaction between treatment and time (p<0.001), with birds showing higher activity levels later in the day (Table 3.1).

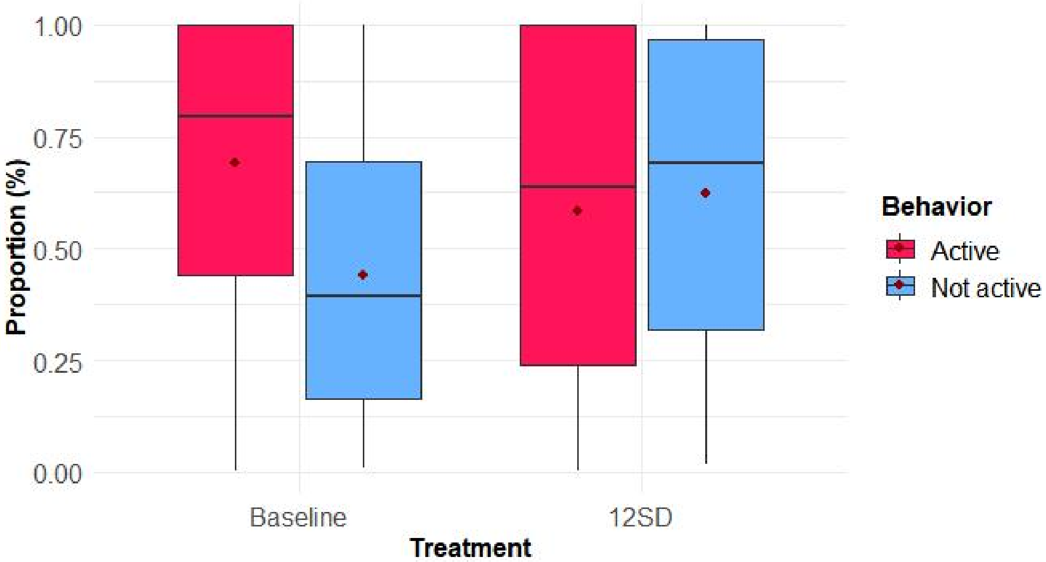


Figure 3.1. Boxplots presenting the difference in proportion of five minutes of active/inactive time per half hour during the 12-hour sleep deprivation experiment. The lines extending above and below the box represent the maximum and minimum values of the dataset, respectively. The thick line within the box marks the median, while the top and bottom lines of the box correspond to the upper and lower quartiles, respectively. Points denote the mean. (Note: the boxplots do not consider additional factors such as bird ID and observation, which are included in the linear model analysis.)

Table 3.1. Summary of the generalized linear model on the effects of 12h sleep deprivation (12SD) on next-day activity levels (bird ID as a random effect, and observations is the recording of active and inactive time within five minutes every half-hour from 6:00 to 17:30 of common mynas).

	12SD			
Predictors	*Estimates*	*Std. Error*	*z value*	*P*
(Intercept)	0.51	0.46	1.11	0.267
TreatmentSD12h	-3.85	0.71	-5.42	**<0.001**
Observation	0.00	0.00	0.79	0.429
TreatmentSD12h:Observation	0.00	0.00	4.71	**<0.001**
Random Effects				
Birds Variance	0.19			
Birds Std.Dev.	0.44			
Observations	564.00			
Groups	Bird, 13			

Note：bold=p<0.05

3.1.2 Half night sleep deprivation, last 6 hours

When being deprived of sleep in the last half of the night (Last6SD), compared to after normal sleep, the common mynas exhibited an increase in inactivity during the day, with an average increase of 10.35%. However, this increase was less pronounced than after full night sleep deprivation (12SD). After 6 hours of sleep deprivation in the last half of the night, the average daytime activity still exceeded the average inactivity (Figure 3.2).

Deprivation of sleep for 6 hours during the latter half of the night significantly negatively impacted daytime activity levels (p<0.001). On the day following the sleep deprivation treatment, the birds spent more time resting compared to the control group (Table 3.2). The interaction between treatment and time had a lesser effect on activity levels (p<0.01), with activity peaking in the evening (Table 3.2).

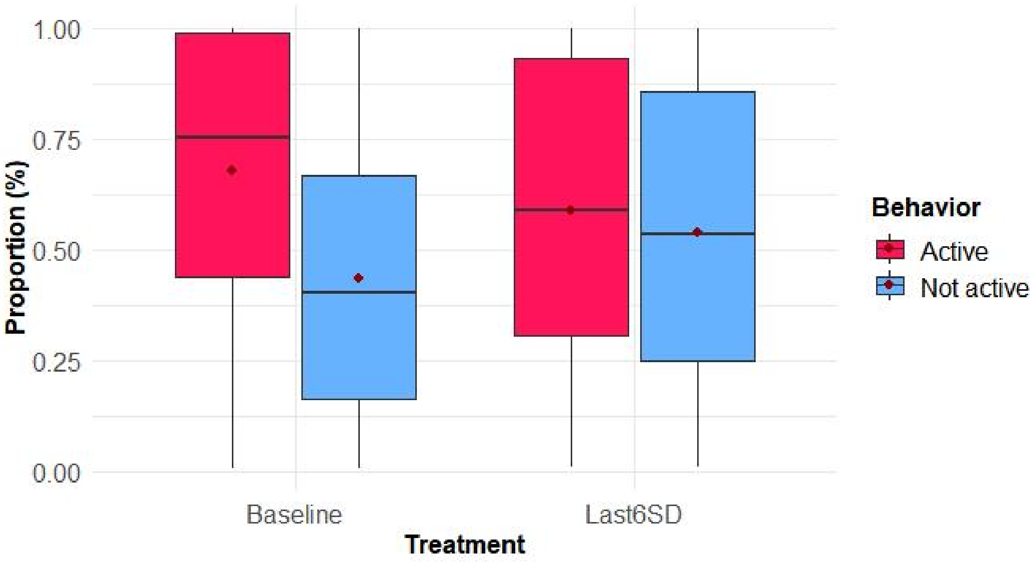


Figure 3.2. Boxplots presenting the difference in proportion of five minutes of active/inactive time per half hour in the last night sleep deprivation experiment.The lines extending above and below the box represent the maximum and minimum values of the dataset, respectively. The thick line within the box marks the median, while the top and bottom lines of the box correspond to the upper and lower quartiles, respectively. Points denote the mean. (Note: the boxplots do not consider additional factors such as bird ID and observation, which are included in the linear model analysis.)

Table 3.2. Summary of the generalized linear model on the effects of 6h sleep deprivation in the last half of the night (Last6SD) on next-day activity levels (bird ID as a random effect, and observations is the recording of active and inactive time within five minutes every half-hour from 6:00 to 17:30 of common mynas).

	Last6SD			
Predictors	*Estimates*	*Std. Error*	*z value*	*P*
(Intercept)	1.76	0.48	3.65	**<0.001**
TreatmentSD6h	-2.22	0.63	-3.52	**<0.001**
Observation	0.00	0.00	-1.75	0.081
TreatmentSD6h:Observation	0.00	0.00	2.73	**0.006**
Random Effects				
Birds Variance	0.19			
Birds Std.Dev.	0.44			
Observations	599.00			
Groups	Bird, 13			

Note：bold=p<0.05

3.1.3 Half night sleep deprivation, first 6 hours

When being deprived of sleep in the first half of the night (First6SD), compared to after normal sleep, the common mynas also exhibited an increase in inactivity during the subsequent day, with an average increase of 21.56%. The baseline group's average daytime activity on the following day was significantly higher than their average inactivity, whereas after First6SD, the average daytime activity on the following day was slightly lower than the average inactivity (Fig. 3.3).

Although deprivation of sleep for 6 hours during the first half of the night did not significantly impact daytime activity levels (p>0.05), on the day following the sleep deprivation treatment, the birds spent more time resting compared to the control group (Table 3.3).

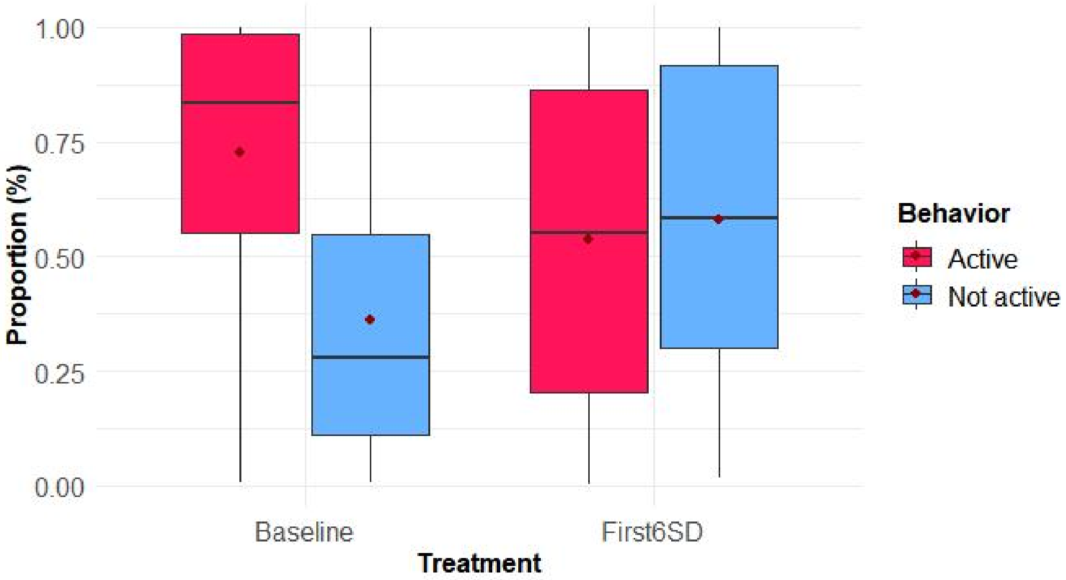


Figure 3.3. Boxplots presenting the difference in proportion of five minutes of active/inactive time per half hour in the first night sleep deprivation experiment. The lines extending above and below the box represent the maximum and minimum values of the dataset, respectively. The thick line within the box marks the median, while the top and bottom lines of the box correspond to the upper and lower quartiles, respectively. Points denote the mean. (Note: the boxplots do not consider additional factors such as bird ID and observation, which are included in the linear model analysis.)

Table 3.3. Summary of the generalized linear model on the effects of 6h sleep deprivation in the first half of the night (First6SD) on next-day activity levels (bird ID as a random effect, and observations is the recording of active and inactive time within five minutes every half-hour from 6:00 to 17:30 of common mynas).

	First6SD			
Predictors	*Estimates*	*Std. Error*	*z value*	*P*
(Intercept)	1.84	0.52	3.56	**<0.001**
TreatmentSD6h	-0.89	0.68	-1.31	0.191
Observation	0.00	0.00	-1.13	0.259
TreatmentSD6h:Observation	0.00	0.00	-0.28	0.783
Random Effects				
Birds Variance	0.10			
Birds Std.Dev.	0.32			
Observations	564.00			
Groups	Bird, 13			

Note：bold=p<0.05

3.2 Light disturbance effects daytime behavioural activity

When being exposed to continuous light disturbance throughout the night (12LightSD), there was only a slight difference in the inactivity time of common mynas during the subsequent day compared with normal sleep, with an average increase of 0.47% and a slight decrease in the average active time (Fig. 3.4).

Sleep disturbance from all-night light exposure for 12 hours and diurnal time changes both had a highly significant negative impact on daytime activity levels ($p<0.001$) (Table 3.4). The interaction between the two also significantly negatively affected activity levels ($p<0.001$), with activity level reaching its lowest in the evening (Table 3.4).

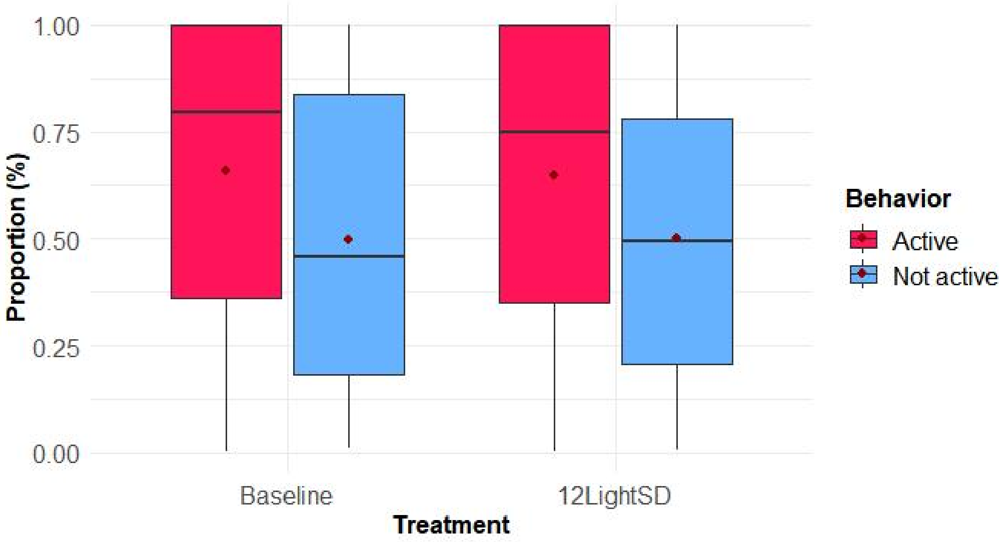


Figure 3.4. Boxplots presenting the difference in proportion of 5-minute active/inactive time per half hour in 12h all-night light-disturbed sleep experiment. The lines extending above and below the box represent the maximum and minimum values of the dataset, respectively. The thick line within the box marks the median, while the top and bottom lines of the box correspond to the upper and lower quartiles, respectively. Points denote the mean. (Note: the boxplots do not consider additional factors such as bird ID and observation, which are included in the linear model analysis.)

Table 3.4. Summary of the generalized linear model on the effects of 12h light disturbance (12LightSD) on next-day activity levels (bird ID as a random effect, and observations is the recording of active and inactive time within five minutes every half-hour from 6:00 to 17:30 of common mynas).

		12LightSD		
Predictors	*Estimates*	*Std. Error*	*z value*	*P*
(Intercept)	3.39	0.48	7.09	**<0.001**
TreatmentSD12h	-1.64	0.29	-5.71	**<0.001**
Observation	0.00	0.00	-6.52	**<0.001**
TreatmentSD12h:Observation	0.00	0.00	4.96	**<0.001**
Random Effects				
Birds Variance	0.74			
Birds Std.Dev.	0.86			
Observations	576.00			
Groups	Bird, 13			

Note：bold=p<0.05

3.3 Comparison of full night deprivation to full night light disturbance

In the fixed effects, it can be observed that the treatment effect estimate for full night sleep deprivation (12SD) is -3.85, with a p-value less than 0.001, indicating a significant negative impact of 12SD on the activity level of mynas. The treatment effect estimate for full night light disturbance (12Light SD) is -1.64, which also has statistical significance. Comparing the treatment effects under the two conditions, the effect of 12SD (-3.85) is stronger than that of 12Light SD (-1.64), suggesting that full night sleep deprivation has a more adverse effect on the activity level of birds than full night light disturbance (Table 3.1, Table 3.4).

3.4 Comparison of last 6h sleep deprivation to first 6h sleep deprivation

In the fixed effects analysis, the estimated treatment effect for the last 6 hours of sleep deprivation was -2.22, with a P-value of less than 0.001, indicating that Last6hSD has a significant negative impact on the activity levels of mynas. For the first 6 hours of sleep deprivation, the estimated treatment effect was -0.89, but with a P-value of 0.19, suggesting that the impact of First6hSD is not statistically significant. Comparing the treatment effects under the two conditions, the impact of Last6hSD (-2.22) was greater than First6hSD (-0.89). This suggests that sleep deprivation in the last part of the night has a greater effect on the activity levels of the birds (Table 3.2, Table 3.3).

3.5 Temporal Changes in Activity Proportion under Different Treatment Conditions

The variable 'Observation' represents the progression of time, and its estimated interaction effects with different treatments are all exceedingly small, rounded to about 0. When the p-values is notably small, it indicates that the varying times of observation can alter the magnitude of the treatment effect. Specifically, the time of observation has a significant moderating influence on the effect of the treatment (Table 3.1-3.4).

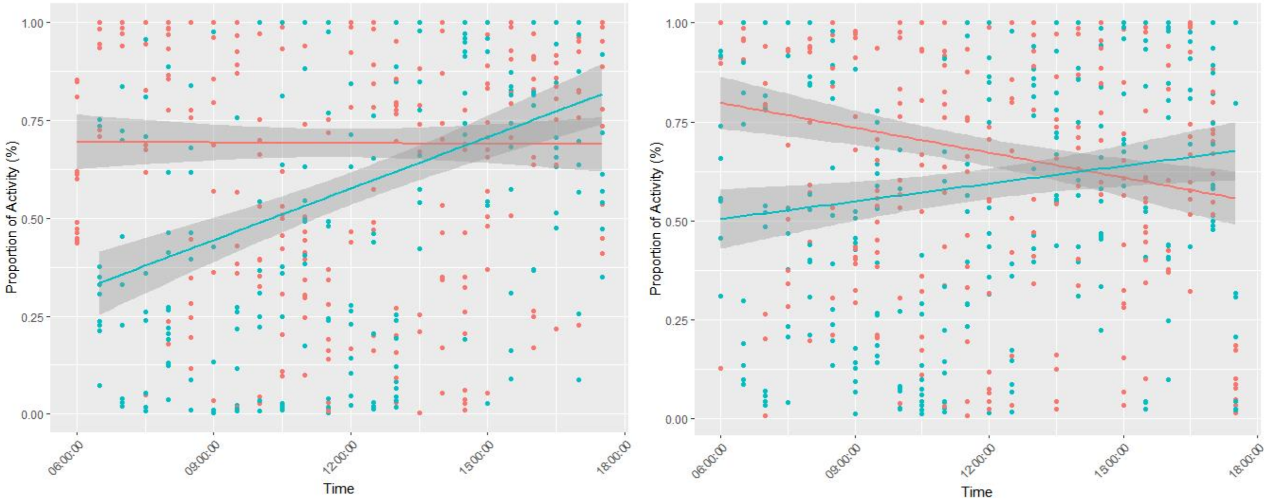
During the baseline periods, the birds generally maintained relatively stable activity throughout the entire day. However, in three of the four baseline periods, birds were slightly more active in the morning than the afternoon or evening (Table 3.1-3.4, Fig. 3.5) .

Birds subjected to overnight sleep deprivation (12SD) exhibited lower activity levels than the baseline earlier in the day. Activity increased throughout the day, birds were more active than in the baseline late in the evening (Table 3.1, Fig. 3.5a).

Birds subjected to sleep deprivation during the last half of the night (Last6SD) showed an upward trend in activity from morning to evening (Table 3.2, Fig. 3.5b).

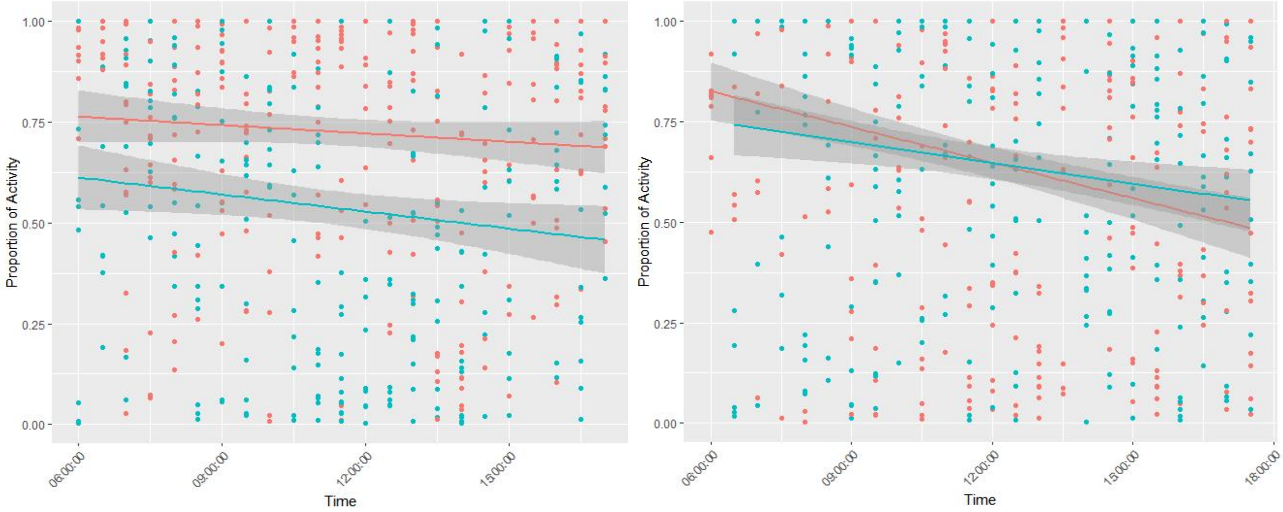
Conversely, birds subjected to sleep deprivation during the first half of the night (First6SD) exhibited a declining trend in activity from morning to evening (Table 3.3, Fig. 3.5c).

Notably, Birds exposed to overnight light disturbance (12LightSD) showed daytime activity levels that were not significantly different from the baseline day (Table 3.4, Fig. 3.5d).



a) 12SD

b) Last6SD



c) First6SD

d) 12LightSD

Figure 3.5. Interaction between treatment (Baseline: red, SD: green) and time and its effect on bird activity the next day. (a) Effects of 12 hours of sleep deprivation. (b) Effects of 6 hours sleep deprivation in the last half night. (c) Effects of 6 hours sleep deprivation in the first half night. (d) Effects of 12 hours light disturbance on sleep. The grey band indicates 95% confidence intervals.

By averaging the baselines across the four experiments and comparing it with different treatments (Fig. 3.6), it was found that 12 hours of sleep deprivation, deprivation of sleep for the last 6 hours of the night, and time had a very significant effect on the activity level the following day. Deprivation of sleep for the first 6 hours of the night had a highly significant effect on activity levels. Moreover, 12-hour sleep deprivation and 6-hour sleep deprivation in the last of the night both had significant interaction with time (Table 3.5).

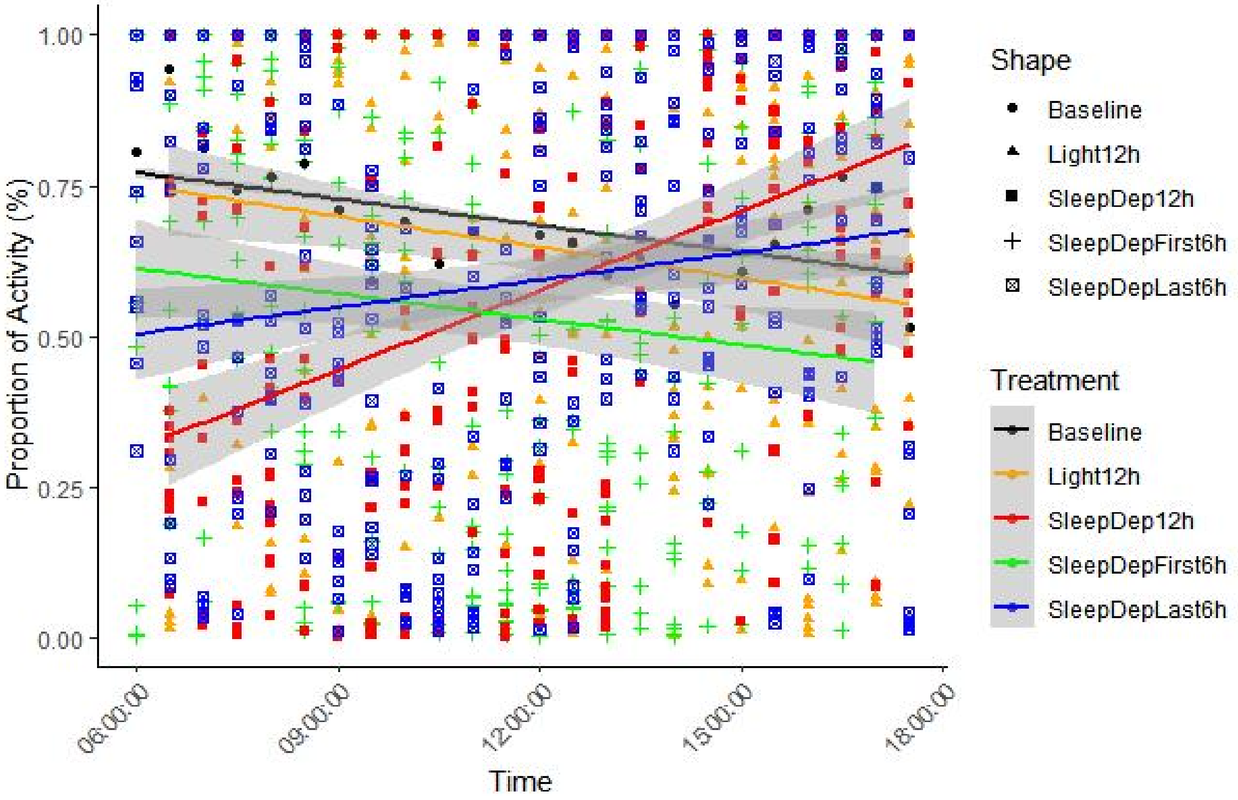


Figure 3.6. Effects of different treatments at night on bird activity the next day. Treatment represents different experimental treatments and baseline, and different shaped symbol scatter points represent the proportion of bird activity under specific treatment conditions. The Baseline here is the average of the Baseline in the four experiments. The grey band indicates 95% confidence intervals.

Table 3.5. Summary of the Linear mixed models of the effects of different night treatments on bird activity the next day relative to baseline group (Baseline is the average of Baseline in the four experiments here). Bird ID as random effect, and observation is the record of the active and inactive time during the first five minutes of every half hour between 6:00 and 17:30 in the daytime of mynas.

Predictors	*Estimates*	*Std. Error*	*df*	*t value*	*P*
(Intercept)	0.86	0.03	102.28	29.72	**<0.001**
TreatmentLight12h	-0.01	0.06	2281.02	-0.14	0.887
TreatmentSD12h	-0.81	0.06	2281.29	-13.53	**<0.001**
TreatmentSDFirst6h	-0.17	0.06	2281.21	-2.97	**0.003**
TreatmentSDLast6h	-0.45	0.05	2281.14	-8.23	**<0.001**
Observation	0.00	0.00	2281.05	-7.43	**<0.001**
TreatmentLight12h: Observation	0.00	0.00	2281.02	-0.50	0.621
TreatmentSD12h: Observation	0.00	0.00	2281.22	12.29	**<0.001**
TreatmentSDFirst6h: Observation	0.00	0.00	2281.17	0.25	0.805
TreatmentSDLast6h: Observation	0.00	0.00	2281.09	6.70	**<0.001**
Random Effects					
Residual Variance	0.06				
Residual Std.Dev.	0.24				
Birds Variance	0.00				
Birds Std.Dev.	0.06				
Observations	2303.00				
Groups	Bird,13				

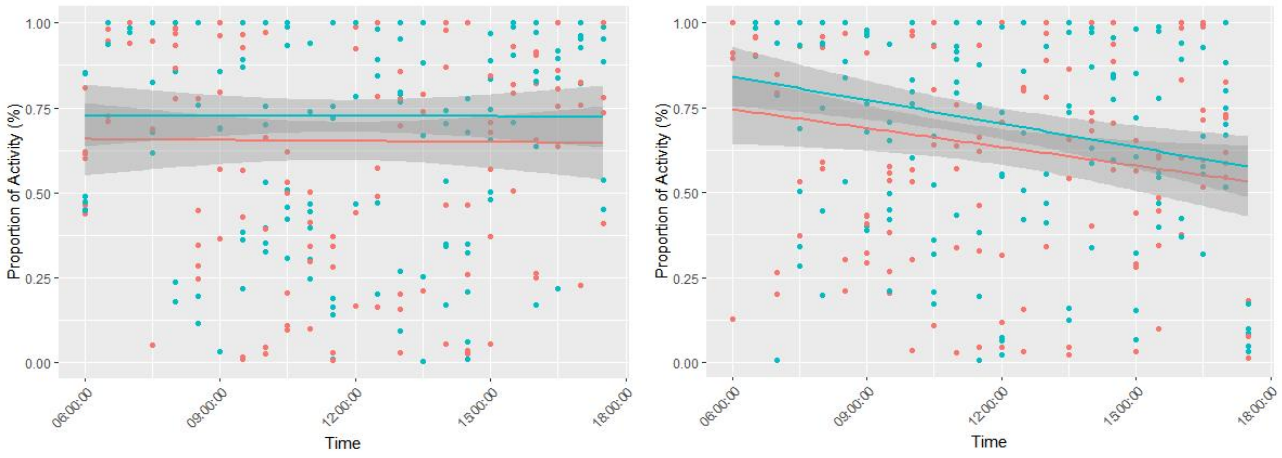
Note：bold=p<0.05

3.6 Does sex influence response to daytime activity

Incorporating the factor of sex, the differences in the performance of male and female common mynas within the baseline groups of the four experiments were compared separately (Fig. 3.7). Based on the observation of trend lines, although males may exhibit higher average activity levels during the same time period at baseline (Figure 3.7), these differences were not statistically significant in the final model (Table 3.6).

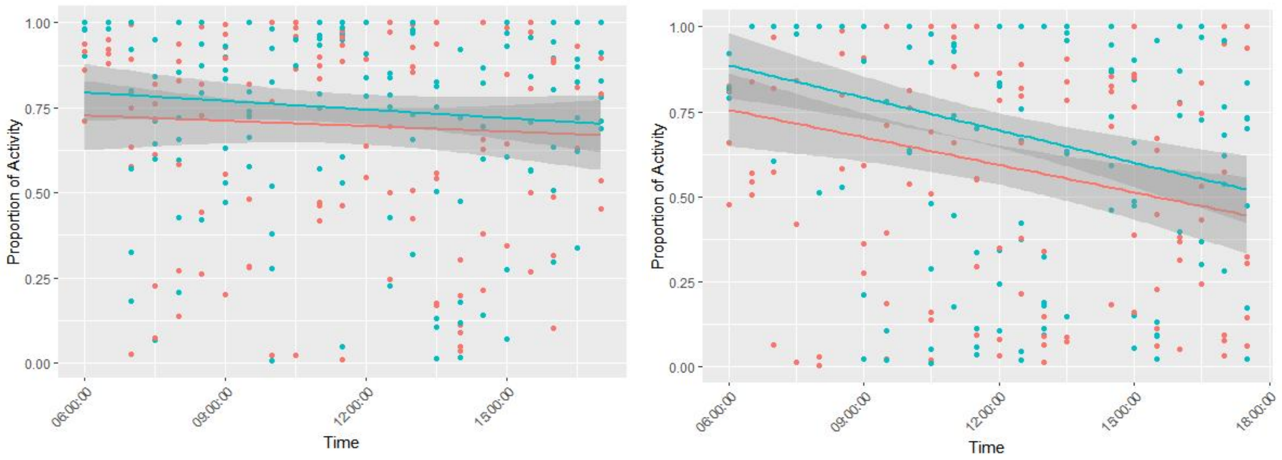
The trend lines for both females and males showed a general trend, but individual data points (scatter) were widely distributed across the graph, indicating significant individual variability. Further analysis on the impact of sex differences through the establishment of a linear mixed model and examining the removal of statistically non-significant effects revealed that sex had no significant impact on the outcomes (Table 3.6).

The importance of individual variation is illustrated by calculating the percentage of total variation of individual variation by using individual variance and residual error of random effects in the mode. The specific formula used was: Individual Variation Percentage = (Birds Variance / (Birds Variance + Residual Variance)) = 10%.



a) 12SD_Baseline

b) Last6SD_Baseline



c) First6SD_Baseline

d) 12LightSD_Baseline

Figure 3.7. Comparison of activity proportion of female (F: red) and male (M: blue) birds in Baseline group during different sleep deprivation/disturbance experiments. (a) Baseline for 12h sleep deprivation experiment. (b) Baseline for experiment of 6h sleep deprivation in the last half night. (c) Baseline for experiment of 6h sleep deprivation in the first half night. (d) Baseline for 12h light disturbance experiment. The grey band indicates 95% confidence intervals.

Table 3.6. Summary of the linear mixed model incorporating sex differences and various baseline day's activity levels of birds. Bird ID as a random effect, and observation is the record of the active and inactive time during the first five minutes of every half hour between 6:00 and 17:30 in the daytime of mynas.

Predictors	*Estimates*	*Std. Error*	*df*	*t value*	*Pr(>|t|)*
(Intercept)	0.64	0.08	226.77	8.18	<0.001
BaselineFirst6h	0.11	0.09	1188.05	1.26	0.208
BaselineLast6h	0.23	0.09	1188.03	2.52	**0.012**
BaselineLight	0.29	0.09	1188.03	3.23	**0.001**
Observation	0.00	0.00	1188.06	0.16	0.877
SexM	0.11	0.08	90.82	1.27	0.206
BaselineFirst6h: Observation	0.00	0.00	1188.01	-0.87	0.384
BaselineLast6h: Observation	0.00	0.00	1188.02	-2.92	**0.004**
BaselineLight: Observation	0.00	0.00	1188.01	-4.18	<0.001
BaselineFirst6h: SexM	-0.02	0.05	1188.13	-0.41	0.684
BaselineLast6h: SexM	0.00	0.05	1188.04	-0.05	0.962
BaselineLight: SexM	0.03	0.05	1188.06	0.65	0.516
Observation: SexM	0.00	0.00	1188.06	-0.58	0.560
Random Effects					
Residual Variance	0.09				
Residual Std.Dev.	0.30				
Birds Variance	0.01				
Birds Std.Dev.	0.09				
Observations	1201.00				
Groups	Bird,13				

Note：bold=p<0.05

4 Discussion

My study findings indicate that sleep deprivation from the previous night affects the daily activity levels of common mynas the following day, whether it is for 12 hours or 6 hours; the impact of 12 hours of sleep deprivation is greater than that of 6 hours on activity levels, with the effect of 6 hours of sleep deprivation during the latter half of the night being greater than that during the first half. And 12 hours of sleep disturbance due to light exposure has minimal impact on the next day's activity levels. Furthermore, sex differences do not have a significant impact on activity levels.

4.1 The impact of sleep deprivation on daytime activity in common mynas

The impact of total sleep deprivation in the previous night on avian daytime activity levels was large and in the direction predicted. Following a full night of sleep deprivation (12SD), common mynas exhibited a notable increase in daytime inactivity/resting behaviours. Similarly, whether deprived of sleep during the first half of the night (First6SD) or the latter half for 6 hours (Last6SD), common mynas also showed an increase in daytime inactivity on the subsequent day , but the effect was not as great as that of the whole night.

This finding is consistent with previous research on sleep deprivation in Australian magpies and common mynas, which showed that overnight sleep deprivation had greater effects on cognitive ability and singing performance than midnight sleep deprivation (Gaviraghi Mussoi, 2023; Johnsson et al., 2022). Our study further revealed that the longer duration of sleep deprivation also had a more significant effect on the daytime activity of birds, reflecting that the loss of sleep has an important impact on the daily behaviour patterns of birds, especially their rest and activity rhythms, and long-term sleep deprivation may lead to significant fatigue or stress responses. Similarly, studies on sleep deprivation in humans have also shown that prolonged sleep deprivation has a greater impact on daily behaviour (Orzeł-Gryglewska, 2010).

In addition, the effects of sleep deprivation not only persist, but may manifest differently at different times of the day, suggesting that the effects of sleep deprivation are dynamic. However, sleep deprivation in the middle of the night has different results depending on the time of day, and the effects of sleep deprivation also change over time.

4.2 Differential impact of sleep deprivation periods on daytime activity

When sleep deprivation occurs during the latter half of the night (Last6SD), there is a significant increase in daytime inactivity the following day, although the increase is not as pronounced as that resulting from the full-night sleep deprivation. When sleep deprivation occurs during the first half of the night (First6SD), there is also an increase in daytime inactivity the following day, but the effect was weak and not statistically detectable.

This result indicates that the timing of sleep deprivation may have differential impacts on avian daytime activity. Compared to Last6SD, First6SD has a lesser impact on daytime activity in birds. This could be related to different sleep architectures and physiological recovery processes. Different sleep stages exert distinct effects on sleep quality, with studies suggesting that the first half of the night may involve more deep sleep, dominated by slow-wave sleep (SWS) (Born & Diekelmann, 2010; Carskadon & Dement, 2010; Sullivan et al., 2022; Yordanova et al., 2010), which is particularly important for memory consolidation (Groch et al., 2015), physical repair (Born et al., 1988; Horne, 1979), energy conversion (Pastukhov, 2016), and growth hormone regulation (Born et al., 1988). In contrast, the latter half of the night is characterized by a predominance of REM sleep (Born & Diekelmann, 2010; Sullivan et al., 2022), which is beneficial for energy balance (Horne, 2009) and the restoration and optimization of brain functions (He et al., 2011; Kim et al., 2005; Shaffery et al., 2002; Yordanova et al., 2010).

A study measured and compared the physical activity of men who slept for four hours during the first half of the night, the latter half of the night, and those who had a normal eight hours of sleep, found that reduced sleep duration inherently increases the sensation of fatigue. However, despite equal durations of sleep, the impact on physical activity and subjective fatigue is greater following late-night sleep loss compared to early-night sleep restrictions (Wilms et al., 2020). A Meta-analytical review on human sleep insufficiency also conclude that sleep deprivation affects physical performance, particularly full sleep deprivation and late sleep restriction (early awakening) have a more significant negative impact on the next day's physical activity compared to early sleep restriction (delayed sleep) (Craven et al., 2022). These findings align with our experimental results, where the impact of acute sleep insufficiency is more pronounced following deprivation in the latter half of the night.

4.3 Comparison between anthropogenic disturbance and light interference

Compared with sleep deprivation at night by anthropogenic activities, light interference with overnight sleep (12LightSD) appeared to have a limited effect on daytime activity in common mynas. Unlike the significant increase in inactivity the next day after 12 hours of sleep deprivation or 6 hours of sleep deprivation, the negligible increase in inactivity after light disturbance suggests that light disturbance may not affect birds' sleep as severely as other human disturbances.

Nonetheless, the sensitivity of the biological clock to light exposure cannot be overlooked. Natural lighting plays a crucial role in regulating our circadian rhythms, controlling the cycles of sleep and wakefulness, and dictating the rhythmic behaviours of both plants and animals (Allard, 1930; Dominoni, 2015; Hopkins et al., 2018; Russart & Nelson, 2018). For birds, lighting is a significant trigger for singing, with many species initiating their calls at dawn (Allard, 1930; Allen, 1913; Miller, 2006; Wright, 1912). However, singing may be delayed on cloudy mornings (Bruni et al., 2014; Da Silva et al., 2014; Nordt & Klenke, 2013), while a bright moon can lead to earlier calling (Bruni et al., 2014; Leopold & Eynon, 1961; Wright, 1913; York et al., 2014). Miller recorded and compared the dawn chorus of American Robins (*Turdus migratorius*) under different intensities of artificial nighttime light, finding that robins in areas with substantial artificial light begin their morning singing during the night, and both he and Nordt suggest that nighttime clouds and mist seem to amplify the effects of artificial light, prompting birds to start singing earlier in a brighter environment (Miller, 2006; Nordt & Klenke, 2013). However, artificial light at night not only advances dawn chorusing but also delays nocturnal activities in birds. Observing the slender-billed nuthatch (*Sitta carolinensis aculeata*) in California in 1928, Blake found that the time of sunset and the birds' return to their nests for rest were correlated, suggesting that light interference could likely delay the nocturnal rest of birds (Blake, 1928). Observations of urban blackbirds (*Turdus merula*) living under varying intensities of light exposure revealed that individuals in higher light conditions engaged in longer nocturnal foraging times, according to Anja et al. (Russ et al., 2015). Domoni and Partecke, using light loggers and radio telemetry on European blackbirds (*Turdus merula*) in the wild, discovered that those living in light-polluted areas showed longer activity periods and more unstable circadian rhythms compared to their forest-dwelling counterparts (Dominoni & Partecke, 2015). In Norway, where winter days are short, it has been recorded that some passerine birds even extend their diurnal activity time by 4-5 hours due to artificial light (Byrkjedal et al., 2012).

In previous research from this same set of experiments, the effects of light on specific active behaviours were examined, specifically singing. After one night of light exposure, the common mynas sang less and called more compared to baseline. Not much different from the baseline day, except that songs were output slightly less in the morning and late afternoon, and calls were output a little more in the morning. In this study, the activity of mynas recorded after a night of light exposure did not differ much from that recorded on the baseline day and was slightly lower the next morning. This may be attributed to urban birds having developed a certain degree of adaptation to nocturnal light exposure, which could be physiological or behavioural, thereby reducing their sensitivity to light disturbance and minimizing the impact on their daytime behavioural rhythms. Bird behaviour is influenced by their ecological environment. In certain settings, birds may have evolved strategies to cope with changes in light exposure, thus mitigating the impact of illumination on their nocturnal sleep. Silva and Kempenaers examined how natural and artificial light influences the dawn singing behaviour of birds across different latitudes in Europe (under varying natural lighting conditions), as suggested by some other studies, different bird species exhibit varying levels of light sensitivity and adaptive behaviours (Berg et al., 2006; McNeil et al., 2005; Thomas et al., 2004; Thomas et al., 2002), leading to diverse responses to illumination (Da Silva & Kempenaers, 2017). Some early-singing species that are sensitive to light might become more active due to artificial light being brighter at night than at their singing onset, while late-singing birds with lower light sensitivity maintain their singing rhythms (Da Silva & Kempenaers, 2017). However, in high-latitude regions like Finland, where natural sunrise already occurs early, the local songbirds have adapted to this environment and might not start their dawn chorus earlier under artificial nighttime lighting, as they require time for rest (Da Silva & Kempenaers, 2017; Mace, 1989). According to the results of this experiment, I speculate that as a common urban bird, the light sensitivity of common myna is not particularly high.

Furthermore, the impact of artificial light at night (ALAN) on avian behaviour also depends on the intensity, duration, and period of the illumination. Da Silva et al. investigated the effects of artificial nighttime lighting and daytime traffic noise on the singing behaviour of six common European songbird species, finding that with higher artificial light intensities, birds start their dawn chorus earlier and the dusk chorus lasts longer (Da Silva et al., 2014). During the breeding season, common swifts (*Apus apus*) exposed to moderate (0.83 lx) and relatively high (3.85 lx) artificial light conditions show a slight extension in their nocturnal activities, but under very intense artificial light levels (120 lx), they may remain active throughout the entire night (Amichai & Kronfeld-Schor, 2019). Studies in laboratory settings on great tits (*Parus major*) further corroborate this: under varying nighttime light intensities, great tits exposed to high light intensity conditions not only start their daily activities earlier but also experience a reduction in nocturnal melatonin levels, potentially leading to sleep disturbances and alterations in sleep patterns, making them more active throughout the night (de Jong et al., 2016). In our laboratory, the lighting setup was not very intense detection lights but simulated natural lighting, suggesting that the observed results may be partially due to the intensity of the lighting.

The work of Dominoni et al. focused on how artificial nocturnal light and noise affect the daily activity patterns of adult male European blackbirds (*Turdus merula*) in urban environments. They found that, compared to rural areas or forests, blackbirds living in cities start their daily activities significantly earlier when exposed to higher levels of artificial light at night (Dominoni et al., 2013), whereas noise did not have a significant impact on the activity patterns of these birds (Dominoni et al., 2014). Marín Gómez's research on the early calling behaviour of the Saffron Finch (*Sicalis flaveol*a) in Colombia demonstrated that the advancement of dawn singing in birds was only related to nocturnal artificial light and not to human-made noise (Marín Gómez, 2022). Similarly, Da Silva et al.'s investigation of the singing times of six common songbird species revealed that artificial light, rather than noise, leads to earlier dawn singing and extended dusk singing times (Da Silva et al., 2014). In contrast, Nordt and Klenke's survey of dawn chorus in European urban blackbirds yielded a different conclusion, finding that both artificial night light and traffic noise significantly advance birds' singing times, but traffic noise was considered to be a more dominant influence (Nordt & Klenke, 2013).

Compared to these field studies in the wild, the records from our laboratory provided different results, where anthropogenic (noise) influences seem to cause more severe disruption to nocturnal sleep in birds, while light interference throughout the night has almost no significant effect on the overall daytime activity of common mynas the following day. As we mentioned above, it is not surprising that anthropogenic noise disturbances lead to greater impact on birds compared to light disturbances (Fuller et al., 2007), possibly due to differences in our experimental environment, bird species, or the conditions of disturbance. Obviously, in our experiments, ordinary light disturbance may not affect the sleep quality of birds as severely as other anthropogenic activities, which (such as sound disturbance) directly lead to birds waking up more frequently or experiencing sleep interruptions, whereas mere light disturbance does not elicit such intense stress responses. Moreover, birds in the laboratory had ample food sources, unlike birds in the wild, where nighttime artificial light may increase the likelihood of predation and being preyed upon (Leveau, 2020; Miles et al., 2013; Russ et al., 2015; Stracey et al., 2014), leading them to be more nocturnally active. Of course, in the free environment of the wild, birds can easily fly away from light sources or anthropogenic noise disturbances, but in urban environments, this may be difficult to avoid (de Jong et al., 2016).

4.4 Change in daily activity patterns under different treatment conditions

During the baseline periods of the four experiments, our study subjects, common mynas, generally exhibited a relatively stable level of activity throughout the day, with slightly higher activity levels in the morning and the lowest in the evening. This pattern reflects their natural diurnal behavioural rhythms, particularly in terms of foraging and social activities. The increase in morning activity is often associated with foraging behaviour, as many birds choose to forage in the early morning (Diallo et al., 2023; Kendall, 2014; Kersten et al., 1991). At the same time, morning song is an important activity for songbirds at dawn, serving not only to mark territory but also potentially to attract mates or strengthen social bonds within the group through vocal communication (Foote et al., 2011; Moller, 1991).

Common mynas experiencing full-night sleep deprivation (12SD) displayed significantly lower activity levels in the morning compared to the baseline, but subsequently showed a significant increase, especially with higher activity levels at nightfall above baseline. This could be due to initial fatigue caused by sleep deprivation, resulting in lower morning activity. As the day progresses, birds began to become progressively more active after getting some rest, engaging in foraging and social activities at dusk.

After experiencing sleep deprivation in the latter half of the night (Last 6SD), birds also showed an upward trend in daytime activity levels contrary to the baseline, but the overall trend was slower than that of activity after a full night sleep deprivation. This suggests that the longer the duration of sleep deprivation, the greater the impact on the birds' behaviour the following day. The loss of sleep in the latter half of the night resulted in lower morning activity levels for the birds. As the day progressed, the birds might regulated for their physiological state by increasing their activity, similarly reaching higher activity levels at dusk.

Conversely, after the first half of the night sleep deprivation (First 6SD), birds showed the same downward trend in daytime activity as at baseline. However, though they followed the same pattern of activity, they showed lower activity levels overall. This may indicate that sleep in the first half of the night is more crucial for maintaining the avian activity levels and energy for the following day. Losing sleep in the first half of the night resulted in the birds feeling fatigued throughout the entire day, with their overall activity levels being lower than the baseline. Birds that have been disturbed by sleep deprivation during the first half of the night may continue to maintain a vigilant wakefulness, becoming increasingly fatigued and drowsy by the following day, which leads to a persistent decline in their activity levels throughout the entire day.

In our study, the impact of all-night light disturbance (12Light SD) on the daytime activity levels of common mynas the following day appears to be limited, similar to the trend line of activity on the baseline day. Although light disturbance had some effect on the sleep of birds, this interference may not have been sufficient to significantly alter their daytime activity patterns. Similar observations have been made in other studies, such as monitoring great tits (*Parus major*) in the wild active under artificial lighting at night, showing that frequent nocturnal activity may not necessarily lead to reduced their daytime activity, but there is also an accumulation of sleep debt (Ouyang et al., 2017) . Likewise, investigations into breeding female great tits (*Parus major*) found that they would sleep more the following night to compensate for sleep loss due to the previous night's disturbances (Raap et al., 2016). While studies have generally claimed that nocturnal lighting leads to earlier waking in birds (Dominoni et al., 2014; Marín Gómez, 2022). In fact, our results show the opposite pattern. Perhaps because of the difference between the laboratory and the field experiment, the birds in the field can feel the sky getting dark, but there is light, and the birds in our laboratory do not receive the same signal, and the lights are always on at night. I speculate that common mynas disturbed by all night lighting had prolonged nocturnal activities (Ouyang et al., 2017), affecting behaviours like singing and foraging (Sanders et al., 2021). Increased nocturnal activity caused their morning activity levels the following day being slightly lower than normal, possibly because the increased nocturnal activity led to greater energy expenditure, so they needed more rest time to recover.

4.5 Sex differences in activity

Males and females often employ different behavioural strategies to maxmise reproductive success such as differences in foraging, territorial defense, or breeding behaviour in different seasons, with male birds possibly displaying higher activity levels due to these behaviours (Steinmeyer et al., 2010). Though there appeared to be a trend for males to be more active than females in our study, this was not a statistical difference. This lack of sex difference is in contrast to previous research in other species. Investigations into blue tits (*Cyanistes caeruleus)* have found that there are sex differences in bird sleep behaviour, with males sleeping later and waking earlier than females (Steinmeyer et al., 2010). Related studies observing blackbirds (*Turdus merula*) and great tits (*Parus major*) found that male birds are more sensitive to artificial light and noise conditions than females (Grunst et al., 2023; Russ et al., 2015). Male birds, compared to females, may delay waking in noisy environments, whereas they wake up earlier and leave the nest in quieter territories (Grunst et al., 2023). However, there are other research indicates that both male and female birds may choose to leave the nest box earlier to avoid noise disturbances in the morning (Grunst et al., 2021). These different conclusions may vary according to the life history stages of the bird and seasonal fluctuations of environmental variables (Grunst et al., 2023).

While trend lines show a general tendency, the widespread distribution of data points across the graph suggests that there are individual variability. The percentage of individual variation is calculated at 10%, which means that differences between individual birds (all individual differences including sex, age, and health status) account for only 10% of the total variation, and most of the variation may be caused by a variety of other factors, including experimental treatment conditions, environmental factors, and so on. The presence of individual variation points to the fact that, although sex is an important biological variable, it is not the not the only determinant of avian behaviour.

Further analysis through the construction of linear mixed models to assess the impact of sex differences revealed that, after statistically removing insignificant effects, sex does not significantly influence the diurnal activity levels of common mynas. This suggests that under the conditions of sleep interference examined in this study, sex may not be a primary factor affecting the diurnal activity levels of common mynas. This finding is consistent with observed individual differences and underscores the need to consider a variety of interacting factors when analyzing avian behaviour.

4.6 Biological significance of the experiment

These findings are crucial for understanding the biological significance of avian sleep patterns. They reveal the importance of sleep quality on daytime behaviour in birds, particularly in terms of stress response. This could have significant implications for the survival strategies and adaptive behaviours of wild birds, especially in the face of environmental disturbances (such as human activities and light pollution). Investigations into avian sleep behaviour provide a prototypical example of the harm caused by human activity disturbances and the alteration of circadian rhythms in urban areas to wildlife, serving as a cautionary tale for humanity.

4.7 Research limitations and future directions

Although this study provides important insights, there are still some limitations. For instance, there is personal subjectivity in human judgment in recording bird behaviour, sometimes it is difficult to distinguish; the experimental conditions lack the diversity, complexity, and dynamism of natural environments, clearly unable to fully simulate the sleep patterns of birds in the wild; and the sample size may also limit the understanding of broader sex differences; as a common urban bird, the common myna may have some immunity to light or noise disturbances in cities.

4.8 Conclusion

This study investigates the effects of sleep deprivation and disturbances from the previous night on the daily behavioural activity levels of birds the following day, as well as the manifestation of sex differences in activity levels.

I found that sleep deprivation reduces bird activity levels, whether it be total night deprivation of 12 hours or partial deprivation of 6 hours during either the first or last half of the night. As anticipated, the negative impact of 12 hours of sleep deprivation was stronger than that of 6 hours. Specifically, prolonged sleep loss resulted in common mynas being more fatigued the next day, spending more time resting or sleeping. Although the duration of sleep deprivation was the same, sleep deprivation in the latter half of the night had a greater impact on daily behaviour than deprivation in the first half, which may relate to the distribution of different sleep stages during these periods. Studies suggest that the first half of the night contains more deep sleep, with slow-wave sleep (SWS) dominating, while the latter half favors REM sleep (Born & Diekelmann, 2010; Sullivan et al., 2022). Sleep deprivation causes changes in sleep architecture and biological functions, likely affecting the physiological recovery processes in birds. Experiments on human sleep deprivation have similarly confirmed that sleep insufficiency impacts physical performance, with total sleep deprivation and late sleep restriction having a greater negative effect on physical activity than early sleep restriction (Craven et al., 2022; Wilms et al., 2020). Furthermore, although many birds typically exhibit sex-specific differences in daily behaviour and sleep (Grunst et al., 2023; Russ et al., 2015; Steinmeyer et al., 2010), sex differences did not show significance in our sleep deprivation experiment. This may be due to individual variability among birds in different environments and periods, possessing different behavioural strategies.

Future research could integrate electrophysiology, using electroencephalography (EEG) or related instruments to more precisely track and record avian sleep or activity states, with particular attention to the recovery period following sleep deprivation or disturbance. This includes investigating changes in the intensity, distribution, and duration of REM sleep and SWS, to explore the deeper physiological impacts of sleep loss on birds. Subsequent studies should expand sample sizes and consider more environmental factors to further investigate the responses of different bird species during breeding and non-breeding seasons to sleep deficiency. Additionally, in our laboratory studies, birds living in captivity obviously lead lifestyles distinctly different from those of their wild counterparts, suggesting future research might validate our results in natural settings. Our study subjects, common mynas, as urban birds, may have already adapted to human and light disturbances. Future research could select the same species from urban and rural areas to compare whether birds from different regions exhibit different behavioural responses under the same experimental conditions. Moreover, our experiment was limited to a single night of sleep deprivation or disturbance; however, understanding the long-term impact of sleep quality on avian physiological health, physical performance, and behavioural strategies is crucial for better protecting disturbed wildlife species. Whether birds develop certain adaptabilities when exposed to disturbances over the long term should also be considered in future work.

References:

Alhola, P., & Polo-Kantola, P. (2007). Sleep deprivation: Impact on cognitive performance. *Neuropsychiatric Disease and Treatment*, 3(5), 553-567.

Ali, S., & Ripley, S. D. (1972). *Handbook of the birds of India & Pakistan (Vol. 5)*. Bombay, India: Oxford University Press.

Allard, H. A. (1930). The First Morning Song of Some Birds of Washington, D. C.; Its Relation to Light. *The American Naturalist*, 64(694), 436-469. http://doi.org/10.1086/280329

Allen, F. H. (1913). More Notes on the Morning Awakening. *The Auk*, 30(2), 229-235. http://doi.org/10.2307/4071548

Aly, M., & Moscovitch, M. (2010). The effects of sleep on episodic memory in older and younger adults. *Memory (Hove)*, 18(3), 327-334. http://doi.org/10.1080/09658211003601548

Amichai, E., & Kronfeld-Schor, N. (2019). Artificial Light at Night Promotes Activity Throughout the Night in Nesting Common Swifts (*Apus apus*). *Scientific Reports*, 9(1), 11052-11058. http://doi.org/10.1038/s41598-019-47544-3

Amidi, A., Wu, L. M., Buskbjerg, C. R., & Zachariae, B. (2023). The importance of sleep in memory, learning, and other cognitive functions. *Ugeskrift for Læger*, 185(26)

Amrhein, V., Kunc, H. P., & Naguib, M. (2004). Non – territorial nightingales prospect territories during the dawn chorus. *Proceedings of the Royal Society. B, Biological Sciences*, 271(Suppl 4), S167-S169. http://doi.org/10.1098/rsbl.2003.0133

Amrhein, V., & Erne, N. (2006). Dawn singing reflects past territorial challenges in the winter wren. *Animal Behaviour*, 71(5), 1075-1080. http://doi.org/10.1016/j.anbehav.2005.07.023

Andersen, M. L., Antunes, I. B., Silva, A., Alvarenga, T. A. F., Baracat, E. C., & Tufik, S. (2008). Effects of sleep loss on sleep architecture in Wistar rats: Gender-specific rebound sleep. *Progress in Neuro-Psychopharmacology & Biological Psychiatry*, 32(4), 975-983. http://doi.org/10.1016/j.pnpbp.2008.01.007

Aserinsky, E., & Kleitman, N. (2003). Regularly occurring periods of eye motility, and concomitant phenomena, during sleep. *The Journal of Neuropsychiatry and Clinical Neurosciences*, 15(4), 454-455. http://doi.org/10.1176/appi.neuropsych.15.4.454

Aulsebrook, A. E., Connelly, F., Johnsson, R. D., Jones, T. M., Mulder, R. A., Hall, M. L., Vyssotski, A. L., & Lesku, J. A. (2020). White and Amber Light at Night Disrupt Sleep Physiology in Birds. *Current Biology*, 30(18), 3657-3663. http://doi.org/10.1016/j.cub.2020.06.085

Aulsebrook, A. E., Jones, T. M., Rattenborg, N. C., Roth, T. C., & Lesku, J. A. (2016). Sleep Ecophysiology: Integrating Neuroscience and Ecology. *Trends in Ecology & Evolution (Amsterdam)*, 31(8), 590-599. http://doi.org/10.1016/j.tree.2016.05.004

Banks, S., & Dinges, D. F. (2007). Behavioral and physiological consequences of sleep restriction. *Journal of Clinical Sleep Medicine : Jcsm : Official Publication of the American Academy of Sleep Medicine*, 3(5), 519–528. https://doi.org/10.5664/jcsm.26918

Beesley, A., Whibley, A., Santure, A. W., & Battles, H. T. (2023). The introduction and distribution history of the common myna (*Acridotheres tristis*) in New Zealand. *New Zealand Journal of Zoology*, 50(4), 497-509. http://doi.org/10.1080/03014223.2023.2182332

Benedict, C., Brooks, S. J., O'Daly, O. G., Almèn, M. S., Morell, A., Åberg, K., Gingnell, M., Schultes, B., Hallschmid, M., Broman, J., Larsson, E., & Schiöth, H. B. (2012). Acute Sleep Deprivation Enhances the Brain's Response to Hedonic Food Stimuli: An fMRI Study. *The Journal of Clinical Endocrinology and Metabolism*, 97(3), E443-E447. http://doi.org/10.1210/jc.2011-2759

Berg, K. S., Brumfield, R. T., & Apanius, V. (2006). Phylogenetic and ecological determinants of the neotropical dawn chorus. *Proceedings of the Royal Society. B, Biological Sciences*, 273(1589), 999-1005. http://doi.org/10.1098/rspb.2005.3410

Beyaert, L., Greggers, U., & Menzel, R. (2012). Honeybees consolidate navigation memory during Sleep. *Journal of Experimental Biology*, 215(22), 3981-3988. http://doi.org/10.1242/jeb.075499

Blake, S. F. (1928). Field Notes on Certain California Birds. *The Condor*, 30(4), 249-250. http://doi.org/10.1093/condor/30.4.249

Blumberg, M. S., Lesku, J. A., Libourel, P., Schmidt, M. H., & Rattenborg, N. C. (2020). What Is REM Sleep? *Current Biology*, 30(1), R38-R49. http://doi.org/10.1016/j.cub.2019.11.045

Bobbo, D., Galvani, F., Mascetti, G. G., & Vallortigara, G. (2002). Light exposure of the chick embryo influences monocular sleep. *Behavioural Brain Research*, 134(1), 447-466. http://doi.org/10.1016/S0166-4328(02)00059-1

Bobbo, D., Nelini, C., & Mascetti, G. G. (2008). Binocular and monocular/unihemispheric sleep in the domestic chick (*Gallus gallus*) after a moderate sleep deprivation. *Experimental Brain Research*, 185(3), 421-427. http://doi.org/10.1007/s00221-007-1165-z

Boerema, A. S., Riedstra, B., & Strijkstra, A. M. (2003). Decrease in Monocular Sleep After Sleep Deprivation in the Domestic Chicken. *Behaviour*, 140(11-12), 1415-1420. http://doi.org/10.1163/156853903771980657

Born, J., Muth, S., & Fehm, H. L. (1988). The significance of sleep onset and slow wave sleep for nocturnal release of growth hormone (GH) and cortisol. *Psychoneuroendocrinology*, 13(3), 233-243. http://doi.org/10.1016/0306-4530(88)90021-2

Born, J., & Diekelmann, S. (2010). The memory function of sleep. *Nature Reviews. Neuroscience*, 11(2), 114-126. http://doi.org/10.1038/nrn2762

Bruni, A., Mennill, D. J., & Foote, J. R. (2014). Dawn chorus start time variation in a temperate bird community: relationships with seasonality, weather, and ambient light. *Journal of Ornithology*, 155(4), 877-890. http://doi.org/10.1007/s10336-014-1071-7

Byrkjedal, I., Lislevand, T., & Vogler, S. (2012). Do passerine birds utilise artificial light to prolong their diurnal activity during winter at northern latitudes? *Ornis Norvegica*, 35, 37-42. http://doi.org/10.15845/on.v35i0.269

Campbell, S. S., & Tobler, I. (1984). Animal sleep: A review of sleep duration across phylogeny. *Neuroscience and Biobehavioral Reviews*, 8(3), 269-300. http://doi.org/10.1016/0149-7634(84)90054-X

Carskadon, M. A., & Dement, W. C. (2010). Normal Human Sleep: An Overview *Principles and Practice of Sleep Medicine* (Fifth Editioned., Vol. 16-26). http://doi.org/10.1016/B978-1-4160-6645-3.00002-5.

Cassada, R. C., & Russell, R. L. (1975). The dauerlarva, a post-embryonic developmental variant of the nematode *Caenorhabditis elegans*. *Developmental Biology*, 46(2), 326-342. http://doi.org/10.1016/0012-1606(75)90109-8

Cochran, W. W., & Graber, R. R. (1958). Attraction of Nocturnal Migrants by Lights on a Television Tower. *The Wilson Bulletin (Wilson Ornithological Society)*, 70(4), 378-380.

Connelly, F., Johnsson, R. D., Aulsebrook, A. E., Mulder, R. A., Hall, M. L., Vyssotski, A. L., & Lesku, J. A. (2020). Urban noise restricts, fragments, and lightens sleep in Australian magpies. *Environmental Pollution*, 267, 115484. http://doi.org/https://doi.org/10.1016/j.envpol.2020.115484

Corsi-Cabrera, M. X., A, Isabel Sánchez, A., Del-Rı, X., O-Portilla, Y., Villanueva, Y., & Pérez-Garci, E. (2003). Effect of 38 h of total sleep deprivation on the waking EEG in women: sex differences. *International Journal of Psychophysiology*, 50(3), 213-224. http://doi.org/10.1016/S0167-8760(03)00168-5

Craig, A., Feare, C., Croucher, B., & Shields, C. (1998). *Starlings and Mynas*. Bloomsbury Publishing Plc.

Craven, J., McCartney, D., Desbrow, B., Sabapathy, S., Bellinger, P., Roberts, L., & Irwin, C. (2022). Effects of Acute Sleep Loss on Physical Performance: A Systematic and Meta-Analytical Review. *Sports Medicine (Auckland)*, 52(11), 2669-2690. http://doi.org/10.1007/s40279-022-01706-y

Cusa, M., Jackson, D. A., & Mesure, M. (2015). Window collisions by migratory bird species: urban geographical patterns and habitat associations. *Urban Ecosystems*, 18(4), 1427-1446. http://doi.org/10.1007/s11252-015-0459-3

Da Silva, A., Samplonius, J. M., Schlicht, E., Valcu, M., & Kempenaers, B. (2014). Artificial night lighting rather than traffic noise affects the daily timing of dawn and dusk singing in common European songbirds. *Behavioral Ecology*, 25(5), 1037-1047. http://doi.org/10.1093/beheco/aru103

Da Silva, A., Valcu, M., & Kempenaers, B. (2016). Behavioural plasticity in the onset of dawn song under intermittent experimental night lighting. *Animal Behaviour*, 117, 155-165. http://doi.org/10.1016/j.anbehav.2016.05.001

Da Silva, A., & Kempenaers, B. (2017). Singing from North to South: Latitudinal variation in timing of dawn singing under natural and artificial light conditions. *The Journal of Animal Ecology*, 86(6), 1286-1297. http://doi.org/10.1111/1365-2656.12739

Davidson, A. J., & Menaker, M. (2003). Birds of a feather clock together – sometimes: social synchronization of circadian rhythms. *Current Opinion in Neurobiology*, 13(6), 765-769. http://doi.org/10.1016/j.conb.2003.10.011

Dawson, A., King, V. M., Bentley, G. E., & Ball, G. F. (2001). Photoperiodic Control of Seasonality in Birds. *Journal of Biological Rhythms*, 16(4), 365-380. http://doi.org/10.1177/074873001129002079

Day, R. H., Rose, J. R., Prichard, A. K., & Streever, B. (2015). Effects of Gas Flaring on the Behavior of Night-Migrating Birds at an Artificial Oil-Production Island, Arctic Alaska. *Arctic*, 68(3), 367-379. http://doi.org/10.14430/arctic4507

de Jong, M., Jeninga, L., Ouyang, J. Q., van Oers, K., Spoelstra, K., & Visser, M. E. (2016). Dose-dependent responses of avian daily rhythms to artificial light at night. *Physiology & Behavior*, 155, 172-179. http://doi.org/10.1016/j.physbeh.2015.12.012

Diallo, A. Y., Piersma, T., Van Eerden, A. O. K., Ndiaye, S., & Ndiaye, P. I. (2023). Seasonal Occurrence and Daytime Behaviour of Eurasian Spoonbills *Platalea leucorodia leucorodia* in Senegal's Atlantic Coastal Areas. *Waterbirds (De Leon Springs, Fla.)*, 45(2), 199-205. http://doi.org/10.1675/063.045.0210

Dinges, D. F., Pack, F., Williams, K., Gillen, K. A., Powell, J. W., Ott, G. E., Aptowicz, C., & Pack, A. I. (1997). Cumulative sleepiness, mood disturbance, and psychomotor vigilance performance decrements during a week of sleep restricted to 4-5 hours per night. *Sleep (New York, N.Y.)*, 20(4), 267-277. http://doi.org/10.1093/sleep/20.4.267

Dominoni, D. M. (2015). Effects of light pollution on biological rhythms of birds: an integrated, mechanistic perspective. *Journal of Ornithology*, 156(Suppl 1), 409-418. http://doi.org/10.1007/s10336-015-1196-3

Dominoni, D. M., Carmona Wagner, E. O., Hofmann, M., Kranstauber, B., Partecke, J., & Verhulst, S. (2014). Individual-based measurements of light intensity provide new insights into the effects of artificial light at night on daily rhythms of urban-dwelling songbirds. *The Journal of Animal Ecology*, 83(3), 681-692. http://doi.org/10.1111/1365-2656.12150

Dominoni, D. M., Helm, B., Lehmann, M., Dowse, H. B., & Partecke, J. (2013). Clocks for the city: circadian differences between forest and city songbirds. *Proceedings of the Royal Society B: Biological Sciences*, 280(1763), 20130593. http://doi.org/10.1098/rspb.2013.0593

Dominoni, D. M., & Partecke, J. (2015). Does light pollution alter daylength? A test using light loggers on free-ranging European blackbirds (*Turdus merula*). *Philosophical Transactions of the Royal Society B: Biological Sciences*, 370(1667), 20140118. http://doi.org/10.1098/rstb.2014.0118

Dominoni, D., Quetting, M., & Partecke, J. (2013). Artificial light at night advances avian reproductive physiology. *Proceedings of the Royal Society. B, Biological Sciences*, 280(1756), 20123017. http://doi.org/10.1098/rspb.2012.3017

Doppler, M. S., Blackwell, B. F., DeVault, T. L., & Fernández-Juricic, E. (2015). Cowbird responses to aircraft with lights tuned to their eyes: Implications for bird ‐ aircraft collisions. *The Condor (Los Angeles, Calif.)*, 117(2), 165-177. http://doi.org/10.1650/CONDOR-14-157.1

Dutfield, S. (2023). How marine animals sleep: The ways whales, sharks and other sea creatures get a good night's sleep.

How It Works Magazine(177), 42.

Ewart, K. M., Griffin, A. S., Johnson, R. N., Kark, S., Magory Cohen, T., Lo, N., & Major, R. E. (2019). Two speed invasion: assisted and intrinsic dispersal of common mynas over 150 years of colonization. *Journal of Biogeography*, 46(1), 45-57. http://doi.org/10.1111/jbi.13473

Fischer, J. H., Debski, I., Taylor, G. A., & Wittmer, H. U. (2021). Consistent offshore artificial light at night near the last breeding colony of a critically endangered seabird. *Conservation Science and Practice*, 3(9). http://doi.org/10.1111/csp2.481

Foote, J. R., Fitzsimmons, L. P., Mennill, D. J., & Ratcliffe, L. M. (2011). Male black-capped chickadees begin dawn chorusing earlier in response to simulated territorial insertions. *Animal Behaviour*, 81(4), 871-877. http://doi.org/10.1016/j.anbehav.2011.01.028

Frank, K. D. (1988). Impact of outdoor lighting on moths: An assessment. *Journal of the Lepidopterists' Society*, 42(2), 63-93.

Frank, M. G. (2013). Sleep in Amphibians and Reptiles *Encyclopedia of Sleep* (1, pp. 43-44). Elsevier Inc.

Frank, M. G., Waldrop, R. H., Dumoulin, M., Aton, S., & Boal, J. G. (2012). A preliminary analysis of sleep-like states in the cuttlefish *Sepia officinalis*. *Plos One*, 7(6), e38125. http://doi.org/10.1371/journal.pone.0038125

Fransson, T., Jakobsson, S., Johansson, P., Kullberg, C., Lind, J., & Vallin, A. (2001). Bird migration Magnetic cues trigger extensive refuelling. *Nature (London)*, 414(6859), 35-36. http://doi.org/10.1038/35102115

Fuchs, T., Haney, A., Jechura, T. J., Moore, F. R., & Bingman, V. P. (2006). Daytime naps in night-migrating birds: behavioural adaptation to seasonal sleep deprivation in the Swainson's thrush, Catharus ustulatus. *Animal Behaviour*, 72(4), 951–958. https://doi.org/10.1016/j.anbehav.2006.03.008

Fuchs, T., Maury, D., Moore, F. R., & Bingman, V. P. (2009). Daytime micro-naps in a nocturnal migrant: an EEG analysis. *Biology Letters*, 5(1), 77–80. https://doi.org/10.1098/rsbl.2008.0405

Fuller, R. A., Warren, P. H., & Gaston, K. J. (2007). Daytime noise predicts nocturnal singing in urban robins. *Biology Letters (2005)*, 3(4), 368-370. http://doi.org/10.1098/rsbl.2007.0134

Gaviraghi Mussoi, J. (2023). *The importance of sleep for avian vocal communication* (Publication*Number alma99265553391402091), ResearchSpace@Auckland].

Giebultowicz, J. (2004). Chronobiology: Biological Timekeeping. *Integrative and Comparative Biologyintegrative and Comparative Biology*, 44(3), 266. http://doi.org/10.1093/icb/44.3.266

Groch, S., Zinke, K., Wilhelm, I., & Born, J. (2015). Dissociating the contributions of slow-wave sleep and rapid eye movement sleep to emotional item and source memory. *Neurobiology of Learning and Memory*, 122, 122-130. http://doi.org/10.1016/j.nlm.2014.08.013

Grunst, A. S., Grunst, M. L., Raap, T., Pinxten, R., & Eens, M. (2023). Anthropogenic noise and light pollution additively affect sleep behaviour in free-living birds in sex- and season-dependent fashions. *Environmental Pollution (1987)*, 316, 120426. http://doi.org/10.1016/j.envpol.2022.120426

Grunst, M. L., Grunst, A. S., Pinxten, R., & Eens, M. (2021). Variable and consistent traffic noise negatively affect the sleep behavior of a free-living songbird. *Science of the Total Environment*, 778, 146338. http://doi.org/https://doi.org/10.1016/j.scitotenv.2021.146338

Gwinner, E. (1986). *Circannual Rhythms*. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-82870-6

Gwinner, E., & Brandstatter, R. (2001). Complex bird clocks. *Philosophical Transactions of the Royal Society of London. Series B. Biological Sciences*, 356(1415), 1801-1810. http://doi.org/10.1098/rstb.2001.0959

Harrison, Y., & Horne, J. A. (2000). The Impact of Sleep Deprivation on Decision Making: A Review. *Journal of Experimental Psychology. Applied*, 6(3), 236-249. http://doi.org/10.1037/1076-898X.6.3.236

Hasan, N. (2010). The effect of environmental conditions on the start of dawn singing of blackbirds (*Turdus merula*) and Bulbuls (*Pycnonotidae*). *Jordan Journal of Bioloogical Sciences*, 3, 13-16.

He, B., Peng, H., Zhao, Y., Zhou, H., & Zhao, Z. (2011). Modafinil treatment prevents REM sleep deprivation-induced brain function impairment by increasing MMP-9 expression. *Brain Research*, 1426, 38-42. http://doi.org/10.1016/j.brainres.2011.09.002

Heather, B. D., Robertson, H. A., & Onley, D. J. (2015). *The field guide to the birds of New Zealand* (Revised and updated edition.). Penguin Books.

Hendricks, J. C., Finn, S. M., Panckeri, K. A., Chavkin, J., Williams, J. A., Sehgal, A., & Pack, A. I. (2000). Rest in Drosophila is a sleep-like state. *Neuron (Cambridge, Mass.)*, 25(1), 129-138. http://doi.org/10.1016/S0896-6273(00)80877-6

Heswall, A., Miller, L., McNaughton, E. J., Brunton-Martin, A. L., Cain, K. E., Friesen, M. R., & Gaskett, A. C. (2022). Artificial light at night correlates with seabird groundings: mapping city lights near a seabird breeding hotspot. *Peerj (San Francisco, Ca)*, 10, e14237. http://doi.org/10.7717/peerj.14237

Hiscock, H. G., Worster, S., Kattnig, D. R., Steers, C., Jin, Y., Manolopoulos, D. E., Mouritsen, H., & Hore, P. J. (2016). The quantum needle of the avian magnetic compass. *Proceedings of the National Academy of Sciences - Pnas*, 113(17), 4634-4639. http://doi.org/10.1073/pnas.1600341113

Hopkins, G. R., Gaston, K. J., Visser, M. E., Elgar, M. A., & Jones, T. M. (2018). Artificial light at night as a driver of evolution across urban–rural landscapes. *Frontiers in Ecology and the Environment*, 16(8), 472–479. https://doi.org/10.1002/fee.1828

Horne, J. A. (1979). Restitution and human sleep: A critical review. *Physiological Psychology*, 7(2), 115-125. http://doi.org/10.3758/BF03332894

Horne, J. (2009). REM sleep, energy balance and 'optimal foraging'. *Neuroscience and Biobehavioral Reviews*, 33(3), 466-474. http://doi.org/10.1016/j.neubiorev.2008.12.002

Hutchinson, J. M. C. (2002). Two explanations of the dawn chorus compared: how monotonically changing light levels favour a short break from singing. *Animal Behaviour*, 64(4), 527-539. http://doi.org/10.1006/anbe.2002.3091

Jackson, C., McCabe, B. J., Nicol, A. U., Grout, A. S., Brown, M. W., & Horn, G. (2008). Dynamics of a Memory Trace: Effects of Sleep on Consolidation. *Current Biology*, 18(6), 393-400. http://doi.org/10.1016/j.cub.2008.01.062

Jaggard, J. B., Wang, G. X., & Mourrain, P. (2021). Non-REM and REM/paradoxical sleep dynamics across phylogeny. *Current Opinion in Neurobiology*, 71, 44-51. http://doi.org/10.1016/j.conb.2021.08.004

Johnsson, R. D., Connelly, F., Gaviraghi Mussoi, J., Vyssotski, A. L., Cain, K. E., Roth, N. T. C., & Lesku, J. A. (2022). Sleep loss impairs cognitive performance and alters song output in Australian magpies. *Scientific Reports*, 12(1), 6645. http://doi.org/10.1038/s41598-022-10162-7

Kacelnik, A. (1979). The foraging efficiency of great tits (*Parus major* L.) in relation to light intensity. *Animal Behaviour*, 27, 237-241. http://doi.org/10.1016/0003-3472(79)90143-X

Kempenaers, B., Borgström, P., Loës, P., Schlicht, E., & Valcu, M. (2010). Artificial Night Lighting Affects Dawn Song, Extra-Pair Siring Success, and Lay Date in Songbirds. *Current Biology*, 20(19), 1735-1739. http://doi.org/10.1016/j.cub.2010.08.028

Kempenaers, B., Verheyen, G. R., & Dhondi, A. A. (1997). Extrapair paternity in the blue tit (*Parus caeruleus*) : female choice, male charateristics, and offspring quality. *Behavioral Ecology*, 8(5), 481-492.

Kendall, C. J. (2014). The early bird gets the carcass: Temporal segregation and its effects on foraging success in avian scavengers. *The Auk*, 131(1), 12-19. http://doi.org/10.1642/AUK-13-201.1

Kendall-Bar, J. M., Vyssotski, A. L., Mukhametov, L. M., Siegel, J. M., & Lyamin, O. I. (2019). Eye state asymmetry during aquatic unihemispheric slow wave sleep in northern fur seals (*Callorhinus ursinus*). *Plos One*, 14(5), e217025. http://doi.org/10.1371/journal.pone.0217025

Kersten, M., Britton, R. H., Dugan, P. J., & Hafner, H. (1991). Flock Feeding and Food Intake in Little Egrets: The Effects of Prey Distribution and Behaviour. *The Journal of Animal Ecology*, 60(1), 241-252.

http://doi.org/10.2307/5457

Killgore, W. D. S. (2010). Effects of sleep deprivation on cognition. *Human Sleep and Cognition*, 185(C), 105-129. http://doi.org/10.1016/B978-0-444-53702-7.00007-5

Kim, E. Y., Mahmoud, G. S., & Grover, L. M. (2005). REM sleep deprivation inhibits LTP in vivo in area CA1 of rat hippocampus. *Neuroscience Letters*, 388(3), 163-167. http://doi.org/10.1016/j.neulet.2005.06.057

Klinzing, J. G., Niethard, N., & Born, J. (2019). Mechanisms of systems memory consolidation during sleep. *Nature Neuroscience*, 22(10), 1598-1610. http://doi.org/10.1038/s41593-019-0467-3

Lambrechts, M. M., Blondel, J., Maistre, M., & Perret, P. (1997). A Single Response Mechanism is Responsible for Evolutionary Adaptive Variation in a Bird's Laying Date. *Proceedings of the National Academy of Sciences - Pnas*, 94(10), 5153-5155. http://doi.org/10.1073/pnas.94.10.5153

Leopold, A., & Eynon, A. E. (1961). Avian Daybreak and Evening Song in Relation to Time and Light Intensity. *The Condor*, 63(4), 269-293. http://doi.org/10.2307/1365621

Lesku, J. A., Aulsebrook, A. E., Kelly, M. L., & Tisdale, R. K. (2019). Evolution of Sleep and Adaptive Sleeplessness. *Handbook of Sleep Research*

Lesku, J. A., Rattenborg, N. C., Valcu, M., Vyssotski, A. L., Kuhn, S., Kuemmeth, F., Heidrich, W., & Kempenaers, B. (2012). Adaptive Sleep Loss in Polygynous Pectoral Sandpipers. *Science*, 337(6102), 1654–1658. http://doi.org/10.1126/science.1220939

Leung, L. C., Wang, G. X., Madelaine, R., Skariah, G., Kawakami, K., Deisseroth, K., Urban, A. E., & Mourrain, P. (2019). Neural signatures of sleep in zebrafish. *Nature (London)*, 571(7764), 198-204. http://doi.org/10.1038/s41586-019-1336-7

Leveau, L. M. (2020). Artificial Light at Night (ALAN) Is the Main Driver of Nocturnal Feral Pigeon (*Columba livia* f. domestica) Foraging in Urban Areas. *Animals*, 10(4), 554. http://doi.org/10.3390/ani10040554

Libourel, P. A., Lee, W. Y., Achin, I., Chung, H., Kim, J., Massot, B., & Rattenborg, N. C. (2023). Nesting chinstrap penguins accrue large quantities of sleep through seconds-long microsleeps. *Science (American Association for the Advancement of Science)*, 382(6674), 1026-1031. http://doi.org/10.1126/science.adh0771

Lima, S. L., Rattenborg, N. C., Lesku, J. A., & Amlaner, C. J. (2005). Sleeping under the risk of predation. *Animal Behaviour*, 70(4), 723-736. http://doi.org/10.1016/j.anbehav.2005.01.008

Long, J. L. (1981). *Introduced birds of the world: the worldwide history, distribution and influence of birds introduced to new environments*. David & Charles.

Lyamin, O. I., Kosenko, P. O., Korneva, S. M., Vyssotski, A. L., Mukhametov, L. M., & Siegel, J. M. (2018). Fur Seals Suppress REM Sleep for Very Long Periods without Subsequent Rebound. *Current Biology*, 28(12), 2000-2005. http://doi.org/10.1016/j.cub.2018.05.022

Lyamin, O. I., Mukhametov, L. M., & Siegel, J. M. (2017). Sleep in the northern fur seal. *Current Opinion in Neurobiology*, 44, 144-151. http://doi.org/10.1016/j.conb.2017.04.009

Lyamin, O. I., Pryaslova, J., Lance, V., & Siegel, J. M. (2006). Sleep behaviour: Sleep in continuously active dolphins; Activity and sleep in dolphins (Reply). *Nature*, 441(7096) http://doi.org/https://doi.org/10.1038/nature04900

Mace, R. (1989). A Comparison of Great Tits' (*Parus major*) Use of Time in Different Daylengths at Three European Sites. *The Journal of Animal Ecology*, 58(1), 143-151. http://doi.org/10.2307/4991

Marín Gómez, O. H. (2022). Artificial Light at Night Drives Earlier Singing in a Neotropical Bird. *Animals : An Open Access Journal From Mdpi*, 12(8), 1015-1025. https://doi.org/10.3390/ani12081015

Martinez Gonzalez, D., Lesku, J. A., & Rattenborg, N. C. (2008). Increased EEG spectral power density during sleep following short‐term sleep deprivation in pigeons (*Columba livia*): evidence for avian sleep homeostasis. *Journal of Sleep Research*, 17(2), 140-153. http://doi.org/10.1111/j.1365-2869.2008.00636.x

Maycock, M. H., You, Y., Ta, U. D., Sundaram, M. V., Pack, A. I., Raizen, D. M., & Zimmerman, J. E. (2008). Lethargus is a Caenorhabditis elegans sleep-like state. *Nature*, 451(7178), 569-572. http://doi.org/10.1038/nature06535

McNeil, R., McSween, A., & Lachapelle, P. (2005). Comparison of the Retinal Structure and Function in Four Bird Species as a Function of the Time They Start Singing in the Morning. *Brain, Behavior and Evolution*, 65(3), 202-214. http://doi.org/10.1159/000083881

Medeiros, S. L. D. S., Paiva, M. M. M. D., Lopes, P. H., Blanco, W., Lima, F. D. D., Oliveira, J. B. C. D., Medeiros, I. G., Sequerra, E. B., de Souza, S., Leite, T. S., & Ribeiro, S. (2021). Cyclic alternation of quiet and active sleep states in the octopus. *Iscience*, 24(4), 102223. http://doi.org/10.1016/j.isci.2021.102223

Merkel, F. R., & Johansen, K. L. (2011). Light-induced bird strikes on vessels in Southwest Greenland. *Marine Pollution Bulletin*, 62(11), 2330-2336. http://doi.org/10.1016/j.marpolbul.2011.08.040

Miles, W. T. S., Parsons, M., Close, A. J., Luxmoore, R., & Furness, R. W. (2013). Predator-avoidance behaviour in a nocturnal petrel exposed to a novel predator. *Ibis (London, England)*, 155(1), 16-31. http://doi.org/10.1111/ibi.12007

Miller, M. W. (2006). Apparent Effects of Light Pollution on Singing Behavior of American Robins. *The Condor (Los Angeles, Calif.)*, 108(1), 130-139. http://doi.org/10.1650/0010-5422(2006)108[0130:AEOLPO]2.0.CO;2

Moller, A. P. (1991). Why Mated Songbirds Sing So Much: Mate Guarding and Male Announcement of Mate Fertility Status. *The American Naturalist*, 138(4), 994-1014. http://doi.org/10.1086/285264

Mouritsen, H., Heyers, D., & Güntürkün, O. (2016). The Neural Basis of Long-Distance Navigation in Birds. *Annual Review of Physiology*, 78(1), 133-154. http://doi.org/10.1146/annurev-physiol-021115-105054

Muheim, R., Sjöberg, S., & Pinzon-Rodriguez, A. (2016). Polarized light modulates light-dependent magnetic compass orientation in birds. *Proceedings of the National Academy of Sciences - Pnas*, 113(6), 1654-1659. http://doi.org/10.1073/pnas.1513391113

Mukhametov, L. M. (1987). Unihemispheric slow-wave sleep in the Amazonian dolphin, Inia geoffrensis. *Neuroscience Letters*, 79(1), 128-132. http://doi.org/10.1016/0304-3940(87)90684-7

Mullington, J. M., Haack, M., Toth, M., Serrador, J. M., & Meier-Ewert, H. K. (2009). Cardiovascular, Inflammatory, and Metabolic Consequences of Sleep Deprivation. *Progress in Cardiovascular Diseases*, 51(4), 294-302. http://doi.org/10.1016/j.pcad.2008.10.003

Mussoi, J. G., Stanley, M. C., & Cain, K. E. (2022). Importance of sleep for avian vocal communication. *Biology Letters (2005)*, 18(8), 20220223. http://doi.org/10.1098/rsbl.2022.0223

Negro, J. J., Bustamante, J., Melguizo, C., Ruiz, J. L., & Grande, J. M. (2000). Noctural activity of Lesser Kestrels under artificial lighting conditions in Seville, Spain. *The Journal of Raptor Research*, 34(4), 327-329.

Nemes, C. E., Cabrera-Cruz, S. A., Anderson, M. J., DeGroote, L. W., DeSimone, J. G., Massa, M. L., & Cohen, E. B. (2023). More than mortality: Consequences of human activity on migrating birds extend beyond direct mortality. *Ornithological Applications*, 125(3), 1-21. http://doi.org/10.1093/ornithapp/duad020

Nordt, A., & Klenke, R. (2013). Sleepless in town--drivers of the temporal shift in dawn song in urban European blackbirds. *Plos One*, 8(8), e71476. http://doi.org/10.1371/journal.pone.0071476

Oleg, I. L., Paul, R. M., Sam, H. R., Lev, M. M., & Jerome, M. S. (2008). Cetacean sleep: An unusual form of mammalian sleep. *Neuroscience and Biobehavioral Reviews*, 32(8), 1451–1484. http://doi.org/10.1016/j.neubiorev.2008.05.023

Orzeł-Gryglewska, J. (2010). Consequences of sleep deprivation. *International Journal of Occupational Medicine and Environmental Health*, 23(1), 95-114. http://doi.org/10.2478/v10001-010-0004-9

Ouyang, J. Q., Jong, M., Grunsven, R. H. A., Matson, K. D., Haussmann, M. F., Meerlo, P., Visser, M. E., & Spoelstra, K. (2017). Restless roosts: Light pollution affects behavior, sleep, and physiology in a free - living songbird. *Global Change Biology*, 23(11), 4987-4994. http://doi.org/10.1111/gcb.13756

Partecke, J., J. Van'T Hof, T., & Gwinner, E. (2005). Underlying physiological control of reproduction in urban and forest-dwelling European blackbirds *Turdus merula*. *Journal of Avian Biology*, 36(4), 295-305. http://doi.org/10.1111/j.0908-8857.2005.03344.x

Pastukhov, Y. F. (2016). Slow-wave sleep and molecular chaperones. *Journal of Evolutionary Biochemistry and Physiology*, 52(1), 87-101. http://doi.org/10.1134/S0022093016010117

Paul-Antoine, L., & Anthony, H. (2015). Sleep in amphibians and reptiles: a review and a preliminary analysis of evolutionary patterns. *Biological Reviews of the Cambridge Philosophical Society*, 91, 833-866. http://doi.org/10.1111/brv.12197

Peever, J., & Fuller, P. M. (2017). The Biology of REM Sleep. *Current Biology*, 27(22), R1237-R1248. http://doi.org/10.1016/j.cub.2017.10.026

Peter, B., Wolfgang, F., & Ulrich, Q. (2000). Die Zugunruhe bei Vögeln — eine Darstellung nach Videoaufnahmen bei Infrarotlichtbeleuchtung. *Journal Ü Ornithology*, 141(3), 285-299. http://doi.org/10.1046/j.1439-0361.2000.00030.x

Philip, P., Taillard, J., Sagaspe, P., Valtat, C., Sanchez Ortuno, M., Moore, N., Charles, A., & Bioulac, B. (2004). Age, performance and sleep deprivation. *Journal of Sleep Research*, 13(2), 105-110. http://doi.org/10.1111/j.1365-2869.2004.00399.x

Piéron, H. (1913). *Le problème physiologique du sommeil*. E. Grevin.

Poesel, A., Kunc, H. P., Foerster, K., Johnsen, A., & Kempenaers, B. (2006). Early birds are sexy: male age, dawn song and extrapair paternity in blue tits, *Cyanistes* (formerly Parus) *caeruleus*. *Animal Behaviour*, 72(3), 531-538. http://doi.org/10.1016/j.anbehav.2005.10.022

Poot, H., Ens, B. J., de Vries, H., Donners, M. A. H., Wernand, M. R., & Marquenie, J. M. (2008). Green Light for Nocturnally Migrating Birds. *Ecology and Society*, 13(2), 47. http://doi.org/10.5751/ES-02720-130247

Pophale, A., Shimizu, K., Mano, T., Iglesias, T. L., Martin, K., Hiroi, M., Asada, K., Andaluz, P. G., Van Dinh, T. T., Meshulam, L., & Reiter, S. (2023). Wake-like skin patterning and neural activity during octopus sleep. *Nature (London)*, 619(7968), 129-134. http://doi.org/10.1038/s41586-023-06203-4

Raap, T., Pinxten, R., & Eens, M. (2016). Artificial light at night disrupts sleep in female great tits (*Parus major*) during the nestling period, and is followed by a sleep rebound. *Environmental Pollution*, 215, 125-134. http://doi.org/https://doi.org/10.1016/j.envpol.2016.04.100

Rattenborg, N. C. (2017). Sleeping on the wing. *Interface Focus*, 7(1), 20160082. http://doi.org/10.1098/rsfs.2016.0082

Rattenborg, N. C., Amlaner, C. J., & Lima, S. L. (2000). Behavioral, neurophysiological and evolutionary perspectives on unihemispheric sleep. *Neuroscience and Biobehavioral Reviews*, 24(8), 817-842. http://doi.org/10.1016/S0149-7634(00)00039-7

Rattenborg, N. C., Lesku, J. A., & Libourel, P. (2022). Sleep in Nonmammalian Vertebrates *Principles and Practice of Sleep Medicine* (7ed., Vol. 106-120). Elsevier Inc. http://doi.org/10.1016/B978-0-323-66189-8.00011-2.

Rattenborg, N. C., Lima, S. L., & Amlaner, C. J. (1999a). Facultative control of avian unihemispheric sleep under the risk of predation. *Behavioural Brain Research*, 105(2), 163-172. http://doi.org/10.1016/S0166-4328(99)00070-4

Rattenborg, N. C., Lima, S. L., & Amlaner, C. J. (1999b). Half-awake to the risk of predation. *Nature (London)*, 397(6718), 397-398. http://doi.org/10.1038/17037

Rattenborg, N. C., Mandt, B. H., Obermeyer, W. H., Winsauer, P. J., Huber, R., Wikelski, M., & Benca, R. M. (2004). Migratory Sleeplessness in the White-Crowned Sparrow (*Zonotrichia leucophrys gambelii*). *Plos Biology*, 2(7), e212. http://doi.org/10.1371/journal.pbio.0020212

Rattenborg, N. C., Martinez-Gonzalez, D., Lesku, J. A., & Scriba, M. (2008). A Bird's Eye View of Sleep. *Science (American Association for the Advancement of Science)*, 322(5901), 527. http://doi.org/10.1126/science.322.5901.527b

Rattenborg, N. C., Martinez-Gonzalez, D., Roth, T. C., & Pravosudov, V. V. (2011). Hippocampal memory consolidation during sleep: a comparison of mammals and birds. *Biological Reviews of the Cambridge Philosophical Society*, 86(3), 658-691. https://doi.org/10.1111/j.1469-185X.2010.00165.x

Rattenborg, N. C., Martinez-Gonzalez, D., & Lesku, J. A. (2009). Avian sleep homeostasis: Convergent evolution of complex brains, cognition and sleep functions in mammals and birds. *Neuroscience and Biobehavioral Reviews*, 33(3), 253-270. http://doi.org/10.1016/j.neubiorev.2008.08.010

Rattenborg, N. C., Obermeyer, W. H., Vacha, E., & Benca, R. M. (2005). Acute effects of light and darkness on sleep in the pigeon (*Columba livia*). *Physiology & Behavior*, 84(4), 635-640. http://doi.org/10.1016/j.physbeh.2005.02.009

Rattenborg, N. C., van der Meij, J., Beckers, G. J. L., & Lesku, J. A. (2019). Local Aspects of Avian Non-REM and REM Sleep. *Frontiers in Neuroscience*, 13, 460268. https://doi.org/10.3389/fnins.2019.00567

Rattenborg, N. C., Voirin, B., Cruz, S. M., Tisdale, R., Dell'Omo, G., Lipp, H., Wikelski, M., & Vyssotski, A. L. (2016). Evidence that birds sleep in mid-flight. *Nature Communications*, 7(1), 12468. http://doi.org/10.1038/ncomms12468

Rattenborg, N. C., & Martinez-Gonzalez, D. (2015). Avian Versus Mammalian Sleep: the Fruits of Comparing Apples and Oranges. *Current Sleep Medicine Reports*, 1(1), 55-63. http://doi.org/10.1007/s40675-014-0001-9

Rattenborg, N. C., & Ungurean, G. (2023). The evolution and diversification of sleep. *Trends in Ecology & Evolution (Amsterdam)*, 38(2), 156-170. http://doi.org/10.1016/j.tree.2022.10.004

Rau, P., & Rau, N. (1916). The sleep of insects; An Ecological Study. *Annals of the Entomological Society of America*, 9(3), 227-274. http://doi.org/10.1093/aesa/9.3.227

Rechtschaffen, A., & Bergmann, B. M. (2002). Sleep deprivation in the rat: An update of the 1989 paper. *Sleep (New York, N.Y.)*, 25(1), 18-24. http://doi.org/10.1093/sleep/25.1.18

Rial, R. V., Akaârir, M., Gamundí, A., Nicolau, C., Garau, C., Aparicio, S., Tejada, S., Gené, L., González, J., De Vera, L. M., Coenen, A. M. L., Barceló, P., & Esteban, S. (2010). Evolution of wakefulness, sleep and hibernation: From reptiles to mammals. *Neuroscience and Biobehavioral Reviews*, 34(8), 1144-1160. http://doi.org/10.1016/j.neubiorev.2010.01.008

Rich, C., & Longcore, T. (2006). *Ecological consequences of artificial night lighting*. Island Press.

Rogers, A. M., Griffin, A. S., Lermite, F., van Rensburg, B., Archibald, C., & Kark, S. (2021). The role of invasion and urbanization gradients in shaping avian community composition. *Journal of Urban Ecology*, 7(1) http://doi.org/10.1093/jue/juab030

Roßler, D. C., Kim, K., De Agro, M., Jordan, A., Giovanni Galizia, C., & Shamble, P. S. (2022). Regularly occurring bouts of retinal movements suggest an REM sleep-like state in jumping spiders. *Proceedings of the National Academy of Sciences - Pnas*, 119(33), 1-2090213177. http://doi.org/10.1073/pnas.2204754119

Russ, A., Rüger, A., & Klenke, R. (2015). Seize the night: European Blackbirds *(Turdus merula*) extend their foraging activity under artificial illumination. *Journal of Ornithology*, 156(1), 123-131. http://doi.org/10.1007/s10336-014-1105-1

Russart, K. L. G., & Nelson, R. J. (2018). Artificial light at night alters behavior in laboratory and wild animals. *Journal of Experimental Zoology. Part a, Ecological and Integrative Physiology*, 329(8-9), 401-408. http://doi.org/10.1002/jez.2173

Ryan, P. G., Ryan, E. M., & Glass, J. P. (2021). Dazzled by the light: the impact of light pollution from ships on seabirds at Tristan da Cunha. *Ostrich*, 92(3), 218-224. http://doi.org/10.2989/00306525.2021.1984998

Sanders, D., Frago, E., Kehoe, R., Patterson, C., & Gaston, K. J. (2021). A meta-analysis of biological impacts of artificial light at night. *Nature Ecology & Evolution*, 5(1), 74-81. http://doi.org/10.1038/s41559-020-01322-x

Sexton, K., Murphy, M., Redmond, L., & Dolan, A. (2007). Dawn song of eastern kingbirds: intrapopulation variability and sociobiological correlates. *Behaviour*, 144(10), 1273-1295. http://doi.org/10.1163/156853907781890922

Shaffery, J. P., Sinton, C. M., Bissette, G., Roffwarg, H. P., & Marks, G. A. (2002). Rapid eye movement sleep deprivation modifies expression of long-term potentiation in visual cortex of immature rats. *Neuroscience*, 110(3), 431-443. http://doi.org/10.1016/S0306-4522(01)00589-9

Shaw, P. J., Cirelli, C., Greenspan, R. J., & Tononi, G. (2000). Correlates of Sleep and Waking in Drosophila melanogaster. *Science (American Association for the Advancement of Science)*, 287(5459), 1834-1837. http://doi.org/10.1126/science.287.5459.1834

Siegel, J. M. (2008). Do all animals sleep? *Trends in Neurosciences (Regular Ed.)*, 31(4), 208-213. http://doi.org/10.1016/j.tins.2008.02.001

Siegel, J. M. (2022). Sleep function: an evolutionary perspective. *Lancet Neurology*, 21(10), 937-946. http://doi.org/10.1016/S1474-4422(22)00210-1

Slagsvold, T., Dale, S., & SÆTRE, G. (1994). Dawn Singing in the Great Tit (*Parus Major*): Mate Attraction, Mate Guarding, or Territorial Defence? *Behaviour*, 131(1-2), 115-138. http://doi.org/10.1163/156853994X00244

Smith, D. A. E., Smith, Y. C. E., & Downs, C. T. (2020). Continental analysis of invasive birds: Australia and New Zealand. CABI. http://doi.org/10.1079/9781789242065.0258.

Smulders, F. T. Y., Kenemans, J. L., Jonkman, L. M., & Kok, A. (1997). The effects of sleep loss on task performance and the electroencephalogram in young and elderly subjects. *Biological Psychology*, 45(1-3), 217-239. http://doi.org/10.1016/S0301-0511(96)05229-5

Staicer, C. A., Spector, D., & Horn, A. G. (2020). The Dawn Chorus and Other Diel Patterns in Acoustic Signaling. *Ecology and Evolution of Acoustic Communication in Birds*, 426-453. https://doi.org/10.7591/9781501736957-033

Stanhope, B. A., Jaggard, J. B., Gratton, M., Brown, E. B., & Keene, A. C. (2020). Sleep Regulates Glial Plasticity and Expression of the Engulfment Receptor Draper Following Neural Injury. *Current Biology*, 30(6), 1092-1101. http://doi.org/10.1016/j.cub.2020.02.057

Stapput, K., Thalau, P., Wiltschko, R., & Wiltschko, W. (2008). Orientation of Birds in Total Darkness. *Current Biology*, 18(8), 602-606. http://doi.org/10.1016/j.cub.2008.03.046

Steinmeyer, C., Schielzeth, H., Mueller, J. C., & Kempenaers, B. (2010). Variation in sleep behaviour in free-living blue tits, *Cyanistes caeruleus*: effects of sex, age and environment. *Animal Behaviour*, 80(5), 853-864. http://doi.org/10.1016/j.anbehav.2010.08.005

Stenuit, P., & Kerkhofs, M. (2005). Age modulates the effects of sleep restriction in women. *Sleep (New York, N.Y.)*, 28(10), 1283-1288. http://doi.org/10.1093/sleep/28.10.1283

Stracey, C. M., Wynn, B., & Robinson, S. K. (2014). Light Pollution Allows the Northern Mockingbird (*Mimus polyglottos*) to Feed Nestlings After Dark. *The Wilson Journal of Ornithology*, 126(2), 366-369. http://doi.org/10.1676/13-107.1

Sullivan, S. S., Carskadon, M. A., Dement, W. C., & Jackson, C. L. (2022). Normal Human Sleep: An Overview *Principles and Practice of Sleep Medicine* (Seventh Editioned., Vol. 16-26). Elsevier Inc. http://doi.org/10.1016/B978-0-323-66189-8.00002-1.

Szymczak, J. T., Kaiser, W., Helb, H. W., & Beszczyńska, B. (1996). A study of sleep in the European blackbird. *Physiology & Behavior*, 60(4), 1115-1120. http://doi.org/10.1016/0031-9384(96)00231-4

Taufique, S. K. T., Prabhat, A., & Kumar, V. (2018). Constant light environment suppresses maturation and reduces complexity of new born neuron processes in the hippocampus and caudal nidopallium of a diurnal corvid: Implication for impairment of the learning and cognitive performance. *Neurobiology of Learning and Memory*, 147, 120-127. http://doi.org/10.1016/j.nlm.2017.12.001

Taufique, S. K. T., & Kumar, V. (2016). Differential activation and tyrosine hydroxylase distribution in the hippocampal, pallial and midbrain brain regions in response to cognitive performance in Indian house crows exposed to abrupt light environment. *Behavioural Brain Research*, 314, 21-29. http://doi.org/10.1016/j.bbr.2016.07.046

Thomas, R. J., Kelly, D. J., & Goodship, N. M. (2004). Eye design in birds and visual constraints on behavior. *Ornitologia Neotropical*, 15(suppl), 243-250. https://digitalcommons.usf.edu/ornitologia_neotropical/vol15/iss5/24

Thomas, R. J., Széskely, T., Cuthill, I. C., Harper, D. G., Newson, S. E., Frayling, T. D., & Wallis, P. D. (2002). Eye size in birds and the timing of song at dawn. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, 269(1493), 831-837. https://doi.org/10.1098/rspb.2001.1941

Tindall, S. D., Ralph, C. J., & Clout, M. N. (2007). Changes in bird abundance following Common Myna control on a New Zealand island. *Pacific Conservation Biology*, 13(3), 202-212. https://doi.org/10.1071/PC070202

Tobler, I., Franken, P., & Scherschlicht, R. (1990). Sleep and EEG spectra in the rabbit under baseline conditions and following sleep deprivation. *Physiology & Behavior*, 48(1), 121-129. http://doi.org/10.1016/0031-9384(90)90272-6

Tobler, I., & Borbély, A. (1988). Sleep and EEG spectra in the pigeon (*Columba Livia*) under baseline conditions and after sleep deprivation. *Journal of Comparative Physiology*, 163, 729-738. http://doi.org/10.1007/BF00604050

Tucker, A. M., Whitney, P., Belenky, G., Hinson, J. M., & Van Dongen, H. P. A. (2010). Effects of Sleep Deprivation on Dissociated Components of Executive Functioning. *Sleep (New York, N.Y.)*, 33(1), 47-57. http://doi.org/10.1093/sleep/33.1.47

van Alphen, B., Yap, M. H. W., Kirszenblat, L., Kottler, B., & van Swinderen, B. (2013). A dynamic deep sleep stage in Drosophila. *The Journal of Neuroscience*, 33(16), 6917-6937. http://doi.org/10.1523/JNEUROSCI.0061-13.2013

Van De Poll, M. N., & van Swinderen, B. (2021). Balancing Prediction and Surprise: A Role for Active Sleep at the Dawn of Consciousness? *Frontiers in Systems Neuroscience*, 15, 768762. http://doi.org/10.3389/fnsys.2021.768762

Van Doren, B. M., Horton, K. G., Dokter, A. M., Klinck, H., Elbin, S. B., & Farnsworth, A. (2017). High-intensity urban light installation dramatically alters nocturnal bird migration. *Proceedings of the National Academy of Sciences - Pnas*, 114(42), 11175-11180. http://doi.org/10.1073/pnas.1708574114

Vorster, A. P., & Born, J. (2015). Sleep and memory in mammals, birds and invertebrates. *Neuroscience and Biobehavioral Reviews*, 50, 103-119. http://doi.org/10.1016/j.neubiorev.2014.09.020

Weimerskirch, H., Bishop, C., Jeanniard-du-Dot, T., Prudor, A., & Sachs, G. (2016). Frigate birds track atmospheric conditions over months-long transoceanic flights. *Science (American Association for the Advancement of Science)*, 353(6294), 74-78. http://doi.org/10.1126/science.aaf4374

Wikelski, M., Martin, L. B., Scheuerlein, A., Robinson, M. T., Robinson, N. D., Helm, B., Hau, M., & Gwinner, E. (2008). Avian circannual clocks: adaptive significance and possible involvement of energy turnover in their proximate control. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363(1490), 411-423. http://doi.org/10.1098/rstb.2007.2147

Wilms, B., Kuhr, M., Chamorro, R., Klinsmann, N., Spyra, D., Mölle, M., Kalscheuer, H., Schultes, B., Lehnert, H., & Schmid, S. M. (2020). Chronobiological aspects of sleep restriction modulate subsequent spontaneous physical activity. *Physiology & Behavior*, 215, 112795. http://doi.org/10.1016/j.physbeh.2019.112795

Wilson, P. R. (1973). The ecology of the common myna (*Acridotheres tristis* L.) in Hawke’s Bay. https://ir.wgtn.ac.nz/handle/123456789/29921

Wilson, P. R. (1975). Starling and myna. *New Zealand Native Heritage*, 5, 1730-1734.

Wilson, P. R. (2013, 2022/1/30). *Common myna | Maina* www.nzbirdsonline.org.nz

Wiltschko, W., Munro, U., Ford, H., & Wiltschko, R. (1993). Red light disrupts magnetic orientation of migratory birds. *Nature (London)*, 364(6437), 525-527. http://doi.org/10.1038/364525a0

Wright, H. W. (1912). Morning Awakening and Even-Song. *The Auk*, 29(3), 307-327. http://doi.org/10.2307/4071038

Wright, H. W. (1913). Morning Awakening and Even-Song: Second Paper. *The Auk*, 30(4), 512-537. http://doi.org/10.2307/4072050

Xie, L., Kang, H., Xu, Q., Chen, M. J., Liao, Y., Thiyagarajan, M., O'Donnell, J., Christensen, D. J., Nicholson, C., Iliff, J. J., Takano, T., Deane, R., & Nedergaard, M. (2013). Sleep Drives Metabolite Clearance from the Adult Brain. *Science (American Association for the Advancement of Science)*, 342(6156), 373-377. http://doi.org/10.1126/science.1241224

Yap, M. H. W., Grabowska, M. J., Rohrscheib, C., Jeans, R., Troup, M., Paulk, A. C., Van Alphen, B., Shaw, P. J., & Van Swinderen, B. (2017). Oscillatory brain activity in spontaneous and induced sleep stages in flies. *Nature Communications*, 8(1), 1815. http://doi.org/10.1038/s41467-017-02024-y

Yokogawa, T., Marin, W., Faraco, J., Pézeron, G., Appelbaum, L., Zhang, J., Rosa, F., Mourrain, P., & Mignot, E. (2007). Characterization of sleep in zebrafish and insomnia in hypocretin receptor mutants. *Plos Biology*, 5(10), 2379-2397. http://doi.org/10.1371/journal.pbio.0050277

Yordanova, J., Kolev, V., Wagner, U., & Verleger, R. (2010). Differential associations of early- and late-night sleep with functional brain states promoting insight to abstract task regularity. *Plos One*, 5(2), e9442. http://doi.org/10.1371/journal.pone.0009442

York, J. E., Young, A. J., & Radford, A. N. (2014). Singing in the moonlight: dawn song performance of a diurnal bird varies with lunar phase. *Biology Letters (2005)*, 10(1), 20130970. http://doi.org/10.1098/rsbl.2013.0970

Zhao, X., Sun, H., Tang, Z., Flanders, J., Zhang, S., & Ma, Y. (2010). Characterization of the sleep architecture in two species of fruit bat. *Behavioural Brain Research*, 208(2), 497-501. http://doi.org/10.1016/j.bbr.2009.12.027

Zhdanova, I. V., Wang, S. Y., Leclair, O. U., & Danilova, N. P. (2001). Melatonin promotes sleep-like state in zebrafish. *Brain Research*, 903(1), 263-268. http://doi.org/10.1016/S0006-8993(01)02444-1

Zimmerman, J. E., Naidoo, N., Raizen, D. M., & Pack, A. I. (2008). Conservation of sleep: insights from non-mammalian model systems. *Trends in Neurosciences (Regular Ed.)*, 31(7), 371-376. http://doi.org/10.1016/j.tins.2008.05.001

Zwaka, H., Bartels, R., Gora, J., Franck, V., Culo, A., Götsch, M., & Menzel, R. (2015). Context Odor Presentation during Sleep Enhances Memory in Honeybees. *Current Biology*, 25(21), 2869-2874. http://doi.org/10.1016/j.cub.2015.09.069