THESIS SUMMARY- Tessa Liebich

Sleep is essential for optimal daytime functioning and good physical and mental wellbeing. Chronically inadequate or poor-quality sleep contributes to a range of physical and mental health impacts, such as insomnia, poor daytime functioning, irritability and increased risks of accidents and adverse health outcomes. Thus, chronic sleep problems are an important cause of potentially avoidable morbidity, mortality and economic costs to the community.

Environmental noises, such as traffic noise, are well known to impact sleep. However, high quality, objective evidence to evaluate the impact of wind turbine noise (WTN) on sleep is limited. Furthermore, the currently available literature is dominated by cross-sectional and observational field studies that show mixed findings and where causation remains equivocal. Given the increasing reliance on wind power generation with continued growth in wind farm developments and ongoing community complaints regarding WTN related sleep disturbance, it is important to investigate potential impacts of WTN on sleep. Therefore, the primary aim of the work presented in this thesis was to investigate the impact of WTN on objective and subjective measures of sleep as well as next-day mood, anxiety, and cognitive performance under carefully controlled experimental conditions in a laboratory environment. A further aim was to examine if WTN exposure effects differ amongst different population groups, including young healthy adults without prior WTN exposure, residents living near a wind farm who do and do not report WTN related sleep disruption, rural residents without WTN exposure and urban residents reporting road traffic noise (RTN) related sleep disruption. A third aim was to gain an understanding of the possible psychological versus physiological contributions to possible WTN effects on sleep by comparing wake only versus sleep only presentations of WTN. These different modes of WTN presentations are detailed in Chapters 4 and 5. This was to investigate if residents living near wind farms and self-reporting WTN related sleep disturbance potentially exhibit a conditioned insomnia response to nocturnal WTN in a carefully controlled laboratory environment. Whilst Chapter 2 and Chapter 3 are independent studies, Chapter 4 and Chapter 5 investigate the same sample and same study design but different outcomes.

In the second Chapter, the first comprehensive systematic literature review and meta-analysis is presented to evaluate the available evidence to date regarding WTN effects on sleep from validated objective and subjective sleep assessment tools. Nine studies were eligible for review and five studies were meta-analysed. Combined data from five objective studies comparing WTN to quiet background noise conditions showed no significant effects on the most widely used objective markers of sleep including sleep latency, total sleep time, wake after sleep onset and sleep efficiency. Subjective sleep outcomes were not sufficiently uniform for combining data or comparisons between studies, but appeared to support that insomnia severity, sleep quality and daytime sleepiness can be impacted by WTN exposure in comparison to quiet background noise. This review highlighted the limited knowledge and data in this area and the need for further carefully controlled experimental studies using ecologically valid WTN as well as objective and psychometrically validated sleep assessments to provide more conclusive evidence regarding the impact of WTN on sleep.

In the third Chapter, the effect of WTN on polysomnographically (objective) and sleep diary determined (subjective) sleep latency was assessed in a pilot study of 23 healthy sleepers living in urban residences away from wind turbines. Participants were exposed, in counterbalanced order, to one night of background noise alone (23 dB(A)) as a control, and another night of WTN at 33 dB(A) (i.e., the upper end of expected indoor values) up until the time of sustained sleep in a sleep laboratory. No significant differences in objective or subjective sleep latency were found between WTN exposure versus control nights. Whilst undetected small effects could not be ruled out, these results do not support the position that WTN increases sleep latency in individuals without prior WTN exposure.

In the fourth Chapter and a separate study and sleep laboratory, objective and subjective sleep macrostructure parameters were assessed in a large carefully controlled laboratory study in four population groups. Participants included two groups habitually exposed to WTN at night, one group with (n = 14) and one without (n = 18) self-reported WTN related sleep disruption, another group of rural residents without WTN exposure (n = 18) and a group of urban residents who reported RTN related sleep disruption (n = 18). All participants were exposed in randomised order to: (1) a quiet control night with background noise only (19 dB(A)); (2) a full night of WTN exposure at 25 dB(A); (3) WTN exposure only during established sleep periods; and (4) WTN exposure only during wake periods. The 25 dB(A) WTN was similar to median indoor night-time WTN levels recorded over a full-year observation period for distances from 1-3 kilometres from a wind farm to illustrate representative WTN levels in the field. All study participants (n = 68) underwent full in-laboratory polysomnography during the four exposure nights. No significant main effects of noise condition or group-by-noise condition interaction effects on objective or subjective sleep efficiency, total sleep time, sleep latency, wake after sleep onset, number of awakenings or any sleep stage outcomes were found.This controlled laboratory study suggests that WTN exposure at a level similar to median indoor WTN levels does not appear to significantly impact key objective or subjective sleep macrostructure parameters or show any wake- versus sleep-dependent effects within or between population groups with varying prior noise exposure and self-reported noise related sleep disruption (i.e., WTN-sleep disturbed, WTN-non sleep disturbed, rural control or RTN-sleep disturbed). Whilst effects of WTN at higher noise exposure levels cannot be ruled out, these findings do not support the idea that residents living near wind turbines and who report WTN related sleep disruption display consistent conditioned responses to nocturnal WTN exposure in a carefully controlled laboratory environment.

Similar to sleep disturbance, experimental studies to investigate the impact of nocturnal WTN on next-day mood, anxiety or cognitive performance outcomes remain lacking. Whilst the work of previous Chapters showed no significant impacts of WTN on objective and subjective markers of sleep time and quality, the potential for WTN to impact subsequent daytime functioning warranted specific investigation. For example, traditional sleep scoring metrics reported in Chapter 4 may not be sufficiently sensitive to detect more subtle sleep disruption that could contribute to daytime functioning impairments. Alternatively, psychological effects without necessarily any detectable sleep disruption could also potentially influence subsequent daytime performance and behavioural outcomes. Thus, in a separate analysis, reported in Chapter 5, next-day mood, anxiety and cognitive performance outcomes were assessed in the same controlled laboratory study. There was a marginal statistically significant noise condition main effect for digit span forwards recall, with greater recall occurring in the WTN-Continuous versus WTN-Sleep condition (p=0.048). However, this finding is difficult to explain and is in the reverse direction expected of noise disruption effects, particularly given no evidence of any differences compared to the no noise control. Thus, Type-1 error seems most likely. There were no further significant noise condition, or group-by-noise condition interaction effects to indicate any systematic differences in any other mood, anxiety, or cognitive performance outcomes. Given no consistent evidence of poorer outcomes in the presence of WTN compared to control conditions, WTN exposure at 25 dB(A) in a carefully controlled environment does not appear to impact mood, anxiety or daytime cognitive performance outcomes the day following nocturnal WTN exposure.

The work presented in this thesis suggests that WTN exposure at 25 dB(A) in a carefully controlled laboratory environment does not appear to significantly impact objective or subjective sleep, next-day mood, anxiety or cognitive performance when assessed via traditional sleep scoring methods of polysomnography and psychometrically validated measures of sleep, mood and anxiety and objective daytime cognitive performance measures. These findings were consistent across different populations including those residing close to wind farms and report sleep disruption from WTN. These studies make an important contribution to understanding the impact of WTN on objective and subjective sleep macrostructure, as well as next-day mood, anxiety, and cognitive performance.