

**Illuminating sleep in the dark:  
The relationship between electric light and sleep on  
Tanna Island, Vanuatu**

**by  
Andrea N. Smit**

M.A., Simon Fraser University, 2014

B.Sc., Trent University, 2008

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# Approval

**Name:** Andrea N. Smit

**Degree:** Doctor of Philosophy

**Title:** Illuminating sleep in the dark:  
The relationship between electric light and sleep  
on Tanna Island, Vanuatu

**Examining Committee:**

**Chair:** Urs Ribary  
Professor

**Ralph Mistlberger**  
Senior Supervisor  
Professor

**Tanya Broesch**  
Supervisor  
Associate Professor

**Myriam Juda**  
Supervisor  
Postdoctoral Fellow

**Mark Collard**  
Internal Examiner  
Professor  
Department of Archaeology

**Ken Wright**  
External Examiner  
Professor  
Department of Integrative Physiology  
University of Colorado, Boulder

**Date Defended/Approved:** April 5, 2019

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## **Abstract**

Ideal sleep duration has been a topic of debate for centuries. In industrialized nations, access to electric lighting has had impacts on our daily circadian rhythms and, consequently, our sleep. Because of this, desire to understand human “ancestral” sleep is increasing. It is hypothesized that industrialization, complete with 24h access to electric lighting, delays sleep onset and shortens sleep period. This could suggest that in industrialized societies, people may be getting insufficient sleep, which is important to overall health. Conversely, study of some non-industrialized societies without electricity has shown sleep durations that are shorter, or no different, from those in Westernized societies. To further investigate the direct effect of light exposure on sleep, actigraphy was used to measure these in individuals living traditional subsistence lifestyles, with or without access to electricity, on Tanna Island, Vanuatu. Bedtime, wake time, and rise time were similar between villages, however sleep onset was delayed in electrically lit villages, leading to shorter sleep duration. This effect was strongly influenced by mothers with infants, who were up throughout the night, and therefore exposed to more light at night in villages with electricity. Comparatively, sleep durations measured on Tanna were long relative to those reported in industrialized nations. The results support a hypothesis that exposure to artificial light after sunset can delay sleep onset and reduce sleep duration. Lifestyle differences appear to play a large role in human sleep, and continued investigation of varying levels of industrialization should uncover other industrialization-related impacts on sleep, and subsequently, health.

**Keywords:** Sleep Duration; Sleep Timing; Electric Light; Non-Industrial; Horticultural subsistence; Vanuatu

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## Glossary

Bislama	The national language of Vanuatu
Kava	A beverage of chewed kava root, which has pharmacological effects
Nakamal	A traditional gathering place for ceremonies including kava drinking.
Ni-Vanuatu	Demonym for peoples indigenous to Vanuatu
Social Jetlag	The mismatch between circadian (biological) time and social time



# Chapter 1.

## Introduction

How much sleep humans really need has been a highly debated topic (Ferrara & Gennaro, 2001). Although sleep is perceived by some as a nuisance, the average person spends approximately 1/3 of their lives asleep. This would be an exorbitant amount of time to spend on something that lacked benefit, but the function and benefits of sleep have been an enduring mystery. Two biological processes regulate sleep and wake cycles; the circadian clock, and the sleep homeostat (Borbély, 1982). There are many aspects of modern society that disrupt these biological systems, notably, electric light. The current research aims to explore to what extent, the modern convenience of electric light may be altering biological sleep patterns, and what “natural” sleep duration is without the influence of electric lighting.

### 1.1. The Circadian Clock

The Earth’s axial rotation produces predictable daily cycles of environmental light and dark that have shaped the evolution of human physiology and behavior. The suprachiasmatic nuclei (SCN) located in the hypothalamus of the brain, acts as the master circadian clock which orchestrates cellular clocks in the rest of the brain and body. The SCN receives direct input from the retina regarding environmental light levels and uses this information to synchronize daily rhythms of physiology and behaviour to the solar day (Mistlberger & Rusak, 2005). As diurnal animals, humans are synchronized such that activity occurs during the daytime and sleep during the nighttime. This adaptation facilitates anticipation of, and preparation for, predictable environmental changes such as dawn and dusk. Anticipation of these events enables access to valuable resources such as food, mates, and avoidance of predators. The timing and duration of sleep in humans is determined to a large degree by this circadian clock (Mistlberger, 2015). Sleep timing is kept synchronized to solar time (a process called entrainment) by phase adjustments of the clock to changes in light exposure at specific times of day. Phase response curves demonstrate that the phase of the clock, and consequently the timing of sleep-wake, is delayed (shifted later) in response to light in

the evening and early night, and advanced (shifted earlier) in response to light in the late night and morning (Czeisler et al., 1989; Minors, Waterhouse, & Wirz-Justice, 1991). This pattern of response to light allows for adaptation of seasonal changes to daylength (photoperiod).

Light information is received by intrinsically photosensitive ganglion cells in the retina and transduced to electrochemical signal via the photopigment melanopsin (Hattar et al., 2002; Foster & Hankins, 2002). Melanopsin is especially reactive to light in the blue/green spectrum, with peak sensitivity to wavelengths between 420 - 480nm (Newman et al. 2003). Light information is relayed to the brain via the retinohypothalamic tract that directly innervates the SCN (Hannibal et al. 2002; Hattar et al., 2002). Input through the retinohypothalamic tract synchronizes the timing of cell-autonomous transcription-translation feedback loops comprised of core clock genes in the neurons of the SCN. Cell autonomous clocks in the SCN maintain internal synchrony with each other through coupling mechanisms mediated by signalling by VIP, AVP, and GABA receptors (Mieda et al 2015, Evans et al 2013) to provide a robust timekeeping apparatus whose outputs can then entrain circadian oscillators in other brain regions and tissues throughout the body (Abe et al., 2002; Schibler & Sassone-Corsi 2002). At the behavioural and cellular level circadian parameters can be measured, including the period of the clock (duration of a full cycle), the phase (any point within a given cycle), and the amplitude (the range from peak to trough).

## **1.2. The Sleep Homeostat**

The circadian clock imposes a daily rhythm of sleep propensity and duration by actively promoting alertness in the day, and sleep at night. But sleep propensity and duration also exhibit history dependence. As the amount of time awake increases, so does sleep propensity, the duration of subsequent sleep, and especially the amount of slow wave sleep (non-rapid eye movement stage N3). Due to the circadian clock, the relationship between prior wake time and the propensity and duration of sleep has a prominent non-linear component; the increase in sleep propensity as a function of time awake is much greater during the usual circadian sleep period and decreases during the wake phase. Sleep timing and duration have therefore been modeled as an interaction between a circadian clock, which keeps track of time of day, and a sleep homeostat, which keeps track of the duration of prior wakefulness (Borbely, 1982). The nature of the

sleep homeostat (e.g., what it is tracking) remains uncertain, but the fact that the need for sleep continues to accumulate with time awake even as we cycle from the daily sleep period to the daily wake period indicates that sleep has some important biological function.

### **1.3. The Importance of Sleep**

Until the early 20<sup>th</sup> century, sleep was thought to be a passive activity, where the brain and body were assumed to be turned off (Loomis, Harvey & Hobart, 1935). Even following Hans Berger's 1929 discovery of neural activity patterns during sleep, the primary function of sleep was left unresolved. Many theories about the function of sleep have been posited (Anafi et al., 2019), including hypotheses about energy conservation (Berger & Phillips, 1995), learning and memory consolidation (Walker & Stickgold, 2004), and, most recently, the finding of 'brainwashing' (removal of toxins during sleep; Xie et al., 2013). Although each of these has merit, none alone seem to fully clarify the need for sleep and its associated stages. What is known, however, is that sleep is an absolute necessity, and without proper sleep there can be severe consequences for health and well-being (Banks & Dinges, 2007; Ford & Kamerow, 1989). Individuals seem aware of the value of sufficient sleep, since when it is lacking, they feel the consequences. In fact, sleep deprivation has been used historically, and presently as an interrogation technique, and it is debated whether it constitutes a form of torture (Nordgren, McDonnell & Loewenstein, 2011). Supporting its importance, a plethora of studies highlight the consequences of sleep loss. Restricted sleep has both short- and long-term impacts on human cognition, mental, and physical health (Banks & Dinges, 2007; Mullington et al., 2009).

#### **1.3.1. Sleep Stages**

Sleep is typically classified into 4 stages defined by patterns of electrical activity in the brain as recorded by macroelectrodes pasted on the scalp. The resulting electroencephalogram (EEG) manifests as waves with characteristic frequencies and amplitudes. Stages 1 and 2 (N1 & N2) are considered light sleep since the threshold for awakening is low, and the EEG exhibits low amplitude and high frequency waves compared to deeper stages of sleep. Stage 2 accounts for ~50% of total sleep time and

has been implicated in memory and learning. Slow wave sleep (SWS; stage 3 & 4 now classified as a single stage, N3) has lower frequency and higher amplitude EEG waves and is considered deep sleep since the threshold for awakening is at its highest. SWS accounts for ~15% of total sleep time but increases linearly with the duration of prior waking. SWS is therefore thought to be associated with homeostatic regulation and restorative properties of sleep. Rapid eye movement (REM) sleep is characterized by high frequency, low amplitude EEG waves similar to waking but accompanied by periodic bursts of eye movement and muscle paralysis.

### **1.3.2. Cognitive Function**

Sleep is important for sustaining basic cognitive functioning, including alertness, learning and memory, sensory perception, and emotional processing (Killgore, 2010). Both acute and chronic sleep restriction reduces alertness, vigilance, and attentive processing (Van Dongen, et al., 2003), and lapses in these have consequences for individual and public safety (Leger, 1994; Mitler et al., 1988). Following 24 hours awake, cognitive psychomotor performance (e.g., hand-eye coordination) declines and vehicle driver error (e.g., lane deviations) increases to levels equivalent to that of someone meeting the legal definition of alcohol intoxication (Dawson & Reid, 1997; Fairclough & Graham, 1999). Following sleep deprivation, neuroimaging studies have shown reduced metabolic activity in areas of the brain important for information processing and executive control (Thomas et al., 2000). Restricting sleep to six hours per night for 14 days produces progressive cognitive performance deficits (including working memory and cognitive throughput) equivalent to 2 nights of total sleep deprivation (Van Dongen et al., 2003). In addition to affecting memory performance, sleep loss is also connected with development of neurodegenerative diseases (Kent & Mistlberger, 2017; Musiek & Holtzman, 2016). During sleep, an increased convective flow of interstitial fluid in the brain allows for removal of toxins and waste products that build up throughout the day (brainwashing; Xie et al., 2013). Accumulation of these waste products may be causally connected to dementias like Alzheimer's disease (Games et al., 1995).

### **1.3.3. Mental Health**

Sleep problems are also co-morbid with many mental health disorders (Ford & Kamerow, 1989). The extent to which sleep disturbances contribute to the onset of

depression, schizophrenia, and bi-polar disorder, or result from these disorders is unclear, but there is evidence that impaired sleep exacerbates these conditions (Gruber et al., 2011; Lustberg & Reynolds, 2000; Ng et al., 2015). Those at-risk for bipolar disorder can have sleep abnormalities preceding diagnosis (Ng et al., 2015). Early sleep researchers (e.g. Kleitman) report psychotic-like symptoms following sleep loss, and it has been more recently discovered that neural networks involved in sleep overlap with those implicated in schizophrenia (Wulff et al., 2010). Sleep deprivation can lead to hallucinations, and a gradual progression towards psychosis (Waters et al., 2018). Treating sleep and circadian rhythm disruption can improve psychiatric symptoms of schizophrenic patients (Pritchett et al., 2012). Similarly, bright morning light sufficient to synchronize the circadian clock and sleep-wake cycles can boost mood and alertness (Cajochen, 2007) and is used as a treatment for seasonal depression (Rosenthal et al., 1985).

#### **1.3.4. Physical Health**

Sleep loss affects physical health in addition to mental health; epidemiological studies have revealed associations between short sleep and population health (Alvarez & Ayas, 2004; Breslau et al., 1996; Ford & Kamerow, 1989), while experimental studies support a causal role for sleep restriction in current epidemics such as: metabolic disorder (Knutson et al., 2007; Mullington et al., 2009); heart disease (Ayas et al., 2003); and obesity (Roenneberg et al., 2012; Jean-Louis et al., 2014). Sleep restriction has impacts on immunity: a partial night of sleep deprivation reduces immune cell functioning (e.g. natural killer cells; Irwin et al., 1996). Disruption of sleep-wake cycles is now being connected with cancer, perhaps via increased light exposure at night, a problem especially relevant for night-shift workers (Jia et al., 2013; Stevens & Zhu, 2015). Melatonin is a pineal hormone secreted at night, the onset of which is correlated with the onset of the normal sleep period. Melatonin synthesis is suppressed by light, and there is evidence to suggest that melatonin suppression increases risk of breast cancer (Blask et al., 2005a; Davis & Mirick, 2006; Navara & Nelson, 2007; Stevens et al., 2013; Kantermann & Roenneberg, 2009). All-cause mortality rates were 1.7 times higher in men, and 1.6 times higher in women who slept either less than 6 hours or more than 9 hours, compared to those sleeping 7-8 hours per night (Wingard & Berkman, 1983).

Loss of sleep seems to impact every aspect of health and well-being. Since the prevalence of such health problems is increasing, this begs the question, in today's societies *are we getting enough sleep?*

## **1.4. Are we getting enough sleep?**

### **1.4.1. Evolution of Human Sleep**

Human sleep duration is not only the shortest of all primates, but researchers Samson and Nunn have also shown that humans sleep much less than would be expected (Samson & Nunn 2015). At 7 - 8 hours a night, humans are exceptionally short sleepers when compared to the average primate sleep of 10.3 hours (Samson & Nunn, 2015). Humans are sleeping much less than would be predicted based on brain and body size and are an extreme outlier in the distribution of typical primate sleep length (Samson & Nunn, 2015).

It has been hypothesized that when hominins moved from sleeping in the trees to sleeping on the ground, this allowed for greater stability which increased sleep quality resulting in improvement in waking cognition (Coolidge & Wynn, 2018). Coolidge and Wynn (2018) suggest that without terrestrial sleeping sites, human cognition (i.e. procedural memory consolidation for visual-motor skills and visual-spatial locations) could not have evolved. There is more support for the role of ecological constraints in determining sleep duration (species who forage more, sleep less) than for functional benefits, although functional benefits may play a role in sleep architecture (Samson & Nunn, 2015). Risk of predation is increased in terrestrial environments, so it is likely that there was an increased selective pressure to fulfill sleep needs in the shortest possible time (Samson & Nunn, 2015; Nunn, Samson & Krystal, 2016). Humans have the highest proportion of REM sleep compared to other primates suggesting that humans are more efficient in their sleep (Samson & Nunn, 2015). More efficient sleep would allow for shorter sleep periods and additional benefits of being awake, such as increased opportunity for learning, social interaction and acquisition of skills.

## 1.4.2. Consequences of Light

There has been speculation that sleep duration has declined over time, and there is biological evidence that might suggest this to be an unsurprising development (Bonnet & Arand, 1995; Ferrara & Gennaro, 2001; Webb & Agnew, 1975). The amount of sleep we get is controlled to a large degree by the circadian clock (Mistlberger, 2015), and the circadian clock is controlled to a large degree by exposure to light (Czeisler et al., 1989; Minors, Waterhouse, & Wirz-Justice, 1991). The advent of electricity and its pervasive adoption in recent evolutionary history has allowed for 24 hour access to light (and light emitting technologies) that invade the environmental and biological night. Constant stimulation alone is likely sufficient to affect sleep, but the light emitted from cell phones, computer monitors, televisions, etc. can disrupt sleep by activating arousal circuits in the brain, and by shifting the circadian clock (Cajochen, 2007; Cajochen et al., 2011; Chang et al., 2015).

In modern industrialized societies, where timing of behaviours is arguably dictated to a greater extent by social time than by environmental cycles, light remains the strongest synchronizer of our circadian clocks (Vetter et al., 2011). With on-demand access to electric lighting, it is likely that exposure to light outside daytime hours has increased, while largely indoor lifestyles reduce exposure to natural light during the day. Those living in large urban areas especially, are becoming less synchronized to environmental light-dark cycles, and more to self-imposed light-dark cycles (Roenneberg, Kumar, & Mellow, 2013). Extension of daylight hours by increased use of electrical light in the evening has delayed the sleep-wake cycle relative to sunset and sunrise (Czeisler et al., 1989; Khalsa et al., 2003; Gooley et al., 2011). Even low intensities of evening light (e.g. ~180 lux) are sufficient to delay the phase of the circadian clock (Boivin, Duffy, Kronauer & Czeisler, 1996; Czeisler et al., 1989). In electrically lit environments, late bedtimes cause delays in the circadian rhythm of melatonin (Burgess & Eastman, 2004), and, if wake onset is fixed by social schedules (e.g., work, school, parenting), then nocturnal sleep will be restricted, and daily sleep duration is likely to decrease. As Webb and Agnew (1975) summarize, “we go to sleep when we wish but we get up when we must.” Social obligations disrupt the natural sleep-wake cycle by forcing individuals to awaken abruptly by the alarm clock during their biological night when the brain and body may still be producing signals that promote sleep. This mismatch between circadian (biological) time and social time is

now formally recognized as 'social jetlag' and can cause significant reductions in sleep duration (Wittman et al., 2006). Social jetlag is demonstrated by markedly shorter sleep on work days, compared to weekends (Roenneberg et al., 2012). Lengthened sleep on weekends suggests not only that rigid modern work schedules are truncating sleep, but also that accumulated sleep debt is being recovered on free days (Wittmann et al., 2006). Mathematical modelling data show higher levels of social jetlag under conditions with electrical light at night and reduced natural daytime light, compared to natural lighting (Swaminathan, 2017). Increases in social jetlag may cause a reduction in sleep length in industrialized nations, but the prevalence and degree of social jetlag is still being explored.

High intensities of daytime light are effective at decreasing sensitivity to evening light (Hébert et al., 2002; Higuchi et al., 2007). However, people in industrialized countries spend much of their time in indoor environments which are lower in light levels relative to the outdoors (Wright et al., 2013). Dynamic lighting technologies that simulate natural light are growing rapidly, but humans in the industrialized world still must spend many waking hours in homes, schools, and workplaces, bathed in light whose spectral characteristics and intensities differ markedly from those of sunlight (Wurtman, 1975). Throughout human evolutionary history light was constrained to the daytime, so light is intuitively connected with awake and alert states. Outdoor light levels are at least 10,000 lux on a clear day, and 1000 lux when overcast. A study conducted in Helsinki, Finland found both young and old adults spent less than 40% of their waking day in light levels above 100 lux (Scheuermaier, Laffan & Duffy, 2010). Office workers exposed only to electric indoor light during the day have shorter sleep duration, reduced sleep efficiency, and lower levels of well-being (Boubekri et al., 2014; Figueiro et al., 2017). High daytime light promotes stronger (i.e. higher amplitude) circadian rhythms and regular sleep-wake cycles (Ancoli-Israel et al., 2003; Park & Tokura, 1999; Takasu et al., 2006). Nighttime light increases alertness, perhaps through suppression of melatonin, therefore in addition to the phase delaying effects of light, initiation of sleep may also be more difficult due to the acute alerting effects of light (Cajochen, 2007; Figueiro, Nagare & Price, 2018). Late wake times also phase delay the melatonin rhythm (Burgess & Eastman, 2006), therefore delayed sleep timing due to evening light may self-perpetuate as individuals miss out on correcting phase advancing light in the morning.

In a small but instructive study, a group of campers exposed only to natural outdoor light, experienced significantly higher daytime light, significantly less evening light, earlier circadian phase (melatonin onset), earlier timing of sleep and wake, and a reduction in inter-individual variation in sleep timing (Wright et al., 2013). Despite an earlier timing of sleep-wake, sleep duration remained unchanged in the camping environment (Wright et al., 2013). It may be the case that these individuals had less restrictive morning social obligations in their daily lives (e.g. students, self-employed), and therefore experienced less social jetlag while in electrically lit environments, compared to populations in other studies. Webb & Agnew 1974a (as cited in Webb & Agnew, 1975), allowed 14 subjects with self-reported sleep duration of 7.5-h to sleep ad-libitum for two weeks without access to environmental cues. Their average daily sleep increased to 8.6-h per day when freed from time limitations. A similar increase in sleep duration was observed in subjects exposed to a 14h night (lights off) for a week or more in a laboratory setting (Barbato et al., 1994). Although persuasive, Webb and Agnew (1975) cautioned that increased sleep is not conclusive evidence of chronic sleep loss, as it is possible that if given the opportunity, we may sleep in excess of our physiological needs, in the same way we may overconsume food and drink.

These multiple lines of evidence lead to conjecture that the average person in the industrialized world sleeps less than the average person prior to industrialization, that this amount is not physiologically optimal, and that this may underlie negative trends in population health.

## 1.5. Modern Sleep

*“Urban human sleep patterns are no more natural than those of the laboratory mice”*

*(Lockley & Foster, 2012, p. 49)*

With increased complaint of fatigue (Bliwise, 1996; Hicks, Fernandez, & Pellegrini, 2001), backed by knowledge of the effects of light on human biology, it has become a common belief that the modern world is chronically sleep deprived (Bonnet & Arand, 1995). Although the rationale is compelling, the degree to which industrialization has reduced average daily sleep duration may be overestimated and is controversial

(Harrison & Horne, 1995). Historical reports of ancestral sleep are based on non-systematic observation. In *The Sleep We Have Lost*, Robert Eckrich (2001) reports of sleep durations between 6 - 8 hours in pre-industrial Europe, as well as citing instances of poor sleep quality, fragmented and bimodal sleep patterns, and a past belief that short sleep is natural, captured in the statement "Nature requires five, Custom takes seven, Laziness nine, And wickedness eleven." (p. 349).

Quantitative examination of this question has produced mixed results, with different measures yielding different trends. Studies using self-report (retrospective or diary based) show declining sleep into modern day. Finnish survey data showed a small (4%) decrease in sleep duration from 1972 to 7.32 hours per night in 2005 (Kronholm et al., 2008). In Denmark, despite variation over time, the number of hours of total sleep (range 7.63 – 8.38 hours) remained the same in 2009 as it had been in the mid 1960's, although an increase in women's employment rates was associated with a 22-minute decrease in women's sleep durations (Bonke, 2015). In the United States, between the years of 1975 – 2006, an increase in work hours was associated with sleeping less than 6 hours (Knutson et al., 2010). Upon examination of US national health survey data, Jean-Louis et al., (2014) found that prevalence of short sleep (< 6 hours) increased significantly in adults between 1977 and 2009 to 29.1%. Another study found self-reported sleep duration in US adults decreased from 7.4 hours in 1990 to 7.18h in 2012, and the number of individuals sleeping less than 6 hours increased by 31% between 1985 and 2012 (Ford, Cunningham, & Croft, 2015). Sleep in college students declined from 7.3 hours in 1978 to 6.82 hours in 1988 (Hicks et al., 1989). Even more striking was a follow up study showing decline in sleep satisfaction: 71% of college students reported dissatisfaction with their sleep in 2000, compared with 53% in 1988 and 24% in 1978 (Hicks, Fernandez, & Pellegrini, 2001). Although there is value in such measurements of self-reported sleep, individuals are quite bad at accurately reporting their own sleep, consistently overestimating sleep duration and quality (Lauderdale et al., 2008). More detailed time-use diaries show increases in amounts of sleep over the past few decades (Lamote de Grignon Pérez et al. 2019; Leech, 2017). A review of literature using objective measures of sleep durations (e.g. polysomnography, actigraphy) across industrialized countries found no significant decrease over the last 50 years (Youngsteadt et al., 2016). Systematic review by Bin, Marshall & Glozier (2012) examining studies from 15 countries in Europe, North America and Asia found no

evidence for systematic change in self-reported sleep duration, with some countries showing increases, and others decreases. This may suggest that cultural factors, variation in demographic structure, economy, social obligations/work hours, and technology use may play a role (Bin, Marshall & Glozier, 2012).

Another method gaining prevalence for measuring sleep/wake behavior is the use of wrist-worn actimetry sensors that measure gross motor movement for identification of activity/rest patterns (aka actigraphy). Because the method of actigraphy has been validated against polysomnography (PSG; e.g. Cole et al., 1992; de Souza et al., 2003; Full et al., 2018; Marino et al., 2013) and is minimally invasive compared to PSG, it has rapidly become recognized as a useful tool for extending sleep measurements out of the lab and into the field. There is evidence to suggest that collection of 3 - 7 days of actigraphy recording provides similar accuracy to that of a 2-week recording (Rowe et al., 2008). In recent years, researchers have exploited this technology to examine modern sleep duration.

Table 1.1 shows recently reported sleep durations in parts of the industrial world (upper section) measured by actigraphy using the Actiwatch (currently Phillips Respironics, Inc.). Studies were included if they reported data from healthy adults (> 18 years of age) on non-restricted sleep schedules. If reports included analysis with multiple Actiwatch software settings (e.g. different activity sensitivity thresholds), only the results using default settings were included in the table, for the purpose of fair comparison with the present study results. Average sleep durations range from 5.62 to 7.94 hours across studies, with a grand average of 6.57 hours.

Review of systematic quantitative research provides a picture of what sleep is like in today's developed populations, but it doesn't resolve the debate around whether industrialization has decreased overall sleep, nor does it reveal how much sleep is needed, or how modern sleep compares to that of our ancestors.

**Table 1.1. Comparison of Industrial and Non-Industrial Sleep Durations Measured by Actigraphy**

Authors	Pub year	Location	Device type	N	N Female	Age Mean	Age SD	TST Mean (mins)	TST SD (mins)	TST Mean (hours)	TST SD (hours)	Sleep Efficiency Mean %	Sleep Efficiency SD	Lighting (Y/N)	Season	Lifestyle
Boubekri et al.,	2014	USA	Actiwatch-L (Mini Mitter, Co.)	10				429.65	39.84	7.16	0.66	89.35	4.22	Y		Windowless Office workers
Boubekri et al.,	2014	USA	Actiwatch-L (Mini Mitter, Co.)	11				476.31	45.23	7.94	0.75	91.24	3.29	Y		Window Office workers
Carnethon et al.,	2016	USA (Chicago)	Actiwatch-2 (Phillips Respironics)	496	298	47.80	8.20	420.92	63.22	7.02	1.05			Y		19% Shift-workers
Cellini et al.,	2016	USA	Actiwatch AW-64 (Phillips Respironics)	30	15	19.24	0.95	358.38	60.63	5.97	1.01	77.98	8.73	Y		
D'Angelo et al.,	2015	Italy	Actiwatch (Mini Mitter, Co.)	12	11	44.00	11.00	428.00	54.00	7.13	0.90			Y		
Lauderdale et al.,	2008	USA (Chicago)	Actiwatch AW-16 (Mini Mitter, Co.)	647	409	42.9	3.60	363.60	69.60	6.06	1.16			Y		
Lee et al.,	2017	Korea	Actiwatch-2 (Royal Philips, Amsterdam)	16	10	22.8	2.80	387.30	98.30	6.46	1.64			Y	May - July	Students
Leger et al.,	2018	Italy	Actiwatch AW-64 (Cambridge Neurotechnology)	13	9	38.00	10.77	423.54	46.06	7.06	0.77	93.01	2.96	Y		
Matsuo et al.	2016	Japan	Actiwatch (Phillips Respironics)	20	9			406.10	37.21	6.77	0.62			Y		
Matthews et al.,	2018	USA (Pittsburg)	Actiwatch AW-16 (Respironics)	223	110	59.9	7.20	346.80	53.40	5.78	0.89			Y		
Pati et al.,	2007	India	Actiwatch AW-64 (Mini Mitter, Co.)	35	13			337.20	49.70	5.62	0.83	76.05	1.23	Y		
Quante et al.,	2018	USA or Finland	Actiwatch Spectrum AWS (Philips Respironics)	22	13	32.3	11.40	444.60	53.70	7.41	0.90	92.40	2.10	Y		
Rupp & Balkin	2011	USA	Actiwatch-64 (Mini Mitter, Co.)	29	9	24.3	5.40	426.00	16.70	7.10	0.29	89.30	3.40	Y		Civilian+active-duty military
Tonetti et al.,	2018	Italy	Actiwatch AW-64 (Cambridge Neurotechnology)	32	14	37.94	12.23	402.06	50.10	6.70	0.84	91.36	3.26	Y		
Tonetti et al.,	2008	Italy	Actiwatch AW (Cambridge Neurotechnology; Mini Mitter, Respironics Inc)	12	6	22.97	2.62	370.17	41.27	6.17	0.69	86.62	7.18	Y		
Ustinov & Lichstein	2013	USA	Actiwatch AW-64 Mini Mitter, Co.)	60	34	47.70	8.90	403.60	44.30	6.73	0.74	85.1	5.50	Y		
<b>Industrial Electric (n = 16 studies)</b>																
Average						<b>36.65</b>	<b>7.09</b>	<b>401.51</b>	<b>48.32</b>	<b>6.57</b>	<b>0.82</b>	<b>87.24</b>	<b>4.19</b>			
StDev						<b>12.57</b>	<b>3.93</b>	<b>38.33</b>	<b>20.21</b>	<b>0.56</b>	<b>0.36</b>	<b>5.94</b>	<b>2.31</b>			

Authors	Pub year	Location	Device type	N	N Female	Age Mean	Age SD	TST Mean (mins)	TST SD (mins)	TST Mean (hours)	TST SD (hours)	Sleep Efficiency Mean %	Sleep Efficiency SD	Lighting (Y/N)	Season	Lifestyle
Knutson	2014	Haiti	Actiwatch-64 (Mini Mitter)	58	29	48.6	16.80	420.00	60.00	7.00	1.00	88.7	5.40	N	Jan-Feb 03	
Samson et al.,	2017b	Madagascar	Motionwatch 8 actigraph (CamNtech)	21	9	40.3	4.60	390.00	96.00	6.50	1.60	70.70	12.20	N	Jul-Aug 15.16	Rice Farming
Yetish et al.,	2015	Namibia; San	Actiwatch-2 (Phillips Respironics)	15		38.5	14.00	372.00	36.00	6.20	0.60	84.00	3.70	N	Summer	Hunter-Gatherer
Yetish et al.,	2015	Tanzania; Hadza	Actiwatch-2 (Phillips Respironics)	10		36.6	11.80	378.00	37.80	6.30	0.63	82.00	5.80	N	May 2013	Hunter-Gatherer
Yetish et al.,	2015	Bolivia; Tsimane	Actiwatch-2 (Phillips Respironics)	12		37.0	15.10	342.00	69.00	5.70	1.15	82.00	5.50	N	Summer	Hunter-Horticulturalist
Samson et al.,	2017a	Tanzania; Hadza	Motionwatch 8 actigraph (CamNtech)	21	21	34.9	14.30	375.00	43.00	6.25	0.72	68.90	7.70	N	Jan-Feb	Hunter-Gatherer
Samson et al.,	2017a	Tanzania; Hadza	Motionwatch 8 actigraph (CamNtech)	12	0	35.6	14.70	372.00	43.00	6.20	0.72	68.70	7.80	N	Jan-Feb	Hunter-Gatherer
Siegmund et al.,	1998	Papua New Guinea	Actometer, ZAK GmbH, Simbach, Germany	23	11	32.96	12.08	504	63	8.40	1.05			N		Horticulturalists & Fishermen
Prall et al.,	2018	Namibia	Actiwatch-2 (Phillips Respironics)	29	0	36.00	14.50	285.60	55.20	4.76	0.92	60.33	9.00	N		Agropastoralist
Prall et al.,	2018	Namibia	Actiwatch-2 (Phillips Respironics)	46	46	35.50	15.40	355.20	57.00	5.92	0.95	70.20	8.80	N		Agropastoralist
Beale et al.,	2017	Mozambique	ActTrust AT0503	37	13	39.10	11.00	433.80	10.20	7.23	1.03	78.50	1.47	N		Rural
Beale et al.,	2017	Mozambique	ActTrust AT0503	37	18	28.70	6.60	436.80	10.80	7.28	1.09	83.30	1.52	Y		Urban Market Town
Pilz et al.,	2018	Brazil	Actiwatch 2: Philips Respironics ActTrust: Condor	27	14	45.20	18.2	529.80	36.00	8.83	0.60			N	Winter	Farmers-housekeepers
Pilz et al.,	2018	Brazil	Actiwatch 2: Philips Respironics ActTrust: Condor	18	11	45.20	18.2	459.60	48.00	7.66	0.80			Y 30 years	Winter	Farmers-housekeepers
de la Iglesia et al.,	2015	Argentina; Toba	Actiwatch-L (Mini Mitter)	6	3	17.30	2.40	418.80	10.80	6.98	0.44			N	Summer	Unemployed
de la Iglesia et al.,	2015	Argentina; Toba	Actiwatch-L (Mini Mitter)	6	3	28.80	5.80	376.20	16.80	6.27	0.67			Y	Summer	Unemployed
de la Iglesia et al.,	2015	Argentina; Toba	Actiwatch-L (Mini Mitter)	8	4	27.40	8.77	508.20	39.00	8.47	0.65			N	Winter	Unemployed
de la Iglesia et al.,	2015	Argentina; Toba	Actiwatch-L (Mini Mitter)	11	8	29.10	8.96	451.80	36.00	7.53	0.60			Y	Winter	Unemployed
Moreno et al.,	2015	Brazil	Mini Basic Motionlogger, (Ambulatory Monitoring, Inc)	20	0	35.70	8.94	504.00	74.40	8.40	1.24			N	May-July	Rubber Tapper Free Days
Moreno et al.,	2015	Brazil	Mini Basic Motionlogger, (Ambulatory Monitoring, Inc)	17	1	38.10	10.72	492.00	74.40	8.20	1.24			Y	May-July	Rubber Tapper Free Days
<b>Non-Industrial Non-Electric (n = 15 studies)</b>																
Average						<b>36.04</b>	<b>12.17</b>	<b>412.56</b>	<b>48.69</b>	<b>6.88</b>	<b>0.89</b>	<b>75.40</b>	<b>6.74</b>			
StDev						<b>7.14</b>	<b>4.41</b>	<b>71.19</b>	<b>22.79</b>	<b>1.19</b>	<b>0.31</b>	<b>8.89</b>	<b>3.03</b>			
<b>Non-Industrial Electric (n = 5 studies)</b>																
Average						<b>33.98</b>	<b>10.06</b>	<b>443.28</b>	<b>37.20</b>	<b>7.38</b>	<b>0.88</b>					
StDev						<b>7.44</b>	<b>4.95</b>	<b>42.59</b>	<b>25.57</b>	<b>0.71</b>	<b>0.28</b>					

## 1.6. Traditional Sleep

Natural patterns and durations of human sleep (without external influence) are essentially unknown. Understanding of ancestral sleep is difficult because information prior to the advent of electric lighting is limited, and what exists is based on subjective reports rather than direct systematic observation (i.e. Ekrich, 2001). To estimate sleep in more natural environments, studying sleep patterns in modern communities living traditional lifestyles without electric lighting could provide value, although such communities are rapidly disappearing. The United Nations has made clean and affordable energy a goal to achieve for its members by 2030 ([www.un.org/sustainabledevelopment](http://www.un.org/sustainabledevelopment)). Although knowledge of the adverse effects of light at night is vague, access electric light is growing dramatically, with light pollution (measured by sky brightness) rates increasing by up to 20% per year depending on geographic location (Hölker et al., 2010). More than 80% of the world live under light polluted skies (Falchi et al., 2016). As rates of electrification increase, a cross-cultural approach to studying sleep could provide tremendous value for comparison of sleep across levels of industrialization and urbanization.

Ekrich (2001) recounts historical reports of explorers and British Europeans before the industrial revolution. In *The Sleep We Have Lost*, he writes: “people fled to their beds soon after sunset to cope with the onset of darkness. Because the light afforded by candles was available chiefly to the wealthiest families, the members of most households, presumably, were unable or too fearful, once enveloped by darkness, to work or socialize” (p. 348). Examination of sleep-in modern-day societies that do not have access to electricity may provide insight into the extent that such reports describe traditional sleeping patterns.

Samson et al., (2017a) propose two hypotheses that may be clarified through sufficient investigation of sleep across levels of industrialization. The *postindustrial sleep degradation hypothesis* predicts, as common belief holds, that sleep duration and quality in industrialized nations is impaired, compared to non-industrial societies. Conversely, the *developing economy sleep degradation hypothesis* predicts that sleep in developing non-industrial settings is impaired due a greater exposure to environmental noise and temperatures. Several observational field studies have recently been undertaken and provide a unique and valuable perspective on modern sleep.

### **1.6.1. Support for the ‘Postindustrial Sleep Degradation Hypothesis’**

Communities that contain households with and without electricity, provide a good natural model to study the effects of lighting on sleep. Peixoto et al., (2009) found that Brazilian students without electric lighting in their homes had earlier sleep timing on school days compared to students with electricity. They found a significant weekday interaction between school schedule and electricity, where sleep durations were longest in students without electricity who were taking morning classes, as opposed to evening classes that kept them awake later. Louzada and colleagues (2004) studied the sleep patterns of one Brazilian female adolescent pre-and-post electrical installation in her home. No differences were found in sleep parameters measured with actigraphy 3 weeks, or 4 months following electrical installation. When weekdays and weekends were examined separately, however, there was a 40-minute delay in average weekend sleep onset after installing electricity. Sleep timing on weekdays remained consistent, revealing a stronger effect of early school start times than the electrical light.

Study of societies living traditional subsistence lifestyles have reported varied results, but several are in line with the postindustrial sleep degradation hypothesis. Study of Toba hunter-gatherers in Argentina found that sleep was shorter in a community with electric lighting, compared to a neighbouring community without electricity (de la Iglesia et al., 2015). The decrease in sleep in electric communities was due to a delay in sleep onset, rather than wake up time, although a seasonal change in sleep duration was due to change in wake timing. Sleep fragmentation was increased in the summer, potentially due to uncomfortably high nighttime temperatures. Regardless of season, both electric and non-electric communities went to bed after sunset. In the winter, wake time occurred at sunrise, whereas in the summer the Toba woke after sunrise. The observed difference in sleep duration between electric and non-electric communities was smaller in the summer, during longer photoperiods. Similarly, Brazilian rubber tappers living in Amazonian villages with electric light also showed shorter sleep duration and delayed sleep onset (when assessed by questionnaire) compared to those without electricity, but the difference in sleep duration was only on work days (Moreno et al., 2015). Objective measure of sleep in the same sample also showed delayed sleep onset in those with electricity, but no significant difference in sleep duration. On work days they woke before sunrise, and just after sunrise on free days. Investigation of varying levels of industrialization in Brazil found decreasing sleep duration with

increasing historical access to electricity (Pilz et al., 2018). Those who had access to electricity for the longest (> 30 years) slept the least (7.66 hours; Pilz et al., 2018). Beale and colleagues (2017) also found some support for the postindustrial sleep degradation hypothesis in Mozambique. Individuals in rural Mozambique had similar sleep durations to those in a nearby urban community, but urbanization, including access to electric light, was associated with delayed sleep timing (Beale et al., 2017). In general, urban populations have been found to be exposed to more light pollution, and have been reported to have shorter sleep periods compared to rural communities (Louzada et al., 2003). Beale et al., (2017) also found evidence for associations between sleep efficiency and bed type, daytime activity, and number of co-sleepers. Individuals in the urban community had higher levels of sleep efficiency although there was no difference in subjective rating of sleep efficiency between the urban and rural communities.

Another piece of evidence in support of the postindustrial sleep degradation hypothesis comes from study of a non-electric subsistence agrarian/fishing community on the Trobriand Islands in Papua New Guinea (Siegmund et al., 1998). Sleep duration ranged from 7 – 10 hours per night and was 8.4 hours on average (Siegmund et al., 1998). This is longer than the average sleep duration of 6.57 hours reported from actigraphy studies in industrialized populations (Table 1.1)

Findings from these studies show at least some evidence that increased access to electricity leads to shorter sleep duration, or delayed sleep timing. To date, only a small sample of electrified communities living traditional non-industrial lifestyles have been studied. Sleep durations for these studies are presented in Table 1.1 and show an average of over 7 hours. As electrification increases globally, the number of small-scale non-industrial communities with electricity will grow, providing new opportunities to study the effects of electric light while living traditional lifestyles.

### **1.6.2. Support for the ‘Developing Economy Sleep Degradation Hypothesis’**

By contrast, study of some non-industrial non-electric hunter-gatherer, agrarian, and pastoralist societies in Africa and South America may show support for the developing economy sleep degradation hypothesis. Recent studies have reported short average sleep durations in non-electric societies (Table 1.1), reported to be shorter than

those in industrialized Western societies (Yetish et al., 2015, Samson et al., 2017, Prall et al., 2018). An agrarian village in Egypt was reported to have insufficient sleep (as defined by the National Sleep Foundation) compared to those in urban Cairo (Worthman & Brown, 2013). Samson et al. (2017a) introduced light into an agricultural rice farming community in Madagascar (400 lumens for 7 days). Increased exposure to light at night did not alter sleep duration (Samson et al., 2017a). Average nocturnal sleep duration in this population was 6.5 hours, although they did nap on 88% of the days recorded, with an average nap duration of 55 minutes. Individuals also had fragmented sleep on 49% of the nights recorded, where they were awake in the night for greater than 20 minutes. High levels of noise were measured at night.

These studies in aggregate suggest that industrialization does not necessarily lead to shortened sleep compared to traditional lifestyles.

### **1.6.3. Characteristics of Non-Electric Sleep**

An overview of actigraphy research shows that average recorded ranges of sleep duration in non-industrialized populations (~ 4.7 - 8.8 hours) overlap with those of industrialized populations and do not show a clear indication that sleep is different in one or the other (Table 1.1). Although individual studies may show support for the developing economy sleep degradation hypothesis, or postindustrial sleep degradation hypothesis, taken together, there seems to be no consistent support for either.

Since consensus is lacking regarding these hypotheses, further research is necessary to understand the characteristics of sleep, and how sleep differs within non-industrial contexts without electricity. Yetish and colleagues (2015) studied three different non-industrial hunter-gatherer groups, including the Hadza of Tanzania, the San of Namibia, and the Tsimane of Bolivia. Average sleep durations ranged between 5.7 - 7.1 hours per night. Sleep onset was several hours after sunset, and daily variation in sleep duration was linked to the time of sleep onset, rather than wake time. Wake occurred most often before sunrise and was closely linked to the trough of environmental temperature, potentially suggesting that the daily rhythm of environmental temperature may act to regulate sleep and wake. Sleep was consolidated to the nighttime with no fragmentation, and daytime napping occurred on less than 22% of the days recorded (Yetish et al., 2015). Another study of the Hadza found higher instance of napping,

where 100% of the individuals studied napped, and a total of 54% of the days recorded contained naps of an average length of 48 minutes (Samson et al., (2017b)). Increased time awake at night led to an increase in naps the following day. Some fragmentation in nocturnal sleep was found and was increased with increases in humidity (therefore decreased sleep efficiency; Samson et al., 2017b). Average nocturnal sleep duration was 6.25 hours, time in bed was 9 hours, and sleep efficiency was 68.9% (Samson et al., 2017b). Prall and colleagues (2018) studied the effect of age and sex specific labour demands on sleep in agropastoralists of Namibia. Nocturnal sleep duration averaged 5.47 hours, and total sleep time remained under 6 hours even when daytime naps were included. Men slept less (4.76 hours) and had lower sleep efficiency (60%) compared to women (5.92 hours; 70%). Those with longer sleep durations not only had earlier sleep onset, but also later wake times. Although men and women had similar sleep onset, wake up time was earlier and more variable for men. Men and boys had time restricted labour demands, where it was common to herd and graze livestock before sunrise to avoid the hottest time of the day (Prall et al., 2018). This suggests that social jetlag is not a modern phenomenon. Increased number of co-sleeping adults increased total sleep time and sleep efficiency. The authors suggest that additional adults sharing one sleeping space helps divide the work involved in caring for children throughout the night (Prall et al., 2018). Knutson (2014) measured sleep durations in a non-electric community in Haiti. Although average time spent in bed was 9.3 hours, individuals slept for only 7 hours. No age or sex related differences in sleep durations were found, but sleep fragmentation was surprisingly less in older individuals compared to young adults. A greater number of individuals sharing a room tended to decrease sleep maintenance (Knutson, 2014). In Papua New Guinea, Trobrianders had social requirement to start subsistence work together in the morning, and more variability was seen in sleep onset than wake time (Siegmund et al., 1998).

The degree to which these findings are specific to lifestyle or the ecology of a specific region, independent of access to artificial light, is uncertain. Data from additional non-industrial societies, living other lifestyles, in other climates, are therefore needed.

## **1.7. Current Research**

Using personal interviews and actigraphy, the present study examined sleep timing and duration in indigenous residents (demonym: ni-Vanuatu) living traditional,

small-scale subsistence horticultural lifestyles, in villages with or without access to electric light, on Tanna Island, Vanuatu. This study population provides some unique advantages, including homogeneity of ethnicity and lifestyle on the island, and relatively low seasonal variation in climate and daylength. Having access to homogeneous populations with and without electricity allows for a direct comparison of the effect of electric lighting on sleep, which is a perfect natural research model, and increasingly rare as electricity becomes more pervasive.

This is the first study of objectively measured sleep in Vanuatu, and exploratory in nature. The primary objective was to test the hypothesis that on-demand access to electric light at night leads to delayed sleep timing and shorter sleep duration.

## Chapter 2.

### Materials & Methods

#### 2.1. Field Preparation

Preparation for data collection in the field included several steps (e.g. research about the culture and languages, budget preparation, equipment procurement, personal health considerations), and careful consideration of research design, including, outlining of collection dates and procedures, creation of interviews, design of record-keeping and note-taking systems. Appendices A through D contain documentation and information about data collection in the field.

##### 2.1.1. Planned Data Collection

The Republic of Vanuatu is an archipelago nation located in the South Pacific Ocean (see Appendix B for map). It was planned that participants would be recruited from both coastal villages where there is access to electricity, and inland villages ~10km east with no access to an electric grid, on Tanna Island (approximate coordinates 19.53° S, 169.27° E). To assess sleep parameters, data from Actiwatch-2 actigraphy monitors (Phillips Respironics, Murrysville, PA), and participant interviews would be collected in both areas.

Seven nights of actigraphy data per participant would provide an accurate assessment (Rae et al., 2018), so it was planned that data collection would span 24 days to allow for three weeks of collection, with one night in between to download data and charge the Actiwatches (see Appendix C for schedule). Out of 45 Actiwatches in our possession, 41 were operational which allowed for a total sample size of 123 ( $n = 61$  from electric communities, and  $n = 62$  from non-electric communities), and a total of 861 nights of data for analysis.

Since biological sex impacts sleep (Tonetti, Fabbri & Natale, 2008), it was of interest to collect data from both males and females. Infant data were also collected for a separate research question/project relating to the sleep of infants in non-industrial contexts, specifically, the effect of co-sleeping on infant-parent sleep quality. This data

will not be presented here. For this reason, we wished to recruit co-sleeping families (i.e. mother-father-infant triads). The initial goal was to collect data from mother-father-infant triads as well as males and females who were not currently caring for infants, in equal numbers per week.

Although participants were instructed not to remove the Actiwatch, it was a very important consideration that watches would not get mixed up during data collection, especially since several participants may be cohabiting. To ensure that each Actiwatch was recording under the correct subject ID, they were colour coded with stickers or nail polish; red (mother), blue (father/male), yellow (infant), and green (female). This allowed the participant to easily identify which watch they had been assigned. Each Actiwatch ID was confirmed by researchers upon pickup to ensure it matched the watch assigned to that participant.

### **2.1.2. Participant Interview Design**

Interviews from Yetish et al., (2015) were adapted with permission for use in Vanuatu (Appendix A). Interviews were designed, and included 31 questions about demographics, light use, and daytime and nighttime activities. A brief follow-up interview was created to assess whether any events altered a participant's sleep from their normal pattern during the week of data collection. The Pittsburgh Sleep Quality Index (PSQI) was also chosen for administration to participants in the field.

Interview text was translated to Bislama (official language of Vanuatu) by a local English-speaking resident, and then back-translated to English by someone different. This was done to ensure that the meaning of the questions had been retained through translation. Careful discussion with a local research assistant (RA) highlighted some difficulties with wording and language. Any question which was believed to be confusing or unclear was re-worded or eliminated. Questions about bed comfort, chronotype, and daytime sleepiness were unfortunately removed as there was no specific wording that was determined to be easily understood or translate well. Western conceptualization of time and the associated language are not common in the villages of Tanna Island. Retrospective measurement of time, such as minutes, hours, or days is not as common or necessary for life in Vanuatu, as it is in Western society. Interview questions that asked "on average" or "usually" were found to be confusing, and an equivalent phrase in

the local language could not be agreed upon. For these reasons it was decided in the field that the PSQI would not be administered during interviews. It was discovered that some words shared by both languages (i.e. afternoon/aftanun) can have different meanings. For example, “afternoon” in the English language generally means the time of day spanning from noon until ~5:00pm, whereas the same word “aftanun” in Bislama is usually used to refer to a time of day that in English would be referred to as early evening. A hand-drawn pictorial timeline was created and used to reference times of day relative to sunrise and sunset during interviews (Figure A.1., Appendix A).

Part way through the second week of data collection, a question about hut type was added to the interviews. Common dwellings found in Tanna villages have walls and roofs made of grasses and palm leaves, and most people lived in these grass huts. Throughout data collection I encountered dwellings that had walls made with cement, or corrugated tin. The research assistant indicated that these dwellings are still called grass huts, because the roof was made of grasses. As it turns out, hut type is defined based on the material used for the roof, not the entirety of the structure. The material with which the walls were constructed seems relevant to sleep since solid cement would likely offer more protection from outdoor elements than woven grasses. As such, a question was added to assess if dwelling type had elements of tin or cement, however this information was collected for less than half of participants.

Based on my first-hand experience witnessing interviews I believe that the concepts and language between Western culture and Vanuatu are significantly different. This reduces confidence in proper interpretation of the subjective data. Discrepancies in interview responses occurred. For example, a cohabiting married couple from an electric community reported differences during independent interviews; one indicated they did currently have electric lights, whereas the other reported they did not. Similarly, a co-sleeping married couple reported a different number of individuals with which they share a sleeping space. The subjective data is not without value, and some is presented here, but the focus of the present analysis is on the objective actigraphy data measuring lighting and sleep. The subjective data was used to better understand the culture and context behind the objective results.

### **2.1.3. Field Notes & Record Keeping**

Notebooks were prepared with a) a calendar to record any community events that may impact research data (e.g. celebrations); b) instructions for field research assistants in English and Bislama, including pictures; c) instructions for participants in English and Bislama; d) data tables used for record keeping and data collection (Appendix B).

A separate notebook was used to free write any detail that emerged during interviews. For example, “Coastal Subject # 9 says the reason they leave the light on all night while sleeping is for the kids.”

## **2.2. Study Population**

Participants gave verbal informed consent, as outlined by the Office of Research Ethics at Simon Fraser University, Burnaby BC, Canada. Research permits were obtained through the Vanuatu Cultural Centre and permission was additionally obtained by the Lounikavek village Chief, and a well-known and respected female leader within Lounikavek village. Gifts equivalent to \$5 CAD were given to each participant, and a monetary gift was also provided to the host village (~\$500 CAD).

Ninety-one native adult residents were recruited from small-scale rural villages on Tanna Island, Vanuatu. Forty-five individuals were recruited from villages where there is access to electricity, and 46 with no access to electricity. Some data were lost due to equipment failure ( $n = 4$ ) or were excluded due to non-compliance (i.e. extended watch removal;  $n = 4$ ). Data from one female from a non-electric village was excluded after it was discovered that she stayed in an electric village for 4 days during data collection. The final sample size was 39 coastal villagers (electric sample) and 43 inland villagers (non-electric sample). Villagers in both electric and non-electric communities live subsistence horticultural lifestyles. Primary differences between community lifestyles are that coastal villagers may also fish, and they have increased proximity to resources such as a local market, school, and an electrical grid (although not all may have electricity year-round).

Data were collected from males, females, and females who were currently breastfeeding (herein referred to as “mothers”, note that “females” were also mothers,

however not to infants of breastfeeding age at the time of collection). All infants on Tanna Island are breastfed, and co-sleeping is the norm. It is expected that breastfeeding will lead to higher levels of sleep disruption due to mother-infant co-arousal, which is why mothers were maintained as a separate sample. Participants classified as mothers had infants less than 10 months of age, whereas females generally had children 2 years or older (note:  $n = 4$  out of 26 females had no children) and were not breastfeeding.

Since sleep can vary with age and sex (Walch, Cochran & Forger, 2016) it was important to match these between electric and non-electric participants. For example, if a ~30-year-old female from an electric village was recruited, the attempt was made to find someone of the same age and sex in a non-electric village. Ni-Vanuatu do not typically track birthdays, which presented an unexpected challenge for this strategy, thus government ID was requested to determine age. When government ID was not available (many individuals lost such documents in 2015 due to devastation from Cyclone Pam), age was estimated visually or relative to the birth of their peers. For these reasons, age-matching was challenging, but was completed to the best ability. Starting on the second week of data collection photos of each participant were taken for in case they were needed at a later date for age estimation purposes. Most participants from week 1 were retroactively tracked down for photos as well, but photos were not obtained for all. Of those included in the final analysis, average age estimation and other sample characteristics are provided in Table 2.1.

### **2.2.1. Family**

Of all participants in the study, 79% of them reported being married, including 24 participants who were married to other participants (i.e. 12 couples: non-electric  $n = 7$ , electric  $n = 5$ ). Although many families could be considered nuclear families, living apart from one's partner and/or children, marital separation, and having children out of wedlock do happen on Tanna Island. Of those who were married, 82% reported sharing a sleeping space with their partner regularly. Women are responsible for most domestic tasks and child-rearing, although men and women both teach the children necessary skills. Participants included 11 women (non-electric  $n = 5$ , electric  $n = 6$ ) who were single mothers. The average number and estimated age of children between community types are presented in Table 2.1. Number of children in the electric communities ranged

from 0 to 5, whereas in the non-electric communities several families had more than 5 children ( $n = 8$  families had between 6 – 9 children). It was not uncommon to see large variation in age between children. In the electric communities, 20 years existed between the youngest and oldest child in one family, and 22 years in a non-electric community.

**Table 2.1. Sample Characteristics (means  $\pm$  SD)**

	Electric Communities				Non-Electric Communities			
	Males	Females	Mothers	Total	Males	Females	Mothers	Total
<i>n</i>	13	13	13	<b>39</b>	15	13	15	<b>43</b>
Est. Age (yrs)	38.3 (9.5)	33.2 (7.5)	29.1 (6.3)	<b>33.54</b> <b>(8.57)</b>	36.3 (9.3)	34.9 (8.7)	31.4 (8.0)	<b>34.12</b> <b>(8.74)</b>
Age range	21 - 48	24 - 49	20- 43	<b>20-49</b>	22 -53	22 – 46	21 - 43	<b>21-53</b>
Height (ft)	5.62 (0.19)	5.42 (0.16)	5.28 (0.20)	<b>5.44</b> <b>(0.23)</b>	5.57 (0.24)	5.43 (0.21)	5.04 (0.41)	<b>5.34</b> <b>(0.38)</b>
Weight (lbs)	170.8 (23.6)	148.4 (25.0)	148.3 (22.4)	<b>155.86</b> <b>(25.49)</b>	134.7 (30.6)	138.3 (17.1)	129.3 (21.9)	<b>133.82</b> <b>(23.79)</b>
Body Fat %	21.15 (7.35)	30.85 (7.19)	31.08 (6.60)	<b>27.69</b> <b>(8.31)</b>	15.50 (4.77)	28.33 (7.23)	25.47 (6.27)	<b>22.90</b> <b>(8.12)</b>
% Married	92.3%	69.2%	69.2%	<b>79.0%</b>	86.7%	69.2%	86.6%	<b>81.4%</b>
% Sleep with Partner	91.7%	66.7%	44.4%	<b>72.4%</b>	100%	77.8%	92.3%	<b>91.4%</b>
% Have Children	76.9%	85.2%	100%	<b>84.6%</b>	93.3%	92.3%	100%	<b>95.4%</b>
Avg # Children	3.20	2.46	2.54	<b>2.70</b>	3.79	3.16	4.20	<b>3.76</b>
Est. Age Children (yrs)	9.85	10.76	5.56	<b>8.56</b>	8.07	9.87	7.09	<b>7.81</b>
# Co-habiting	4.10	3.15	4.15	<b>3.77</b>	4.33	4.07	5.00	<b>4.48</b>
# Co-sleepers	4.92	3.23	3.61	<b>3.55</b>	5.00	4.15	5.09	<b>4.53</b>

Note: Est. Age is the estimated average age, since age & birthdays are not tracked. Height, Weight & Body fat % were measured using a Tanita UM-028F Scale. All other data was is subjective, collected through interview, and should be interpreted with caution due to reasons described in Limitations section of discussion. # Cohabiting & # Co-sleepers represents the average total number of individuals (adults & children) living together, or sharing a sleeping space (includes individual interviewed).

### 2.2.2. Sleeping Spaces

Sleeping arrangements were variable, but most sleeping spaces consisted of blankets or foam mattresses on grass woven mats on the floor of the dwelling (Image 1,

Panel B). Floors were commonly wood plank, or hard-packed ground. Sleeping spaces are shared by immediate family (i.e. parents & children), and sometimes with extended family as well. Reported average number of total individuals sharing a sleeping space was ~3.5 in electric villages and ~4.5 in non-electric villages (Table 2.1). Grass huts were the most common, with separate huts for sleeping and cooking, although some dwellings were made with elements of cement, tin and/or grass (Figure 2.1., Panel C).

Individuals were asked how many people they “live with in the same house.” In electric communities ~3.7 people (range 1 – 7), and ~4.5 people (range 1 – 8) in the non-electric communities cohabitate on average. Individuals on Tanna don’t spend their days living inside, and “live with” may have a different interpretation, such as refer to immediate close family, possibly who share a garden plot, or who share food/meals. These individuals may sleep in the same or different huts at night. Sleeping arrangements are often flexible and can change readily.

### **2.2.3. Light at Night**

Most subjects, including those in the non-electric villages had small solar powered LED lights that were used at night (Image 1, Panel A). Daily use in the evening hours was reported by 83.7% of participants in the non-electric villages. These lights may be placed on the floor to help provide light for household duties or carried by hand when walking through the village. Light intensity produced by these devices did not exceed 2 lux at 1-meter distance, using the Actiwatch-2 light sensor (Phillips Respironics, Murrysville, PA).



**Figure 2.1. Lifestyle Images**

Panel A: Light sources in non-electric villages; Panel B: Sleeping Spaces; Panel C: Dwelling Types (upper = grass huts, middle = tin huts, lower = cement with tin roofs & some grass)

## 2.2.4. Lifestyle

Coffee beans are exported from Tanna Island; however, caffeinated beverages are not commonly used or readily available in the villages studied. Kava drinking ceremonies are an important daily cultural custom in Vanuatu, for purposes such as storytelling and socializing. Men meet in late afternoon in the nakamal (a traditional gathering place for ceremonies including kava drinking) to drink a beverage of chewed kava root, which has sedative, anxiolytic, and antinociceptive/analgesic properties (Jamieson et al., 1989; Pittler & Ernst, 2000; Capasso & Sorrentino, 2005). Sixty-five percent of male participants reported drinking kava daily. Women are not traditionally permitted to drink kava. Food consists primarily of locally cultivated foods, and during the season of data collection included root vegetables (taro, yam, sweet potato, manioc), seasonal fruit (plantain, oranges, grapefruit, papaya, coconut), and on occasion purchased rice, and chicken, beef, fish or pork for ceremonies/celebrations. Cooking takes place directly over a fire, or with hot stones in an earth oven cooking pit. Although both community types practice primarily subsistence horticultural lifestyles, 23% of the population of each community type reported spending time in the day working for money. Farming is the primary daily activity for 93% of the non-electric community members compared to 41% of electric community members, who report spending more time on other daily activities within the village (e.g. fishing, building). Alarm clocks are not used, daily scheduling is flexible, and meal times are not regimented. All individuals

reported having at least 1 day (Saturday, Sunday or Tuesday) when they do not work in the garden. “Free” days are used for attendance at church, or religious practice (most participants practiced a Christian faith, and a minority follow the John Frum Movement, an indigenous religion and political party). Subjective reports of primary evening activities varied by sex, regardless of access to electricity. Most women (including females without infants and mothers with small infants) report their primary evening activity to be caring for children (85% with electricity, 93% without), and also attendance at church groups, whereas men report spending time in the nakamal (77% with electricity, 73% without). Morning social obligations included early awakening by some women to prepare children for school (electric  $n = 5$ ; non-electric  $n = 1$ ), or on Wednesdays many individuals prepare for, and travel to market to sell produce. The present study did not collect information on the prevalence of school attendance, however it can be noted that electric villages have closer access to schools, and are more closely situated to roads where vehicles travel, therefore it would be easier for individuals in the electric communities to access schools.

### **2.2.5. Environment**

Data were collected over a period of 3 weeks between April 14th and May 8th, 2017. On the first day of recording, sunrise occurred at 5:52 (civil twilight start at 5:30) and sunset at 17:32 (civil twilight end at 17:54). By the last day of recording, sunrise had delayed 8 minutes to 6:00 (civil twilight start at 5:37), and sunset had advanced by 15 minutes to 17:17 (civil twilight end 17:40; National Research Council of Canada, Retrieved from <http://app.hia-ihc.nrc-cnrc.gc.ca/cgi-bin/sun-soleil.pl>). Temperature and humidity were measured with iButtons (Maxim Integrated, San Jose, CA) sampling at 20-minute intervals, placed near sleeping spaces. Average temperatures during this period were ~23.3Deg C (86%RH) in the day and ~21.8Deg C (88%RH) at night in inland non-electric villages (range = 17.6 - 26.6 Deg C; 75% – 96%RH). It was warmer and drier in coastal electric villages with an average ~25.9Deg C (78%RH) in the day and ~23.9Deg C (80%RH) at night (range = 19.6 - 31.6Deg C; 63% - 92%RH). Average daily temperature minimum occurred at approximately 6:20, and maximum between 13:20-14:00, in both communities.

## **2.3. Procedure**

### **2.3.1. Field Procedure**

The aim was to collect data from co-sleeping families, including mother-father-infant triads, in addition to single or married males and females without infants. Upon commencement of data collection, it became apparent that many fathers were away, having been recruited for paid work in construction of a road in the north of the island. As such, it was rare to access full families for co-sleeping analysis. The data collection strategy was altered to collect weekly from mother-infant dyads (with fathers where possible), single or married males (regardless of infant status) and single or married females with no infant. Because fathers on Tanna Island typically take a less active role in infant rearing, it was deemed acceptable to collect males as one homogenous group irrespective of “father” status.

#### ***Actigraphy***

Participants were asked to wear an Actiwatch-2 activity monitor (Phillips Respironics, Murrysville, PA) on their wrist for 7 days. These devices use accelerometers to measure movement at 32hz, which was binned into 15 second epochs, and use a light sensor to record illumination exposures ranging from .01 lux to more than 100,000 lux. Accelerometer technology can be used for defining sleep periods, and is less invasive and cumbersome than polysomnography, and is therefore suitable for use in non-industrial settings.

Participants were instructed not to remove or cover the watch, but abrupt periods of inactivity with invariant or no light level did appear in some records. Because it could not be determined whether the Actiwatch was removed, or if this was a period of napping, reported nap data could be overestimated, although extended periods of such static data (> 2 hours) were excluded from data analysis (see Data Cleaning, Exclusions section).

#### ***Interviews***

Participants were visited during the data collection week to complete an interview about sleep habits and light exposure. The interviews were administered by trained local translators and were conducted in the indigenous language specific to each village.

Because BMI has been shown to affect sleep (e.g. Rae et al., 2018) weight, height and body fat % were recorded (Tanita Body Fat Scale UM-028F). Participants also completed a follow-up questionnaire on day 7, where they indicated if there was anything that had disrupted their sleep from its usual pattern (e.g. illness, celebration, etc).

## **2.4. Data Cleaning**

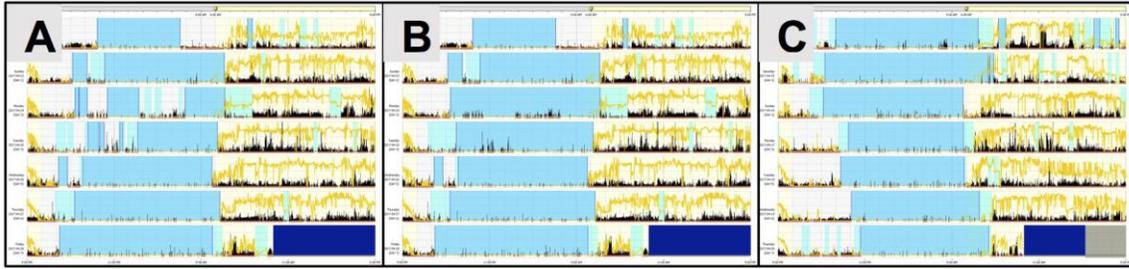
Sleep states were scored by the Actiware 6.0.9 software (Phillips Respironics, Murrysville, PA) using the default settings, except in the scenarios below. Subjects were anonymized, and each actogram was visually inspected prior to analysis.

### **2.4.1. Exclusions**

Segments within a day were excluded if a) the participant indicated during interview or follow-up that they had removed the watch, or if the participant was observed without the watch, or; b) if no activity counts were registered for > 2 hours and the participant did not report napping at this time. Thirty minutes of consistent activity determined the point at which data would again be included for analysis. If > 4 hours (1/6 of the day) was excluded, then activity and light counts for that entire 24h recorded day was excluded. In such cases, sleep onset and wake events were analyzed for those days that were available.

### **2.4.2. Sleep Fragmentation Removal**

In several cases, nocturnal sleep was interrupted by extended periods of waking (Figure 2.2). In 73 of the 519 nights included in analysis (14% of cases), nocturnal bouts of activity/awakening fragmented the nocturnal sleep period. In these cases, the software chose sleep onset and wake times from the longer of two sleep bouts occurring during the nocturnal period. If the following criteria were met, then the two sleep bouts were manually joined to allow reported sleep onset and wake time to represent one sleep period across the entire nocturnal period (by using the sleep onset from the earlier bout and wake time from the later bout). Combining the two sleep periods did not change total sleep time, since any minutes spent awake after sleep onset were subtracted from overall nocturnal sleep duration.



**Figure 2.2. Fragmented, Fragmentation removal, & Consolidated Actogram Examples**

Representative actograms from two males in the electric community depicting: A. Fragmented sleep which on nights 3 & 4 qualified for fragmentation removal; B. The same sleep periods following manual fragmentation removal; note that combining the two sleep periods did not change total time asleep, since wake during the night was subtracted from overall sleep duration. C. Naturally consolidated sleep in another subject.

**Table 2.2. Prevalence of Sleep Fragmentation by % of Sample, and % of Nights of Individuals with Fragmentation**

% of Sample	Males	Females	Mothers	Average
Electric	53.85	46.15	69.23	<b>56.41</b>
Non-Electric	25.67	61.54	53.33	<b>46.85</b>
Average	<b>39.76</b>	<b>53.85</b>	<b>61.28</b>	
% of Nights (all)				Average
Electric	16.47	12.79	24.14	<b>17.83</b>
Non-Electric	9.78	7.50	13.48	<b>10.34</b>
Average	<b>11.24</b>	<b>12.12</b>	<b>18.75</b>	
% of Nights (w/frag)	Males	Females	Mothers	Average
Electric	30.54	26.19	34.67	<b>30.47</b>
Non-Electric	21.43	15.48	23.81	<b>20.24</b>
Average	<b>25.99</b>	<b>20.84</b>	<b>29.24</b>	

Note: % of Sample: percent of individuals that had fragmented sleep; % of Nights (all): percent of all recorded nights (all subjects pooled) that were fragmented; % of Nights (w/frag): Of those individuals with fragmented sleep, the percentage of their nights that were fragmented

The combination consolidates the sleep bouts into one sleep period with reduced sleep efficiency, as opposed to maintaining two sleep bouts that do not represent true sleep onset and final wake up time. Criteria for combining sleep periods were that the period of nocturnal activity must have occurred during a time when the subject was “usually” asleep/inactive (based on visual verification from other nights in the actogram), b) the subject must have been asleep for at least 2 hours prior to the period of awakening, or c) that the period of nocturnal awakening had to be shorter than the shortest period of sleep. For example, if a subject slept for 30 minutes, awoke for 2 hours and went back to bed for 6 hours, this would not qualify for fragmentation removal, and the 6-hour sleep

period would be considered their nocturnal sleep period. However, if a subject slept for 4 hours, awoke for 2, and then slept for 4 hours, this would qualify for fragmentation removal (therefore total sleep period would be 10 hours).

This “first sleep/second sleep” pattern was most common in breastfeeding mothers with 61.28% of all mothers experiencing fragmentation of their sleep, at a frequency of 29.24% of nights effected (Table 2.2). Over half of the participants in the electric communities had fragmentation in their sleep (56.41%), on an average of 30.5% of nights.

## **2.5. Analysis**

### **2.5.1. Variables of Interest**

Outcome variables were: Bedtime (the time at which an individual went to bed); Sleep Onset (the time at which an individual fell asleep); Wake time (the time at which an individual wakes up); Rise time (the time an individual rises from bed); Nocturnal sleep duration (the time in minutes between sleep onset and wake time minus the number of minutes awake after sleep onset); 24h Total Sleep Time (nocturnal sleep duration + nap duration); Sleep Efficiency (number of minutes awake after sleep onset divided by the number of minutes between sleep onset and wake time).

Non-parametric variables were calculated for each subject using Clocklab version 6. Activity variables included M10 (average amount of activity in the 10 most active hours of the day), L5 (average amount of activity in the 5 least active hours of the day), and the onset times for both. Circadian robustness was measured with Intradaily Variability (IV), Interdaily Stability (IS), and Relative Amplitude (RA). IV is used to quantify fragmentation of rest-activity patterns. IV will be low (suggesting robust circadian rhythms) if periods of rest and activity are consolidated, and will increase with increased nighttime activity (e.g. fragmented sleep) or increased daytime inactivity (e.g. napping). IS quantifies synchronization to the 24-hour light-dark cycle, by assessing regularity in timing of rest and activity from day to day. IS will be high (suggesting robust circadian entrainment) when an individual becomes active at the same time every day, and decreases when variability in the timing of sleep and activity is high. RA measures

how much more average activity there is in the most active hours of the day (M10) compared to the least active hours (L5). If M10 has less activity, or L5 has greater activity (e.g. less consolidated sleep/wake) then RA will decrease, suggesting lower amplitude circadian output.

### **2.5.2. Statistics**

Data were analyzed using Prism version 7. Independent samples t-tests or ANOVA's were used to compare variables between electric and non-electric communities. For sleep-related outcome variables (e.g. nocturnal sleep duration, sleep efficiency), two-way ANOVA's were performed with community type (electric vs non-electric), and adult type (males, females, mothers) as dependent variables. ANOVA allowed examination of effects of electric lighting on outcome variables, and also helped uncover interactions due to different lifestyles between adult types. Tukey's post hoc was used to further explore significant main effects of adult type, or significant interactions. Outliers greater than 3.5 standard deviations above the mean were removed in several cases (indicated with a \* in Table 3.1). In such cases, statistical tests were run with and without the outlier, and in none of the cases did the outlier change the decision of the test, however, the outliers were removed in order to decrease risk to assumptions of normality. In cases where ANOVA was not appropriate (i.e. assumption of homogeneity of variance was violated), then a non-parametric independent samples test, Mann-Whitney U, was performed between community types, foregoing analysis by adult type.

The final sample size was  $n = 39$  from electric communities and  $n = 43$  from non-electric communities. Due to an Actiwatch-2 light sensor error, light data is missing for 1 mother from an electric community, therefore sample size for analyses involving light is 38 from electric communities. Seven individuals living within the electric communities reported during interviews that they did not have access to working electricity at the time of data collection. Exclusion of their data did not change statistical results, so they were maintained within analyses for the electric communities.

## Chapter 3.

### Results

Means and standard error for variables of interest are presented in Table 3.1

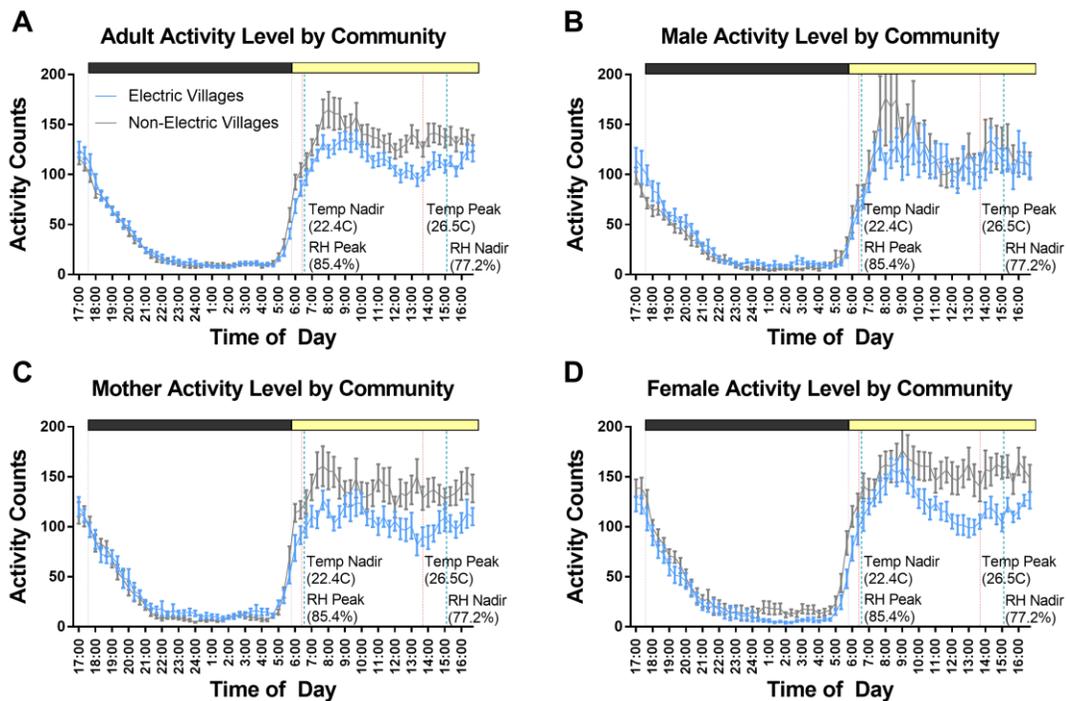
**Table 3.1. Means by Adult Type and Community Type ± SEM**

	Electric <i>n</i> = 39				Non-Electric <i>n</i> = 43			
	Male <i>n</i> = 13	Female <i>n</i> = 13	Mother <i>n</i> = 13	Avg	Males <i>n</i> = 15	Female <i>n</i> = 13	Mother <i>n</i> = 15	Avg
Bedtime (h:mm)	21:16 (11.82)	20:32 (15.66)	20:44 (12.9)	20:50* (8.2)	20:54 (.256)	20:44 (17.22)	20:03 (8.28)	20:33 (8.7)
Sleep Onset (h:mm)	21:42 (10.84)	21:02 (16.46)	21:14 (13.49)	21:19* (8.29)	21:19 (14.39)	21:05 (16.01)	20:24 (9.25)	20:56 (.833)
Wake Up (h:mm)	6:20 (13.31)	6:04 (15.70)	5:20 (9.05)	5:54 (8.36)	6:17 (16.69)	5:36 (13.05)	5:26 (6.21)	5:47 (7.99)
Rise Time (h:mm)	6:39 (12.53)	6:19 (16.61)	5:36 (8.71)	6:11 (8.45)	6:37 (16.90)	5:53 (13.94)	5:44 (5.84)	6:05 (8.19)
Nocturnal Sleep Duration (hours)	7.42 (0.20)	7.91 (0.27)	6.94 (0.29)	7.42 (0.16)	8.05 (0.34)	7.53 (0.13)	8.02 (0.16)	7.88 (0.14)
Nocturnal Sleep Efficiency (%)	79.47 (0.93)	83.47 (1.26)	77.80 (1.73)	80.25 (0.85)	82.95 (1.31)	82.53 (1.12)	82.66 (0.94)	82.72 (0.64)
24h Total Sleep Time (hours)	7.47 (0.24)	8.15 (0.29)	7.32 (0.31)	7.65 (0.17)	8.24 (0.30)	7.63 (0.13)	8.13 (0.17)	8.02 (0.13)
Avg # Naps/Day	0.63 (.13)	0.51 (.11)	1.15 (.25)	0.77 (.11)	0.56 (.14)	0.24 (.09)	0.29 (.09)	0.36 (.07)
Nap Duration (mins)	28.01 (2.71)	30.61 (4.21)	23.53 (2.15)	27.27 (1.81)	37.34 (5.56)	27.74 (4.42)	24.01 (2.22)	32.75 (3.51)
Activity: most active 10h period (M10)	461.36 (47.67)	507.34 (21.25)	454.23 (40.0)	474.31 (21.29)	501.31 (63.50)	627.76 (44.58)	545.59 (44.63)	554.98 (30.57)
Activity: least active 5h period (L5)	21.31 (3.51)	50.18 (15.01)	25.48 (2.60)	31.37 (2.94)	33.75 (5.37)	21.91 (4.14)	38.45 (17.61)	31.49 (5.04)
Relative Amplitude	0.84 (.12)	.92 (.06)	0.84 (.07)	0.87 (.04)	0.90 (.08)	0.85 (.16)	.91 (.04)	0.89 (.03)
Intradaily Variability (IV)	.718 (.04)	.635 (.03)	.8329 (.04)	.7286 (.03)	.6273 (.04)	.5425 (.04)	.7025 (.03)	.6279 (.03)
Interdaily Stability (IS)	.5194 (.04)	.5772 (.03)	.6212 (.02)	.5726 (.02)	.5749 (.05)	.5167* (.02)	.6402 (.02)	.5987* (.02)

Note: \* indicates outlier removal (*n* - 1)

### 3.1. Activity

Activity data were averaged in 20-minute bins for each subject, and then plotted as group mean waveforms (Figure 3.1: A. Electric vs non-electric communities, adults type pooled B. Male activity by community type C. Mother activity level by community type D. Female activity level by community type). During the daytime, residents of the non-electric communities appear to be more active than residents of the electric communities (Figure 3.1A.), but comparison of the 10 most active hours in the day (M10) shows no difference between community type in amount (Mann-Whitney  $U = 641$ ,  $p = .067$ ; median electric = 461.1,  $n = 39$ ; median non-electric = 507.8,  $n = 43$ ) or phase of onset (Mann-Whitney  $U = 774$ ,  $p = .055$  median electric = 7.32,  $n = 39$ ; median non-electric = 6.87,  $n = 43$ ).



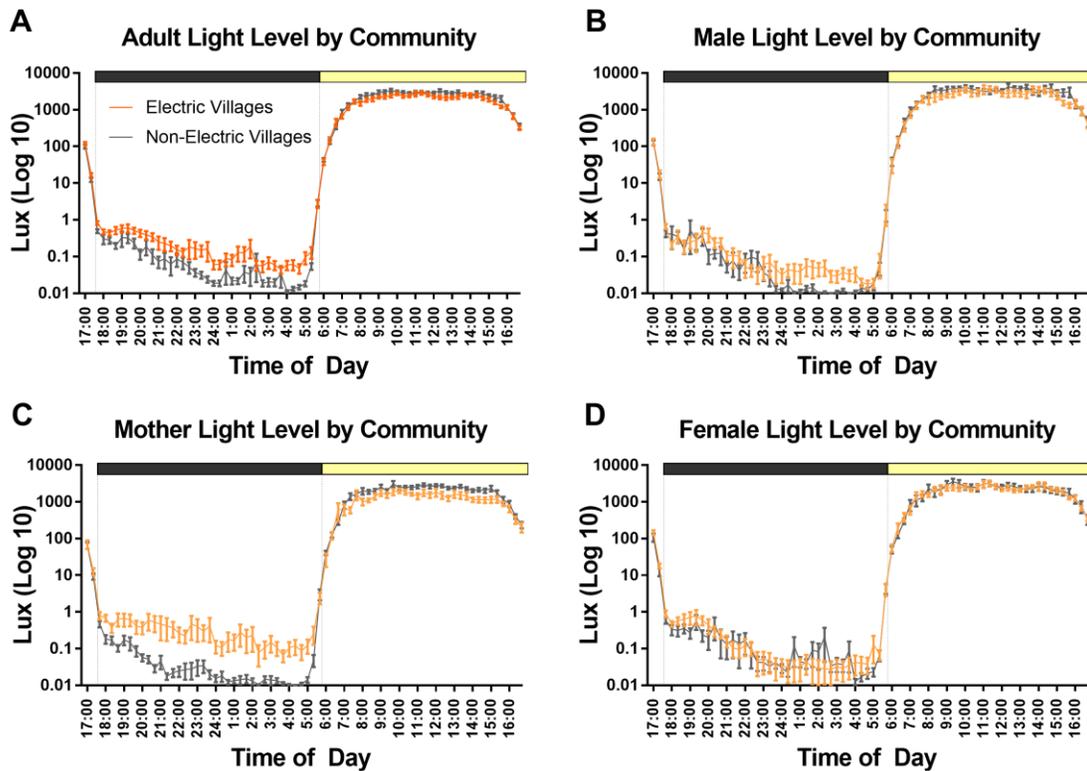
**Figure 3.1. Average Activity Waveforms in 20-Minute Bins**  
Error bars are SEM

Similarly, in the least active 5 hours of the night (L5) there was no difference between community types in the amount (Mann-Whitney  $U = 723$ ,  $p = .287$ ; median electric = 24.76,  $n = 39$ ; median non-electric = 22.76,  $n = 43$ ) or phase of onset of activity (Mann-Whitney  $U = 730.5$ ,  $p = .319$ ; median electric = 23.02,  $n = 39$ ; median non-

electric = 23.08,  $n = 43$ ). Relative amplitude (RA; Table 3.1), the ratio of M10 to L5, also did not differ significantly between the groups (Mann-Whitney  $U = 690$ ,  $p = .170$ ; median electric = 0.90,  $n = 39$ ; median non-electric = 0.91,  $n = 43$ ).

### 3.2. Light

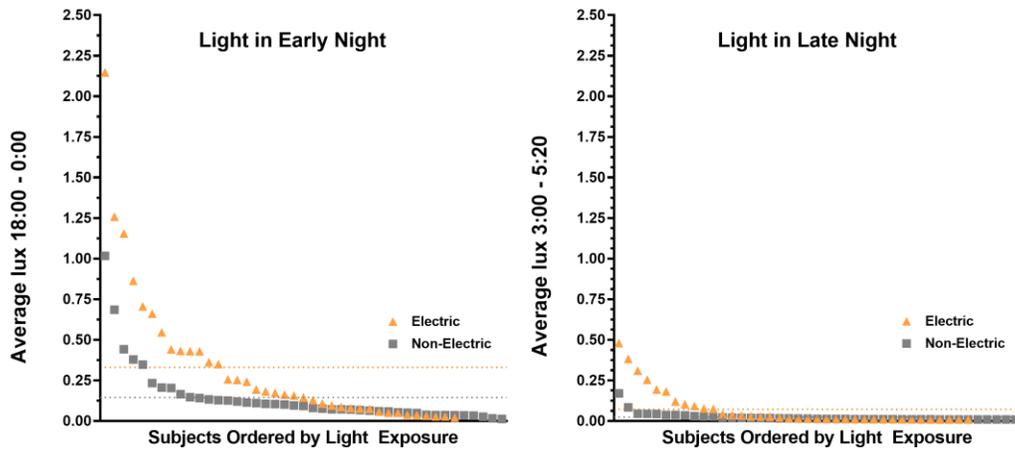
Light exposure data were averaged in 20-minute bins for each subject, and then plotted as group mean waveforms (Figure 3.2: A. Electric vs non-electric communities, adults type pooled B. Male light level by community type C. Mother light level by community type D. Female light level by community type). Average sunrise occurred at 5:56 (average civil twilight start = 5:33), and average sunset at 17:23 (average civil twilight end = 17:46), therefore for statistical purposes, daylight was calculated as 6:00 – 17:20, and nighttime between 18:00 – 5:20 to eliminate times of dawn and dusk where there is still light in the sky.



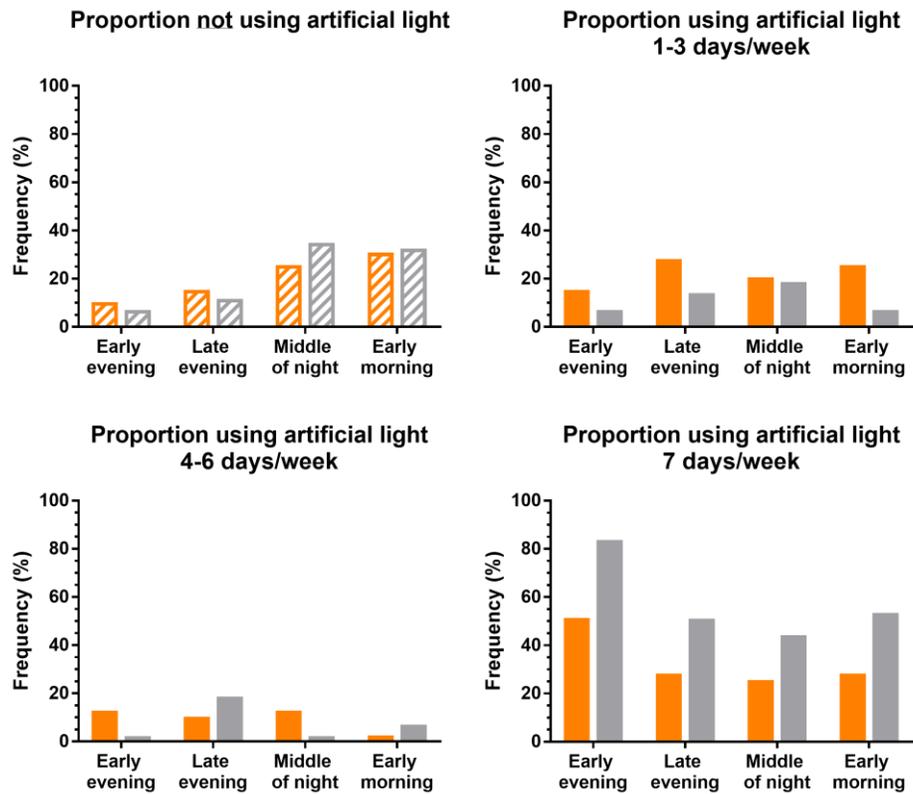
**Figure 3.2. Light Waveforms in 20-Minute Bins**  
Error bars are SEM.

During the daytime both communities were exposed to similar and consistent amounts of light (average lux from 6:00 – 17:20: electric =  $1747 \pm 919$ ; non-electric =  $2158 \pm 1081$ ; Mann-Whitney  $U = 624$ ,  $p = .068$ ; median electric = 1550,  $n = 38$ ; median non-electric = 1721,  $n = 43$ ). Average peak illuminance in the electric community was  $2894 \pm 2029$  lux (11:20 - 11:40), and in the non-electric community was  $3373 \pm 2300$  lux (9:40 - 10:00). Higher amounts of light were found in the electric communities after sunset (18:00 – 0:00), when light can be expected to phase delay circadian rhythms (average lux: electric =  $0.33 \pm 0.43$ ; non-electric =  $0.15 \pm 0.19$ ; Mann-Whitney  $U = 564$ ,  $p = .016$ ; median electric = 0.168,  $n = 38$ ; median non-electric = 0.092,  $n = 43$ ; Figure 3.3). No significant difference was found between community types in the amount of light preceding sunrise (3:00 – 5:20), when light phase advances circadian rhythms (average lux: electric =  $0.07 \pm 0.11$ ; non-electric =  $0.02 \pm 0.03$ ; Mann-Whitney  $U = 672$ ,  $p = .171$ ; median electric = 0.016,  $n = 38$ ; median non-electric = 0.014,  $n = 43$ ; Figure 3.3). Despite the availability of electric lighting, average light levels within the electric communities averaged below 1 lux for the duration of the night (average lux from 18:00 – 5:20: electric =  $0.21 \pm 0.29$ ; non-electric =  $0.09 \pm 0.10$ ). Maximum light levels (brightest 1 min bin) in the early night (18:00 – 00:00) and late night (0:00 – 5:20) were similar between electric and non-electric communities with the average maximums not exceeding 11 lux in the early night and 2 lux in the late night (average max lux early night: electric = 8.67; non-electric = 10.95; late night: electric = 1.77; non-electric = 1.42) suggesting that light exposure differences in the communities may be accumulated over longer durations rather than as single maximum lighting events. This idea is supported by the average waveforms (Figure 3.2).

During interviews, individuals report using light (i.e. electric light or solar torches) most commonly in the early evening. In electric communities, 51.3% of participants reported using electric lighting every evening, 39.4% reported using lights on some or most evenings, and 10.3% reported not using electric light during the study period. In addition to electric light, all participants in the electric communities also report use of torch light, and 6 of 7 participants living in electric communities who reported having no working electricity at the time of data collection report daily torch use (1 of 7 uses light only some evenings or early mornings). In non-electric communities, 83.7% of participants reported using solar torches every evening, 9.3% on some or most evenings, and 7% not at all during the study period (Figure 3.4).



**Figure 3.3** Light Exposure in Early and Late Night



**Figure 3.4. Self-Report Artificial Light Use**

Appendix 1; Figure A1. shows pictorial representation of approximate clock time. Early evening (after sunset) = *stap tudak*; late evening (before midnight) = *bifo middenlente*; middle of the night (after midnight) = *afta middenlente*; early morning (before sunrise) = *stap dei lite*

### 3.3. Sleep Timing

Bedtime ( $F_{(2,80)} = 2.25, p = .138$ ), wakeup time ( $F_{(2,81)} = 0.54, p = .467$ ) and rise time ( $F_{(2,81)} = 0.39, p = .533$ ) did not differ between community types, regardless of electricity access (Table 3.1). Sleep onset, however, was significantly delayed in the electric communities ( $F_{(1,80)} = 5.50, p = .022$ ), with individuals falling asleep 23 minutes later on average (Figure 3.5 & 3.6). Residents in both community types went to bed approximately 3 - 3.5h after sunset (occurring between 17:17 - 17:32) and awoke around sunrise (occurring between 5:52 - 6:00), before the daily ambient temperature nadir (6:20) and peak humidity (6:33; Figure 3.7). Figure 3.8 shows individual sleep onset and wake times ordered by sleep onset within sex.

Despite minimal differences in sleep timing between community types, there was a main effect of adult type on bedtimes ( $F_{(2,75)} = 4.65, p = .013$ ), sleep onset times ( $F_{(2,75)} = 5.87, p = .004$ ), wake up times ( $F_{(2,76)} = 9.49, p < .001$ ), and rise times ( $F_{(2,76)} = 10.03, p < .001$ ). Post hoc tests revealed that, in both community types, all times were significantly earlier in mothers compared to males (means in Table 3.1). Sleep timing of females was intermediate between mothers and males, but differences were not significant.

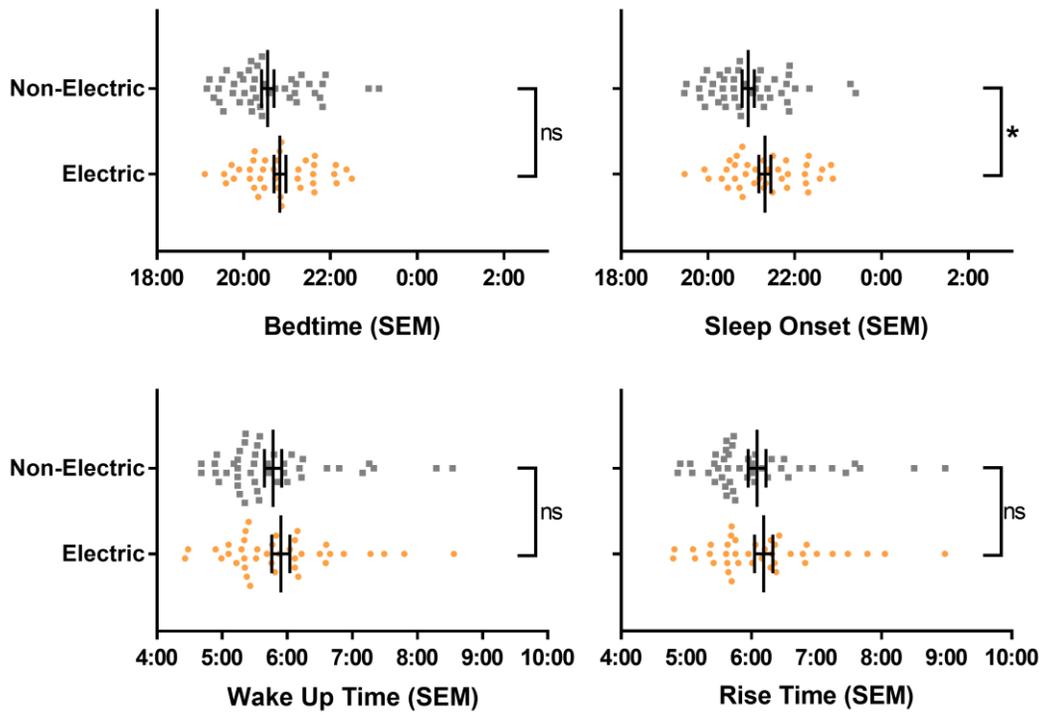


Figure 3.5. Sleep Timing by Community Type

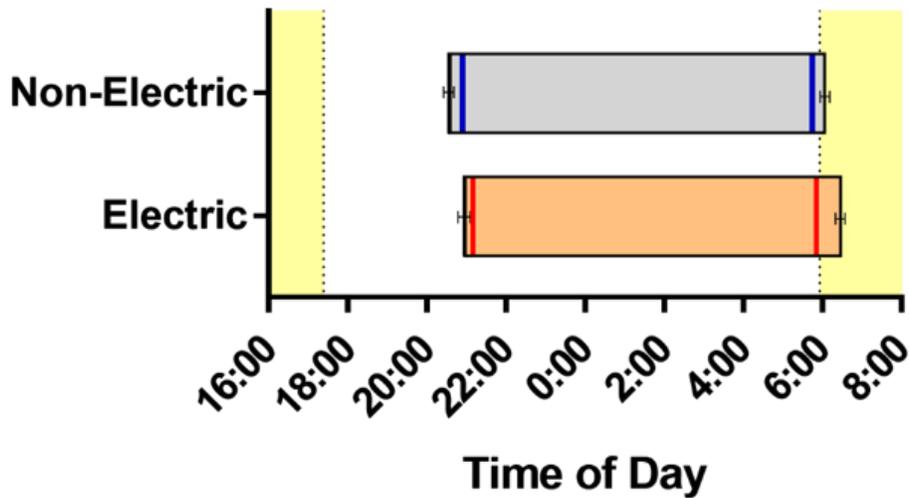
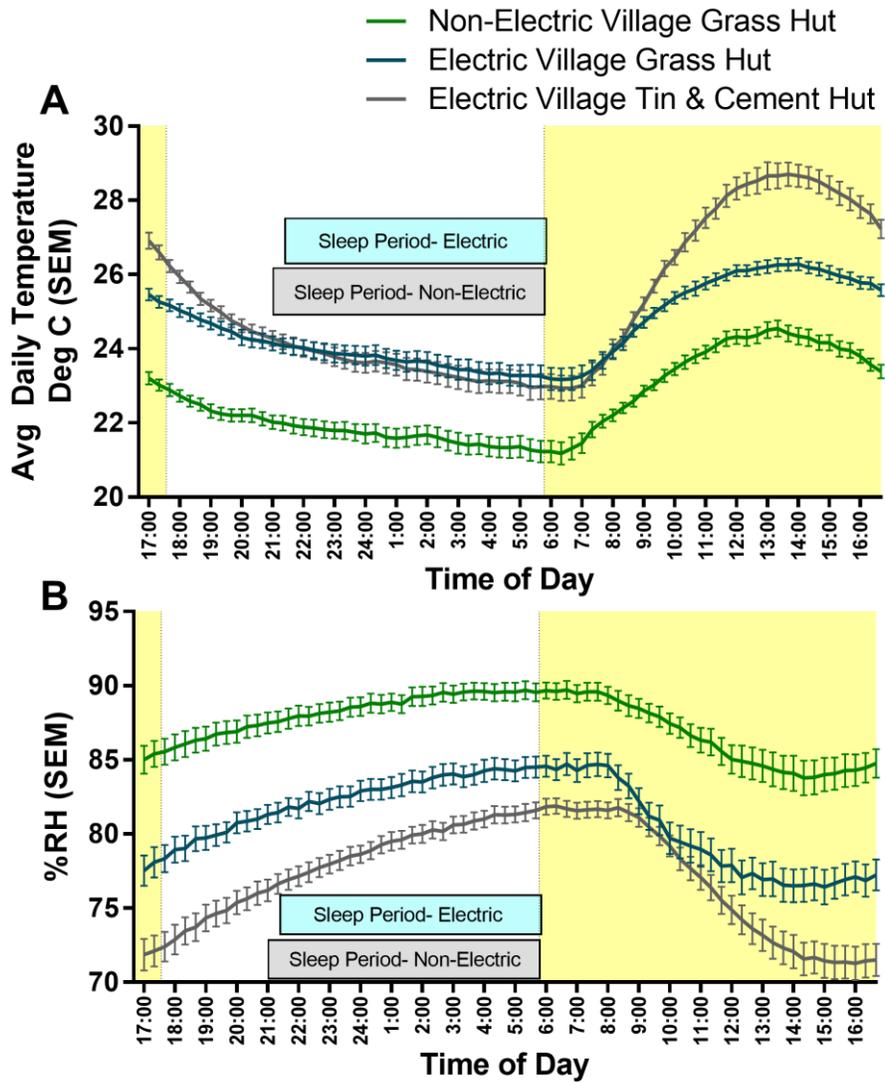
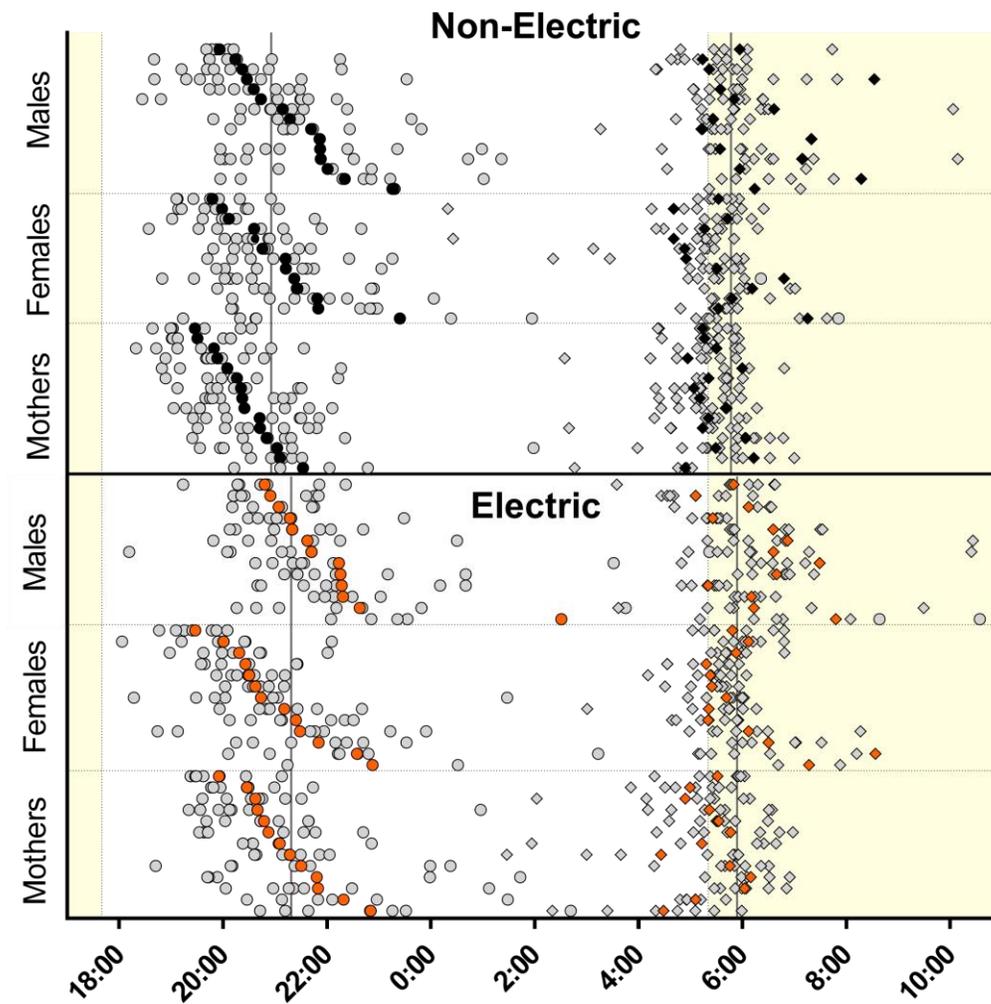


Figure 3.6. Summary of Sleep Timing

A: vertical box edges indicate mean bedtime and rise time; inner coloured bars indicate mean sleep onset and wake up times relative to sunrise; B: Individual data points



**Figure 3.7. Sleep Timing Relative to Average Temperature and Humidity**  
 A: Average daily temperature; B: average relative humidity %; measured between April 15 - May 7, 2017 by buttons placed in sleeping space in huts of grass, and corrugated tin/cement



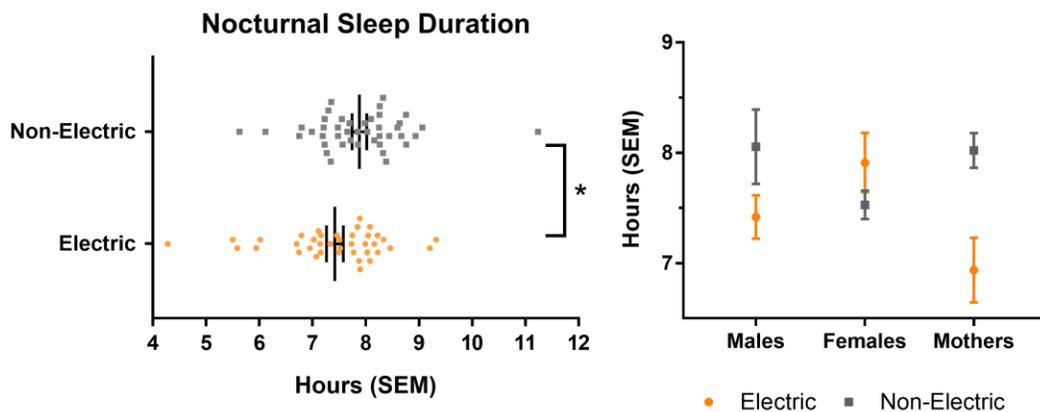
**Figure 3.8. Sleep Onset and Wake Times by Community Type**

Each horizontal row is a one participant, ordered by sleep onset within sex. Raw data points are grey symbols, and averages as black (non-electric) and orange (electric) symbols.

### 3.4. Nocturnal Sleep Duration & Efficiency

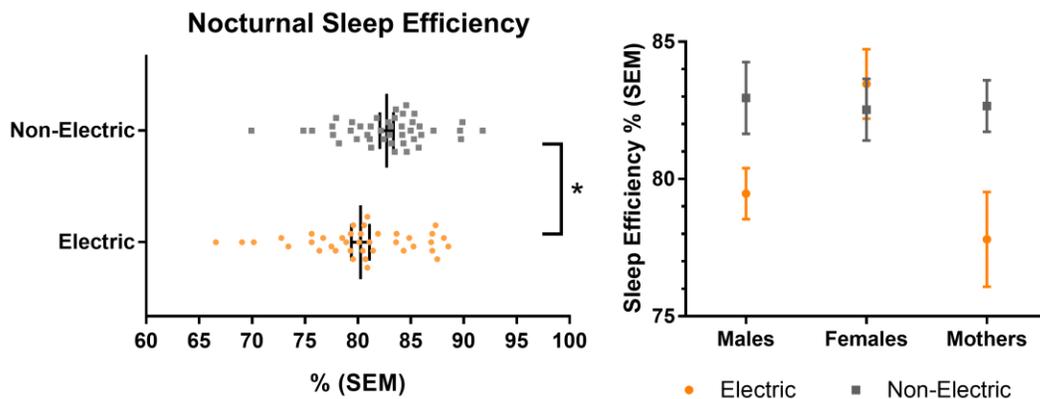
Average nocturnal sleep duration in adult subjects living in the electric and non-electric communities was  $7.42 \pm 0.16$  hours ( $445 \pm 9.47$  minutes) and  $7.88 \pm 0.14$  hours ( $473 \pm 8.23$  minutes), respectively (28-minute difference; Table 3.1; Figure 3.10). Two-way ANOVA indicated a significant main effect of community type ( $F_{(1,76)} = 4.94, p = .029$ ) and a significant interaction ( $F_{(2,76)} = 4.60, p = .013$ ) between community type and adult type. There was no main effect of adult type ( $F_{(2,76)} = 0.55, p = .58$ ). Tukey post hoc tests revealed that community type differences were driven by mothers with access to electricity, who on average slept 65 minutes less than did mothers in the non-electric communities. Mothers slept less than males and females in the non-electric community. Males and females did not differ significantly in either community.

In addition to shorter nocturnal sleep duration, individuals in the electric communities had lower objective measures of nocturnal sleep efficiency by 2.47% ( $F_{(1,76)} = 5.94, p = .017$ ; Figure 3.11)



**Figure 3.9. Nocturnal Sleep Duration by Community Type and by Adult Type**

Note: Statistical difference remains without 2 visible outliers.



**Figure 3.10. Nocturnal Sleep Efficiency by Community Type and by Adult Type**

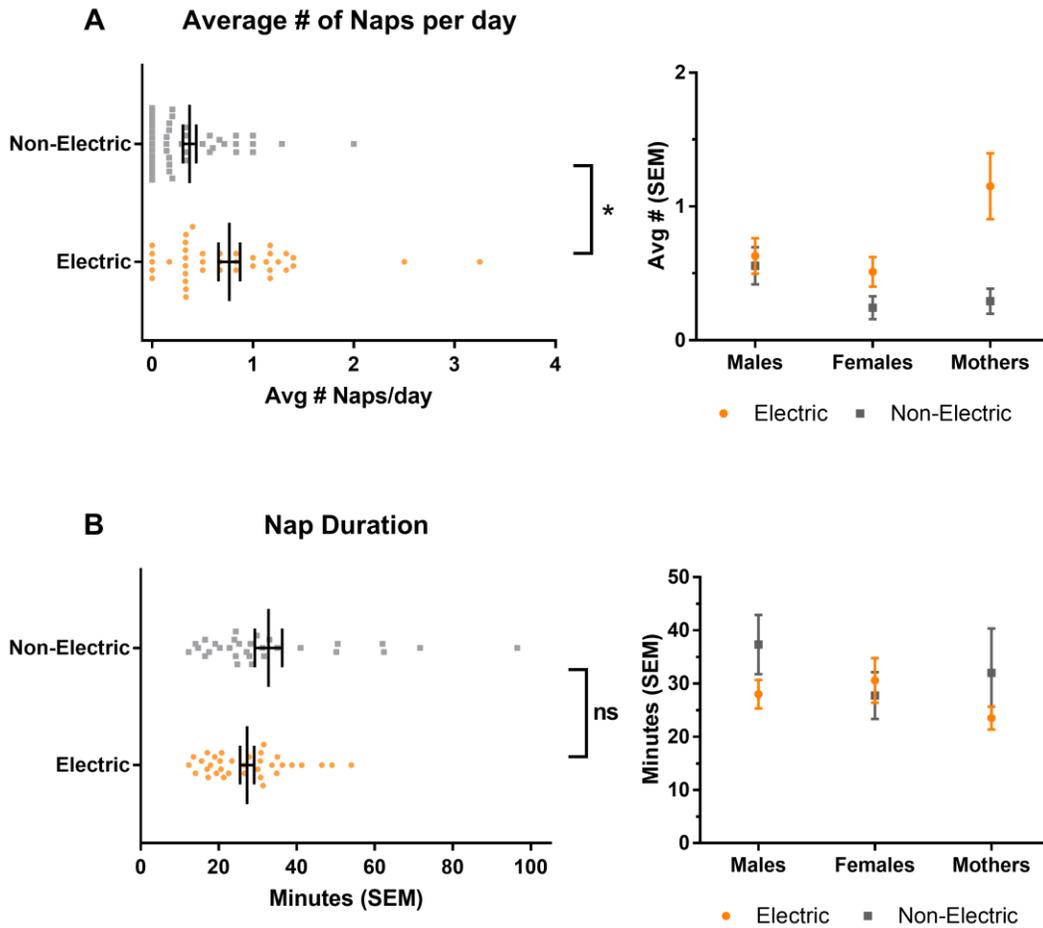
### 3.5. Daytime Napping & 24h Sleep Duration

Table 3.2 shows estimated prevalence of napping (nap data may be overestimated due to watch removals; see 2.4 Data Cleaning). Individuals in the electric communities took a greater number of naps per day (Mann Whitney  $U = 478.5$ ,  $p = .001$ ; median electric = 0.67,  $n = 39$ ; median non-electric = 0.20,  $n = 43$ ), although average duration of the naps did not differ between community type (Mann Whitney  $U = 458.5$ ,  $p = .49$ ; median electric = 26.58,  $n = 34$ ; median non-electric = 27.5,  $n = 30$ ; Figure 3.12). Daily naps were combined with nocturnal sleep to yield 24 hour sleep duration (Total Sleep Time; TST). 24h TST was not significantly different between the electric and non-electric communities (mean electric =  $7.65 \pm 0.17$  hours; mean non-electric =  $8.02 \pm 0.13$  hours; 22.2 minute difference;  $F_{(1,76)} = 3.07$ ,  $p = .084$ ), or between adult types ( $F_{(1,76)} = 0.23$ ,  $p = .079$ ). A significant interaction remained ( $F_{(1,76)} = 4.68$ ,  $p = .012$ ) with adult types showing the same pattern of results as nocturnal sleep (Figure 3.13), although post-hoc testing yielded no significant differences due to correction for multiple comparisons.

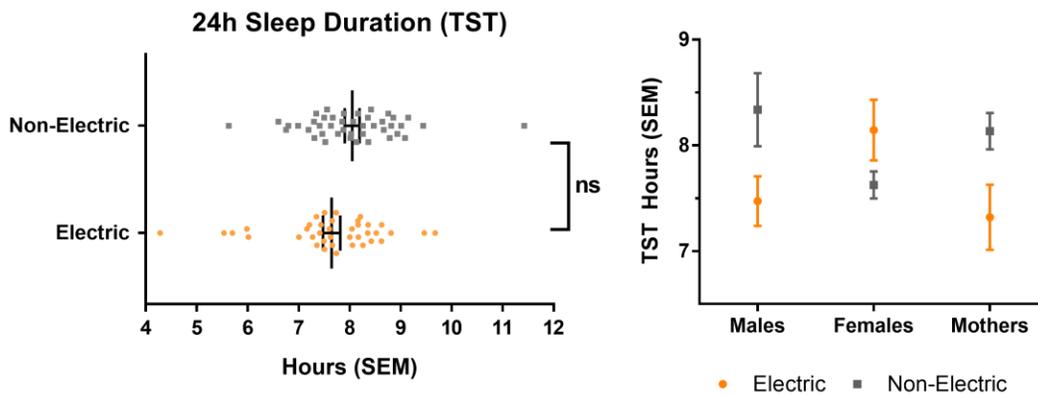
The difference in mean sleep duration between electric and non-electric communities was calculated for each adult type (3.14). Figure 3.14 shows that mothers in the electric communities have significantly shorter sleep than mothers in non-electric communities even when napping is taken into account (i.e. 24h TST).

**Table 3.2. Napping**

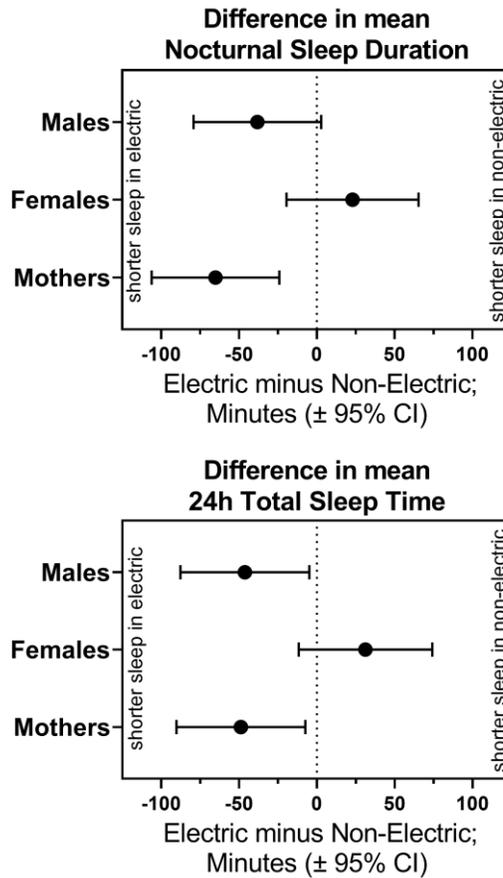
% of Sample	Males	Females	Mothers	Average
Electric	84.62	84.62	92.31	<b>87.17</b>
Non-Electric	80.00	61.54	66.67	<b>69.77</b>
Average	<b>82.14</b>	<b>73.08</b>	<b>78.57</b>	
% of Days w/ naps				Average
Electric	35.29	32.56	36.78	<b>34.88</b>
Non-Electric	27.58	18.48	18.75	<b>21.46</b>
Average	<b>31.40</b>	<b>25.28</b>	<b>27.32</b>	



**Figure 3.11. Number of Naps (A) and Nap Duration (B) by community and by adult type**

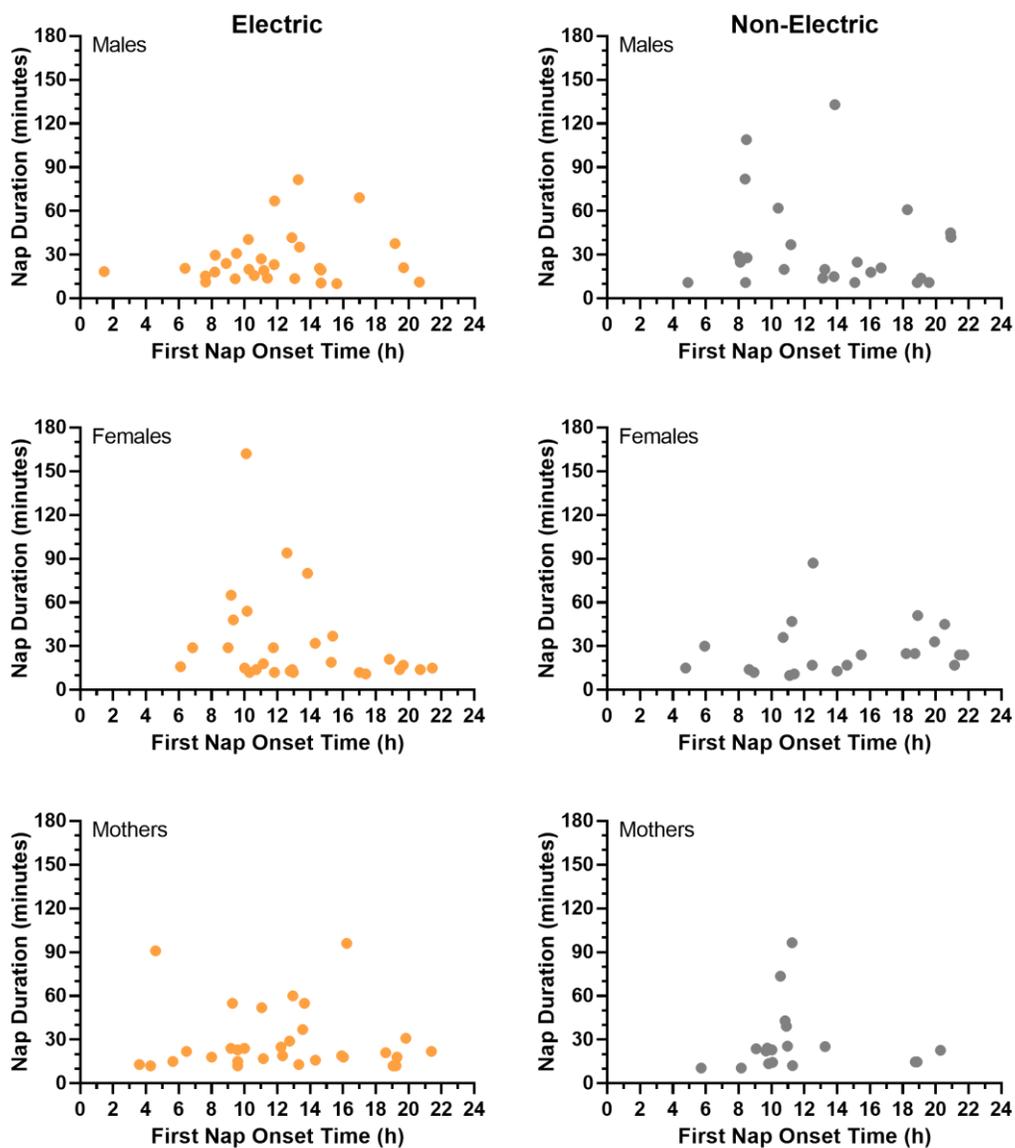


**Figure 3.12 24h Total Sleep Time by Community Type and by Adult Type**



**Figure 3.13 Difference in Mean Sleep Duration between Community Type**  
 Difference between means of electric and non-electric for each adult type. Mean differences less than 0 indicate shorter sleep in the electric community relative to the non-electric. 95% confidence intervals containing 0 indicate no significant difference between the electric and non-electric communities for that adult type.

It was of interest to examine the timing and duration of daily naps. Scatterplots generated between onset time of the first daily nap (if there was more than one nap taken per day) and the nap duration (Figure 3.15) show that naps in the non-electric community are more variable in their timing (spread throughout the day) and duration. To assess if naps were being used to compensate for short nocturnal sleep, the duration of the first daily nap (if there was more than one nap taken per day) as well as cumulative nap duration (Figure 3.16) were plotted relative to prior night sleep, separately for adult type and community type. No consistent pattern emerged.



**Figure 3.14** Scatterplots of Nap Onset Time by Nap Duration (of First Daily Nap)

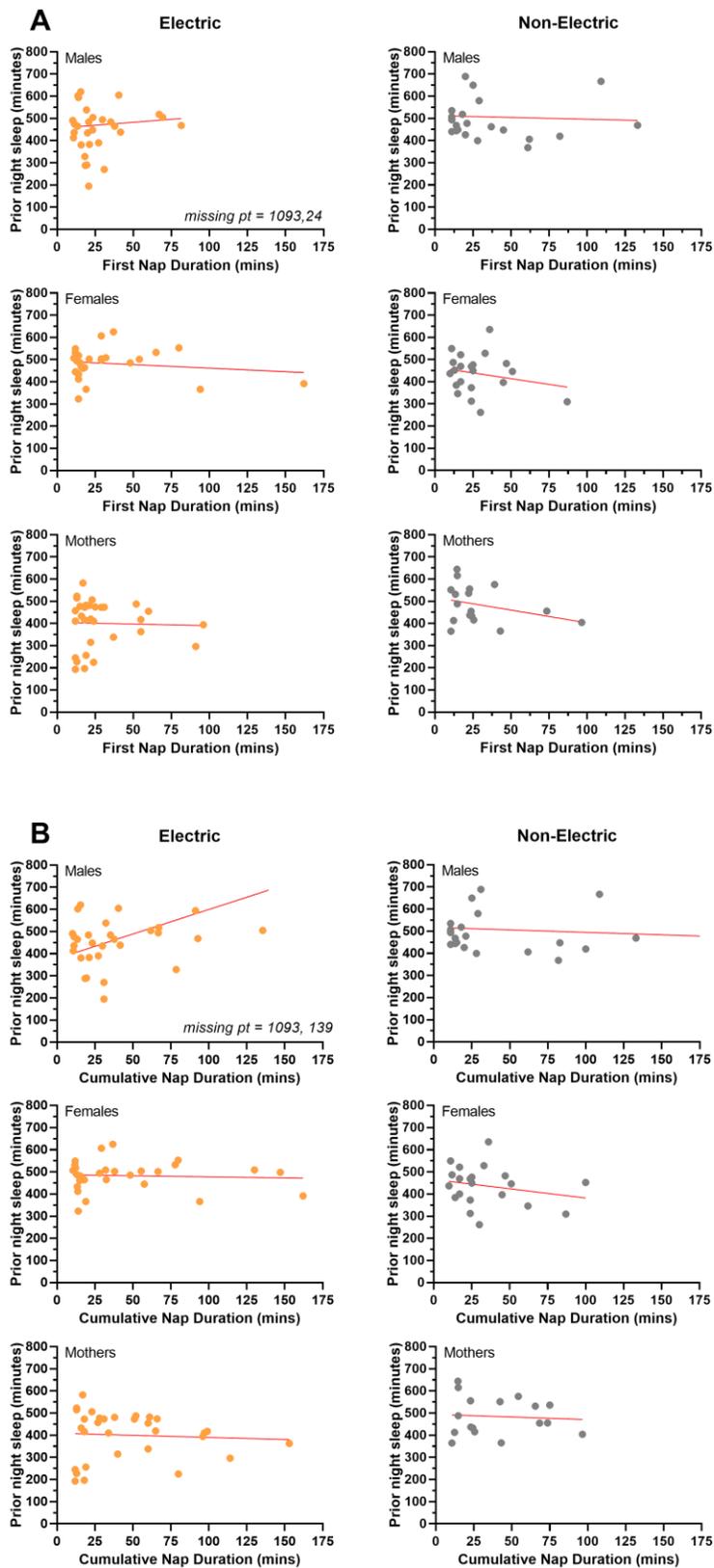


Figure 3.15 Correlation with Prior Night Sleep & Nap Duration

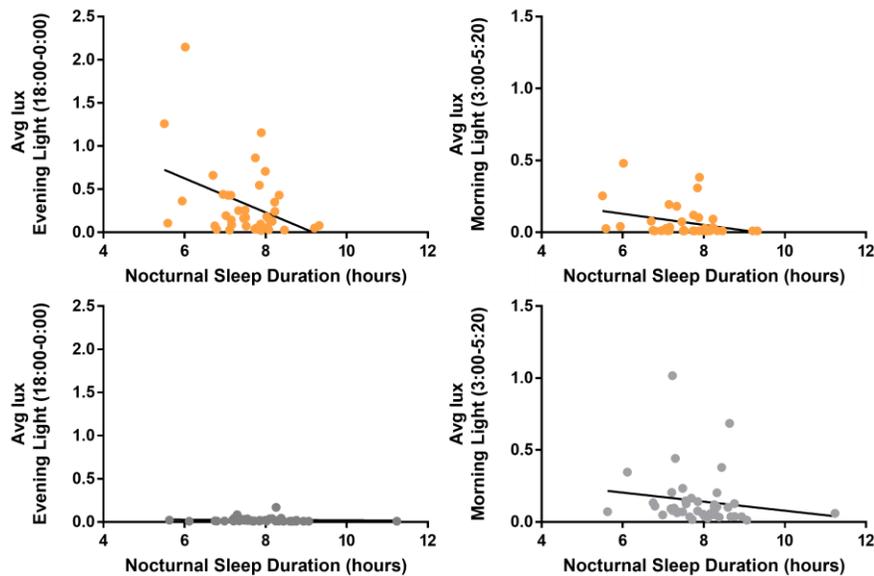
## 3.6. Relationships with Sleep

### 3.6.1. Activity

In the non-electric community (pooling adult types), nocturnal sleep duration was significantly negatively correlated with daytime activity (M10;  $r = -0.35$ ,  $p = .02$ ). There was no significant correlation in the electric community ( $r = -0.15$ ,  $p = .36$ ). M10 did not correlate significantly with sleep efficiency in either community type (electric  $r = -0.03$ ,  $p = .88$ ; non-electric  $r = 0.16$ ,  $p = .29$ ).

### 3.6.2. Light

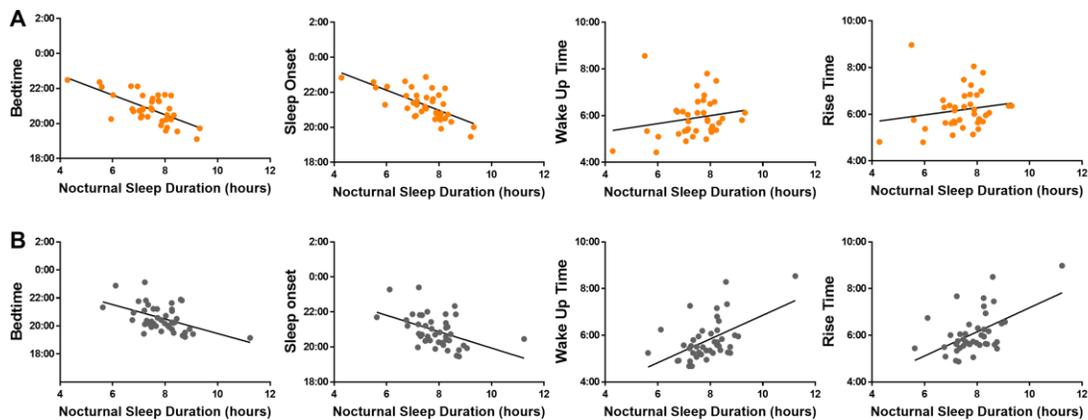
In the electric community (pooling adult types), nocturnal sleep duration was negatively correlated with evening light exposure (18:00 – 0:00;  $r = -0.39$ ,  $p = .02$ ) and with morning light exposure (3:00 – 5:20;  $r = -0.29$ ,  $p = .07$ ), but only the evening correlation was statistically significant. In the non-electric community, correlations between nocturnal sleep duration and evening ( $r = -0.06$ ,  $p = .70$ ) or morning light ( $r = -0.15$ ,  $p = .33$ ) were not significant (Figure 3.17).



**Figure 3.16. Correlations with Nocturnal Sleep Duration & Evening and Morning Light**

### 3.6.3. Sleep Timing

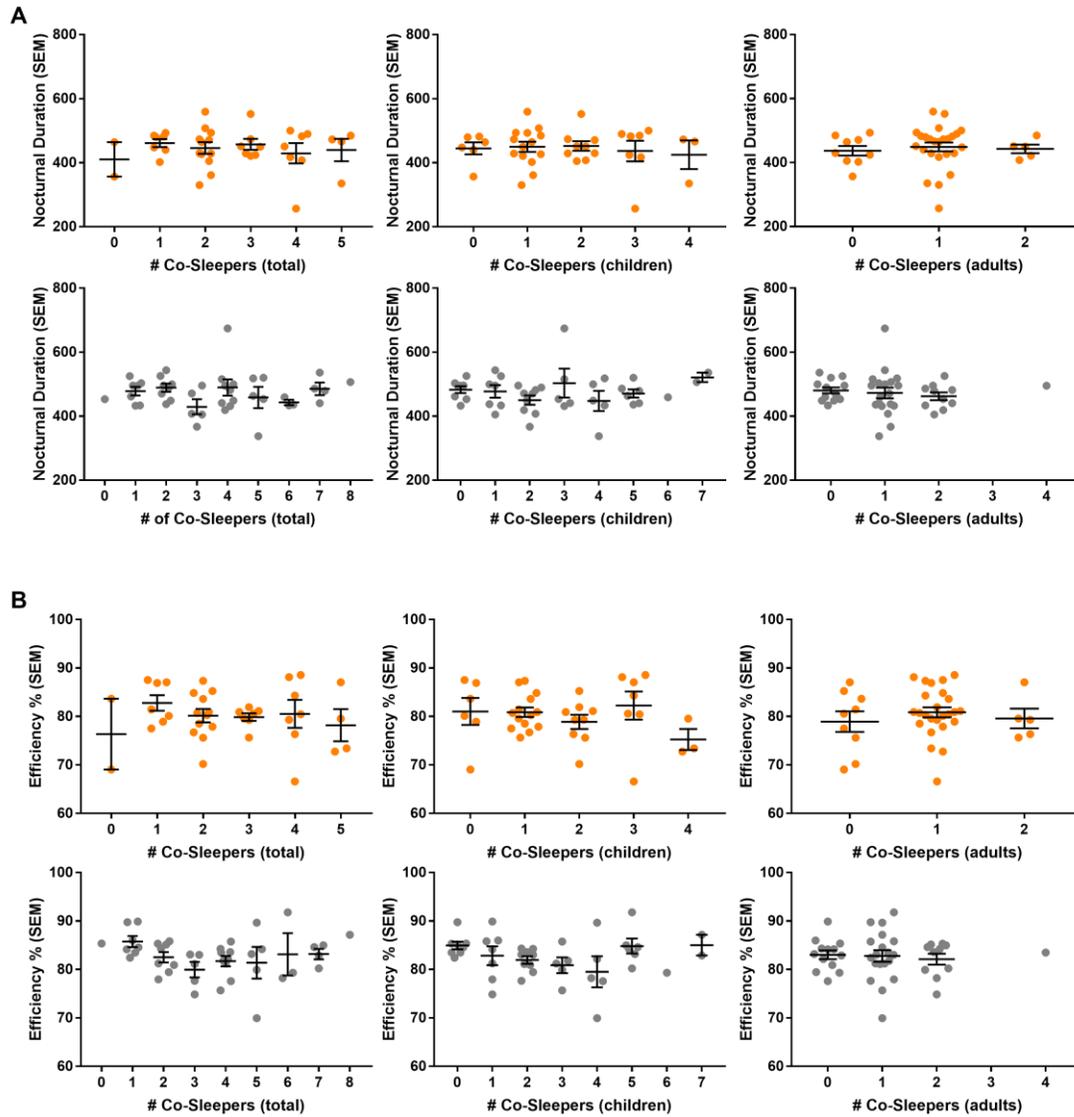
In the non-electric communities, nocturnal sleep duration correlated highly with bedtime ( $r = -.49, p < .00$ ), sleep onset ( $r = -.46, p < .00$ ), wake up time ( $r = .52, p < .00$ ), and rise time ( $r = .52, p < .00$ ). In the electric communities, nocturnal sleep duration also correlated highly with bedtime ( $r = -.47, p < .00$ ) and sleep onset ( $r = -.42, p < .00$ ), but did not correlate significantly with wake up time ( $r = .19, p > .05$ ) and rise time ( $r = .17, p > .05$ ). Removal of one outlier from the electric community bedtime and sleep onset data did not change statistical result. See Figure 3.18.



**Figure 3.17 Correlations with Nocturnal Sleep Duration & Sleep Timing**  
A: Electric Communities, 1 outlier removed bedtime & sleep onset; B: Non-Electric Communities

### 3.6.4. Number of Co-Sleepers

On average the number of total co-sleepers was greater in the non-electric communities ( $n = 4.53$ ) than it was in the electric communities ( $n = 3.55$ ; Table 2.1). Neither nocturnal sleep duration nor nocturnal sleep efficiency was significantly correlated with total number of individuals sharing a sleeping space in electric (duration:  $r = -.06, p = 0.73$ ; efficiency:  $r = -.09, p = 0.58$ ) or non-electric communities (duration:  $r = -.01, p = 0.96$ ; efficiency:  $r = -.11, p = 0.50$ ). No consistent pattern was seen in nocturnal sleep duration or efficiency with increased number of total co-sleepers, or separately for number of children or adult co-sleepers (Figure 3.19).



**Figure 3.18. Relationship between # of Co-Sleepers and (A) Nocturnal Sleep Duration & (B) Efficiency**

### 3.6.5. Physiological Variables: Age, Weight & Body Fat %

**Table 3.3. Correlations with Sleep & Physiological Variables**

		Bedtime	Sleep Onset	Wake Up Time	Rise Time	Nocturnal Sleep Duration	Nocturnal Sleep Efficiency	24h TST
Electric	<i>Age</i>	<i>r = .28</i>	<i>r = .24</i>	<i>r = .22</i>	<i>r = .20</i>	<i>r = .09</i>	<i>r = .19</i>	<i>r = -.02</i>
	<i>Weight</i>	<i>r = .05</i>	<i>r = .04</i>	<i>r = -.13</i>	<i>r = -.14</i>	<i>r = -.21</i>	<i>r = -.01</i>	<i>r = -.22</i>
	<i>Body Fat %</i>	<i>r = -.28</i>	<i>r = -.24</i>	<i>r = -.31</i>	<b><i>r = -.34</i></b>	<i>r = -.14</i>	<i>r = .03</i>	<i>r = -.04</i>
Non-Electric	<i>Age</i>	<i>r = -.14</i>	<i>r = -.07</i>	<i>r = -.18</i>	<i>r = -.18</i>	<i>r = -.22</i>	<b><i>r = -.44</i></b>	<i>r = -.30</i>
	<i>Weight</i>	<i>r = -.23</i>	<i>r = -.20</i>	<i>r = -.17</i>	<i>r = -.14</i>	<i>r = .01</i>	<i>r = -.14</i>	<i>r = -.08</i>
	<i>Body Fat %</i>	<b><i>r = -.35</i></b>	<b><i>r = -.36</i></b>	<i>r = -.29</i>	<i>r = -.30</i>	<i>r = -.02</i>	<i>r = -.16</i>	<i>r = -.13</i>

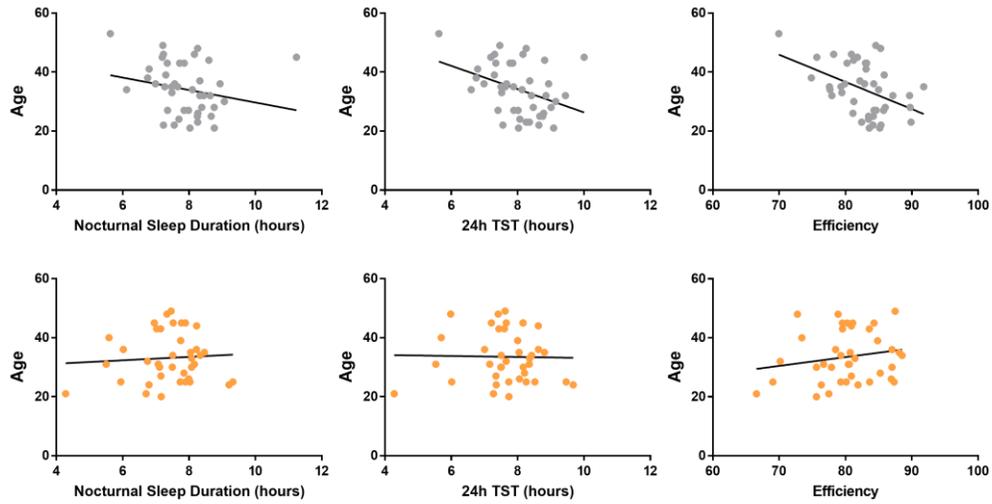
Note: Bold and Italic values are significant at  $p < .05$ .

#### **Age**

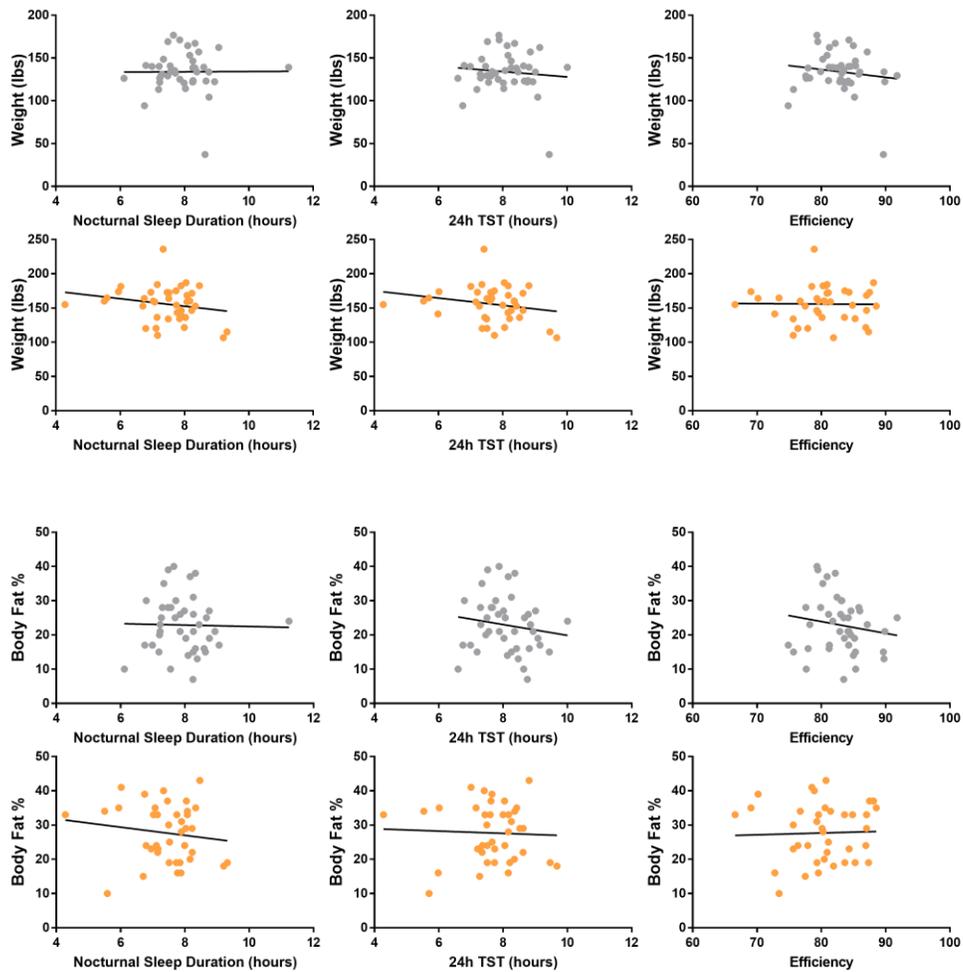
Pooling across adult type within communities, age was negatively correlated with nocturnal sleep efficiency in the non-electric community but not the electric community (Figure 3.20; Table 3.3).

#### **Weight & Body Fat %**

Weight ( $t_{(78)} = 1.03$ ,  $p > .05$ ) and body fat % ( $t_{(78)} = 1.03$ ,  $p > .05$ ) were higher in the electric communities compared to the non-electric (means in Table 2.1). Neither were significantly correlated with nocturnal sleep duration, nocturnal sleep efficiency, or 24h total sleep time (Figure 3.21; Table 3.3).



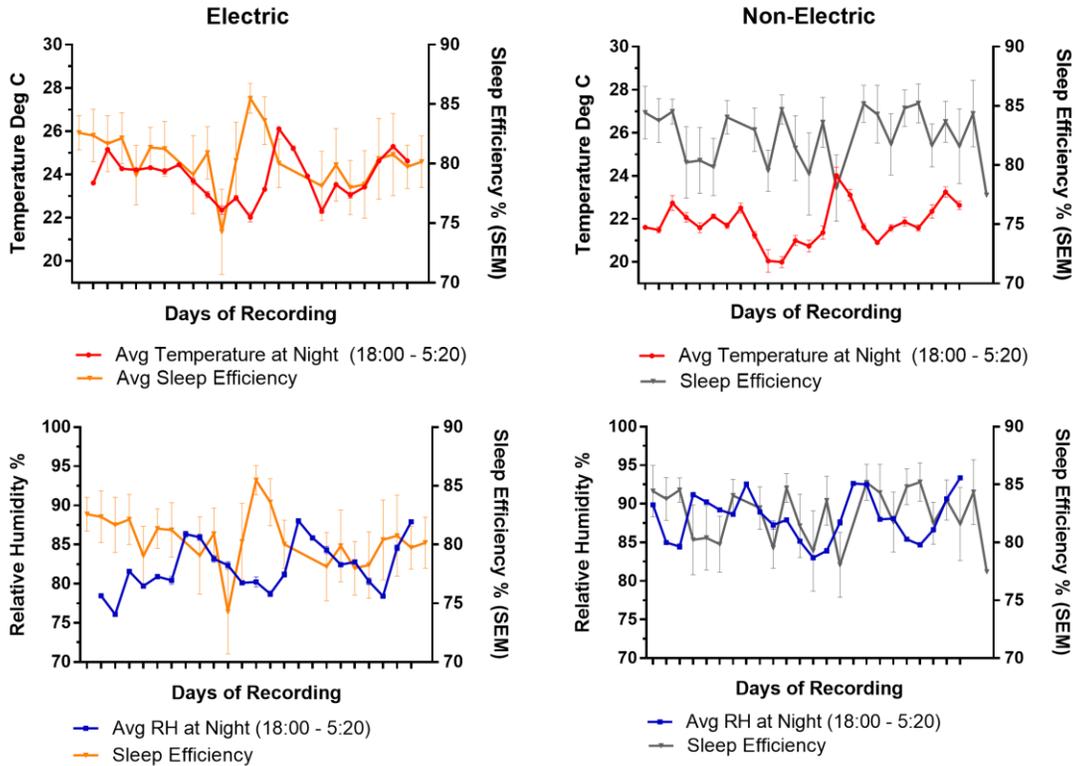
**Figure 3.19. Age Correlation with Sleep Variables**



**Figure 3.20. Weight & Body Fat % Correlation with Sleep Variables**

### 3.6.6. Environmental Temperature & Humidity

Even when controlling for hut type average nighttime temperature (18:00-5:20) was higher in the electric communities ( $t_{(44)} = 7.05, p < .00$ ), and relative humidity lower ( $t_{(44)} = 6.45, p < .00$ ). Daily sleep efficiency did not vary predictably with daily changes in environmental temperature or humidity measured within grass huts (Figure 3.22).

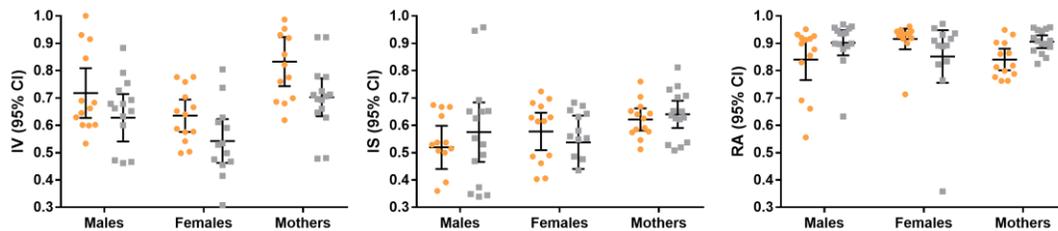


**Figure 3.21. Sleep Efficiency and Nighttime Temperature Variation**  
Temperature and Humidity measured from inside grass huts

### 3.7. Non-Parametric Measures of Circadian Robustness

Intradaily variability (IV) and interdaily stability (IS) were calculated for each subject using Clocklab version 6. IV is used to quantify fragmentation of rest-activity patterns, and IS quantifies synchronization to the 24h light-dark cycle. The electric communities had significantly higher IV ( $F_{(1,76)} = 11.83, p < .001$ ) but no difference in IS ( $F_{(1,76)} = 0.15, p = .678$ ). There was a significant main effect of adult type for both IV

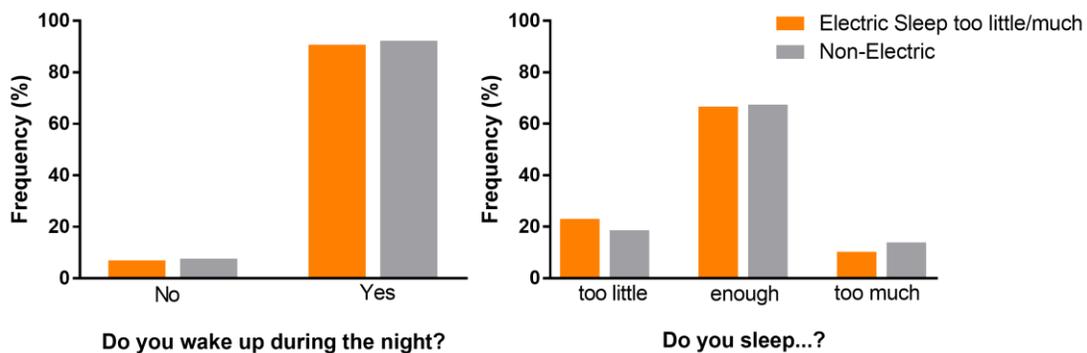
( $F_{(2,76)} = 11.47, p < .001$ ) and IS ( $F_{(2,76)} = 3.17, p = .048$ ). No significant interactions for IV ( $F_{(2,76)} = 0.18, p = .832$ ) or IS ( $F_{(2,76)} = 0.85, p = .43$ ). Mothers have the highest levels of both IV and IS (Table 3.1). Relative amplitude also did not differ significantly between the groups (see Section 3.1, Activity for test statistic). Means and SEM can be found in Table 3.1 and are plotted by adult type with 95% confidence interval in Figure 3.23.



**Figure 3.22 Non-Parametric Comparisons by Adult Type**

### 3.8. Self-Reported Sleep Quality

Subjective report during interviews found that 90.7% of individuals in the electric and 92.3% in the non-electric communities, report waking up during the night, and that 23.1% of individuals in the electric, and 18.6% in the non-electric communities reported sleeping “too little” (Figure 3.24). The cause of sleep interruptions in both community types was most frequently attributed to babies crying, and dogs barking (Figure 3.25).



**Figure 3.23. Self-Report Sleep Quality**

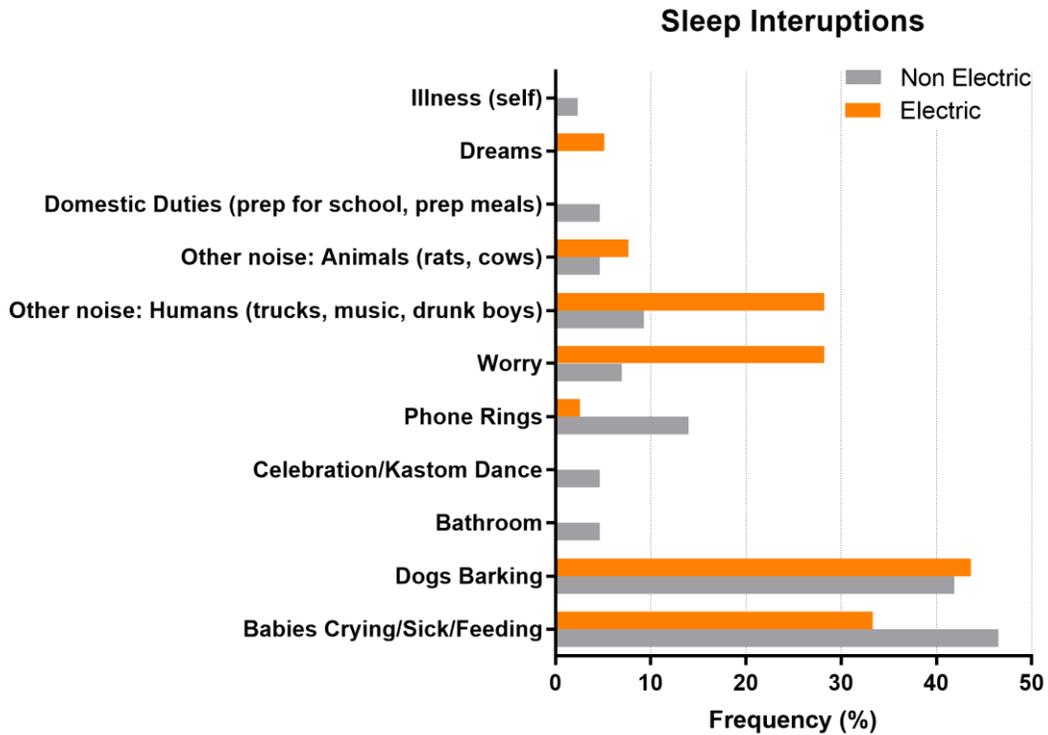
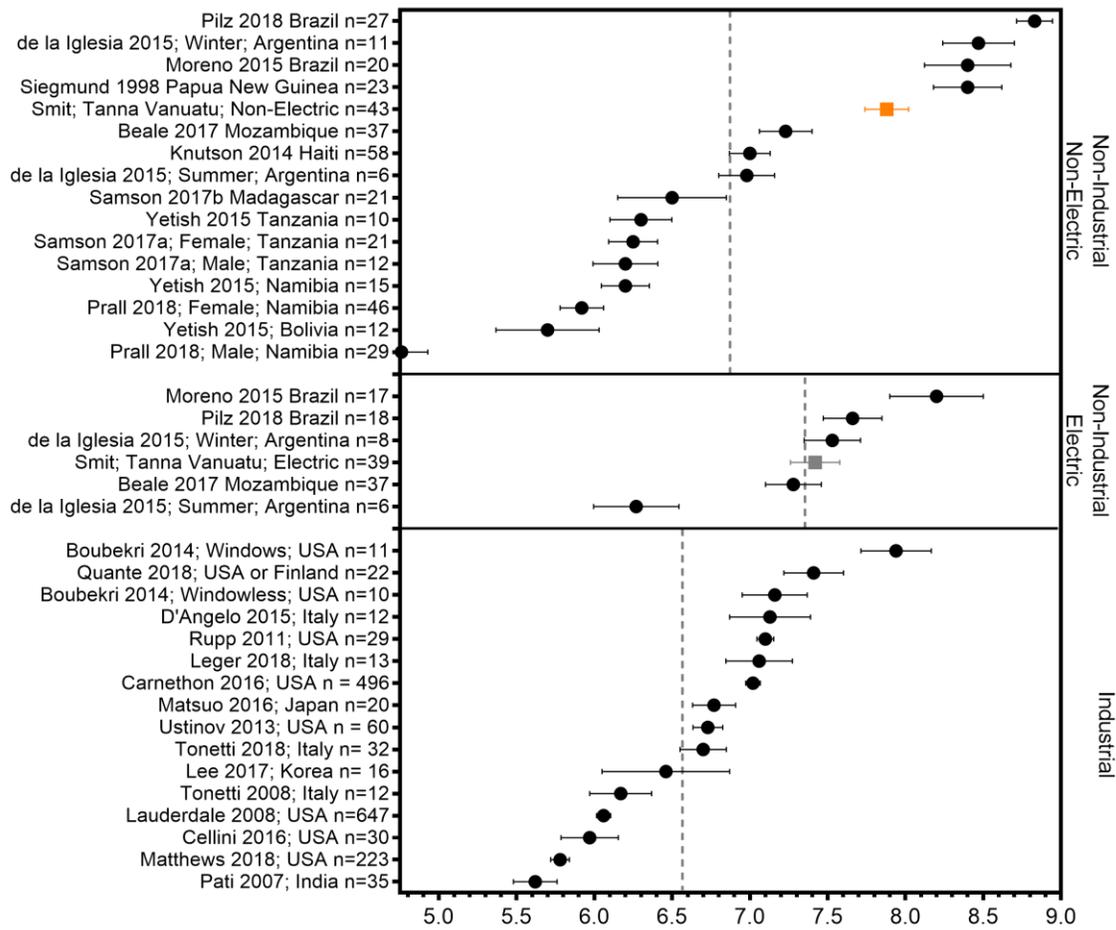


Figure 3.24. Self-Report Sleep Interruptions

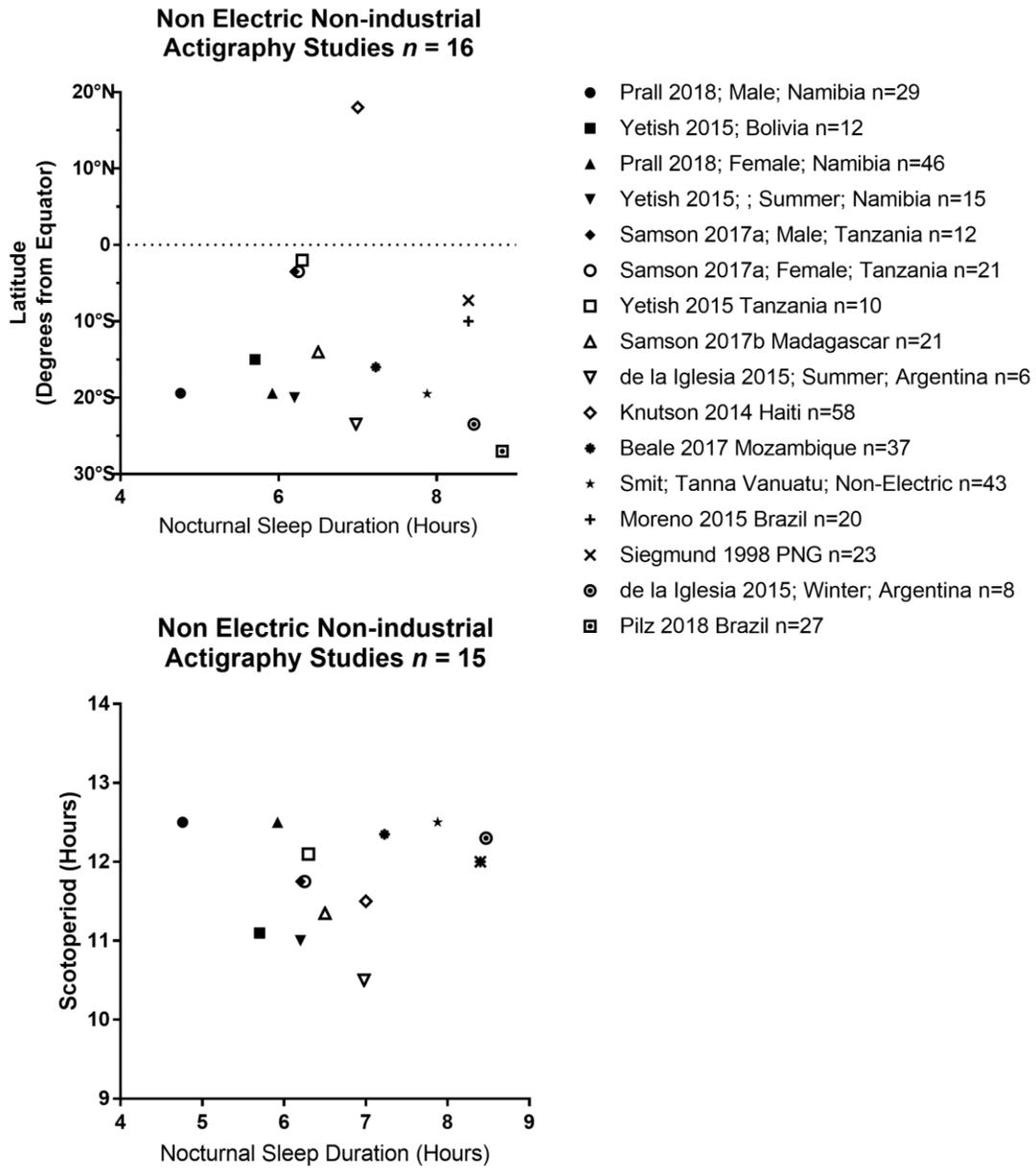
### 3.9. Sleep Duration Comparison

Average nocturnal sleep durations from Tanna Island samples were compared to averages reported for other non-industrialized and industrialized population samples measured with actigraphy (Figure 3.26). Nocturnal sleep duration in both the electric (7.42 hours) and non-electric (7.88 hours) communities on Tanna Island was higher than average nocturnal sleep duration in non-industrial (6.88 hours) and industrial populations (6.57 hours).

To explore possible sources of variability in sleep duration reported in previous studies of non-industrial, non-electric settings, sleep duration was plotted relative to latitude and scotoperiod (period of darkness) at the time of data collection. No clear relationships were evident (Figure 3.27).



**Figure 3.25. Nocturnal Sleep Duration Comparison between Actigraphy Studies**  
 Individual study means  $\pm$  SEM. Vertical lines represent means within industrialization category. Coloured symbols are means from present study (electric = orange; non-electric = grey). See Table 1.1 for additional details (i.e. sample ages). Criteria for inclusion in table are outlined in Section 1.3.



**Figure 3.26. Nocturnal Sleep Duration Plotted against Latitude and Scotoperiod for Non-Industrial Actigraphy Studies**

Note: Pilz 2018 data was not included in plot of sleep duration by scotoperiod since their data were collected across changes in photoperiod, and not one time of year.

## **Chapter 4.**

### **Discussion**

#### **4.1. Nocturnal Sleep Duration & Efficiency**

Delayed sleep onset and reduced nocturnal sleep duration in villages with electricity compared to villages without electricity on Tanna Island are consistent with results obtained in other studies of non-industrial populations (i.e. de la Iglesia, 2015; Moreno et al., 2015; Beale et al., 2017, Pilz, et al., 2018). An increase in sleep onset latency was enough to decrease nocturnal sleep duration by nearly a half hour in the electric compared with the non-electric communities. Nocturnal sleep duration was 28 minutes shorter per night, and sleep efficiency reduced in those with on-demand access to electric light.

At 7.4 to 7.8 hours, sleep lengths on Tanna are on the long-end of ranges reported using actigraphy in industrialized societies, as well as other non-industrialized settings (6.57 - 6.88 hours; Table 1.1). Despite relatively long sleep durations, overall sleep efficiency (% of time spent asleep relative to % of time spent awake during the nocturnal period) on Tanna was reduced compared to Western averages. Industrialized actigraphy studies with similar age groups report sleep efficiencies in the high 80's (87.8%; Table 1.1), compared to ~80% and ~83% percent in Tanna electric and non-electric villages, respectively. Average efficiency in other non-electric actigraphy studies is lower (75%; Table 1.1).

#### **4.2. Daytime Napping & 24h Sleep Duration**

If a 28-minute difference between communities in nocturnal sleep per day represents a decrease in electric villages (as opposed to excess sleep in non-electric villages), then a large sleep debt may accrue resulting in added sleep pressure. If this is the case, then changes in sleep architecture or increased prevalence of daytime sleep would be expected. EEG measures would be necessary to assess sleep architecture, although actigraphy is currently being tested as an adequate proxy (Winnebeck et al., 2018). Increased prevalence of napping in the electric communities was found in the

present sample. When daytime naps were considered, 24h total sleep duration was not significantly different between the electric and non-electric community types. This could suggest that naps are being used to account for nocturnally accumulated sleep debt (however the magnitude of the difference remains similar in both cases). Nonetheless, if individuals from electric communities were compensating for lost sleep using naps, then the difference between communities in mean 24h total sleep time should be decreased relative to the difference in mean nocturnal sleep time (Figure 3.14), which is not the case. Additionally, there is no obvious relationship between nap duration and prior night sleep, which would have been expected if naps were being used to compensate for lost sleep. At this point it is unclear if napping in this population is being used to make up for lost sleep, however it should be noted that data incorporating naps should be interpreted with caution since Actiwatch-2 does not distinguish between sleep and watch removal.

### **4.3. Relationships with Sleep**

The populations from Tanna were chosen in part because of similarity between the community types, the primary difference being access to an electric grid. In addition to differences in light exposure, some unexpected differences were also found between the communities, including differences in the number of total co-sleepers, physiological variables (weight and body fat %), and exposure to environmental temperature and humidity.

#### **4.3.1. Light**

Most individuals in electric communities had on-demand access to electric light. Although the reported high prevalence of use was unexpected, LED solar torches were used commonly, especially in the non-electric villages. LED bulbs emit wavelengths of light that is closer to the blue-green spectrum than electric incandescent bulbs. Our biological clock is most responsive to light in the blue-green spectrum, so such LED sources could potentially have a greater impact than electric light. Despite this, those living in the electric communities showed increased light exposure during the first hours of the night (18:00 – 0:00), and delayed sleep onset times resulting in shorter sleep. This may reflect a phase-delay of the circadian pacemaker controlling sleep onset or an

acute effect of evening light on alertness level (possibility mediated by suppression of melatonin secretion), though the lack of a statistically significant differences in bedtime, wake time, or rise time, suggests the latter. This could be addressed in future studies using salivary melatonin to assess circadian phase by dim light melatonin onset, although careful treatment of the samples would be required in locations without electric access. In either case, the results support a hypothesis that exposure to artificial light after sunset can delay sleep onset and reduce sleep duration. Evening light after sunset (between 18:00-0:00) negatively correlated with nocturnal sleep duration in the electric, but not the non-electric communities. Morning light prior to sunrise (3:00 - 5:20) did not correlate with nocturnal sleep duration in either community type. Currently solar torches on Tanna are often shared between multiple families, and require good weather to charge, so light from these is not as easy to access as electric light, but as their popularity increases, changes in sleep and stronger correlations may be forthcoming.

Delayed sleep onset and reduced sleep duration in villages with electricity are in line with what would be expected when exposed to electric light. Similarly, long sleep durations on Tanna compared industrial populations is not surprising. Long sleep durations compared to the industrialized world may reflect relatively lower levels of electric light exposure on Tanna (many households may have only one lightbulb), combined with much higher levels of natural daytime light, which has been shown to decrease sensitivity to artificial light in the evening (Hébert et al., 2002). During the daytime both communities were exposed to light levels that were generally higher than averages reported for industrialized populations (e.g. ~550-600 lux; Jean-Louis et al. 2000; Thorne et al., 2009). Residents of Tanna Island spend little time indoors during the day, which likely contributed to greater exposure to higher light intensities relative to Western populations. Nevertheless, like many of the islands in the Vanuatu archipelago, Tanna Island is home to a resident active volcano that often blankets the communities with a fine layer of soot and adds a smoky haze the skies. This could explain why the average daytime light intensity on Tanna (1650-2039 lux) was lower than that found during a week of camping in the North American Rocky Mountains (~4487 lux; Wright et al 2013). High daytime light has been suggested to be important for maintaining a high amplitude circadian rhythm of melatonin, which may be more highly connected to health outcomes than exposure to light at night (Kantermann & Roenneberg, 2009). Neither relative amplitude nor interdaily stability (IS) varied between community type suggesting

consistency in stability of entrainment and generally high amplitude of activity during the day (RA electric = 0.87; RA non-electric = 0.89). If factors such as daytime and evening light contribute to nocturnal sleep duration, we may expect to see evidence of decreasing sleep duration on Tanna Island longitudinally, as access to electric lighting, and increased industrialization expands throughout Vanuatu.

#### **4.3.2. Number of Co-Sleepers**

Previous literature has found that co-sleeping is negatively related to sleep efficiency. Prall et al., (2018) found that the number of co-sleepers predicted sleep efficiency in women, and Worthman and Brown (2013) found that co-sleeping reduced nocturnal and total daily sleep duration. Disruption from co-sleepers could be increased in bed types with high transfer of movement. Beale et al., (2017) implicate bed type in general as an important factor in sleep efficiency. Sleeping in a bed with mattress trends towards higher average sleep duration, although some individuals sleeping on mats on the floor achieved similar durations in their study (Beale et al., 2017). Individuals on Tanna are often sleeping on thin mattresses or grass mats on wood plank floors, with many individuals sharing one sleeping space (average 3.55 individuals in electric, and 4.53 in non-electric villages). If an increased number of co-sleepers were to affect sleep on Tanna, it would be predicted that sleep (efficiency and/or duration) would suffer in the non-electric communities. Instead we see shorter sleep and lower efficiency in the electric communities. Prall et al., (2018) found that increased co-sleeping adults increased total sleep time and sleep efficiency, likely because it helped with distribution of nocturnal labour caring for children. On Tanna Island, neither sleep duration nor efficiency varied with increased number of co-sleepers, either adults or children.

Mosko, Richard and McKenna (1997) found that mother-infant co-sleeping in industrialized nations increases nocturnal awakenings. Infants on Tanna co-sleep with caregivers. Breastfeeding mothers were kept as a separate sample from females (who are also mothers, however not currently with children of breastfeeding age) and males. It was expected that mothers who breastfeed young infants will have higher levels of sleep disruption due to mother-infant co-arousal, and therefore shorter sleep durations. Mothers in the electric communities had the shortest sleep durations, as expected, however these sleep durations were also significantly shorter than mothers in the non-electric communities. Sleep duration of the mothers in the non-electric communities did

not differ significantly from the males or females. Numerically, the highest proportion of sleep fragmentation, and lowest % sleep efficiency also emerged in the sample of electric community mothers, although the same patterns did not emerge in the non-electric community mothers. Mothers had the highest intradaily variability compared to other adult types, with the highest levels in the mothers of the electric communities, indicating fragmented activity patterns throughout the 24 hour day.

#### **4.3.3. Physiological Variables: Age, Weight & Body fat %**

Age did not differ between community types, but in general sleep changes significantly with age. A commonly described pattern is decreased sleep efficiency with increased age (Ohayon et al., 2004), however in the present study, sleep efficiency was positively correlated with age, therefore sleep efficiency increased with age. Although this is not what is commonly reported in Western populations, this pattern has been noted in other non-industrial settings (i.e. Knutson, 2014; Prall et al., 2018; Samson et al., year). Samson et al., (year) suggest that those of older age may get preferential treatment and may be able to choose more comfortable sleeping spaces, more bedding etc., which could lead to increased sleep efficiency compared to young adults.

Body fat % was in a healthy range for both community types but weight and body fat % was found to be higher in the electric communities. It is not known why weight and body fat would be higher in electric communities, but it may be the case that individuals in the non-electric communities are traveling farther on foot in a given day (less access to vehicles and roads), although no difference was seen in the M10 measure of activity. Since the electric communities are closer to the coast, they are doing more fishing, which means that they are likely consuming more fish and seafood than those in non-electric villages. Whatever the reason, it does not seem that this difference is leading to the differences we see in sleep duration between community types. No significant correlations were found with weight or body fat % and sleep duration (nocturnal or 24 hour) or efficiency, although body fat % was negatively correlated with bedtime and sleep onset.

#### 4.3.4. Environmental Temperature & Humidity

Populations without electricity (therefore lacking electric heating and cooling, refrigeration, and lighting) have greater exposure to daily and seasonal environmental variations, such as changes in photoperiod, temperature, and diet. Total sleep time has been found to be positively associated with greater temperature (Samson et al., 2017c), and increased sleep fragmentation with humidity (Samson et al., 2017b). Annual variation in temperature in Vanuatu is fairly small, with lows ranging from ~18°C in July, to highs of ~31°C in January (Retrieved from [www.timeanddate.com/weather/vanuatu/port-vila/climate](http://www.timeanddate.com/weather/vanuatu/port-vila/climate)). During the period of data collection, nighttime average temperatures inside sleeping huts on Tanna were 23.9 and 21.8°C (electric and non-electric communities respectively). Thermoneutral zone in humans (range of ambient temperatures where normal body temperature can be maintained without increasing basal metabolic rate) is between 25 – 30°C, but clothing and bed covering can affect thermal comfort (Muzet, Libert & Candas, 1984). Temperatures higher or lower than thermoneutral would be expected to lower sleep efficiency, although there was no indication of a relationship between nighttime temperature, or humidity, and sleep efficiency in the present data, which may indicate that nighttime temperatures on Tanna may have allowed for maintenance of a comfortable thermal range within sleeping spaces. This could contribute to longer and/or more efficient sleep periods relative to those in cooler climates. The minimum temperature on Tanna was 17.6°C, which had increased the next night by 1.5°C. It may require a longer duration of cold temperatures, or larger variability in temperature in order to see associated changes in efficiency. Sleeping spaces contained inside dwellings offer protection from extreme environmental temperatures. Samson et al., (2017c) has found that sleeping within a dwelling leads to less variation in thermal stress relative to outdoor sleeping spaces. On Tanna, all participants slept inside a grass, tin, or cement dwelling, whereas the Hadza have been reported to sleep in outdoor sleeping sites ~25-32% of the time (Samson et al., 2017c). This may contribute to explanation of comparatively shorter sleep in the Hadza (6.25 - 6.30 hours), than the Ni-Vanuatu of Tanna (7.4 – 7.8 hours). As can be seen by differences in temperature and humidity in Figure 3.22, dwelling type likely plays a large role (i.e. materials used for construction) in regulating ambient temperature. Unfortunately, information on dwelling was only collected for a small number of participants on Tanna (see section 2.12), and most

dwelling were grass, thus investigation of relationships between sleep and type of dwelling were not possible in the present study. Yetish et al., (2015) propose that exposure to daily temperature variation, common of non-industrialized sleeping environments, may strongly regulate the timing of sleep. Similar to the Hadza and Tsimane peoples studied by Yetish et al. (2015), wake up times on Tanna occurred near the nadir of the daily temperature rhythm (6:20am), preceding it by ~25-30 minutes, although wake up times aligned more closely to the timing sunrise (5:52-6:00).

#### **4.4. Self-Reported Sleep Quality**

The walls to dwellings are thin and uninsulated, allowing for greater exposure to outdoor temperatures, and greater sound transmission when wild dogs bark, or neighbouring babies cry, compared to Western homes. Reported disruptions in sleep included invasive noises, as well as worry if a partner is away in another village, or stress about how to make money to pay children's school fees. Prall et al., (2018) report sleep similar sleep disturbances (bathroom, kids, pain, fire maintenance). High levels of noise were associated with increased nocturnal activity in the Malagasy population (Samson et al., 2017a). Reported reasons for interrupted sleep differed between community types (Figure 3.25), however proportion of individuals reporting nocturnal awakenings was similar. Overall the majority of individuals (> 60%) in each community reported feeling like they sleep "enough".

Reasons for awakening seem to reflect differences in location. For instance, the electric communities are closer to developed roads and therefore more exposed to automobile related noise, which would be expected to increase as industrialization progresses. Samson et al., (2017a) propose that noise is a large component of the 'developing economy sleep degradation hypothesis' since increasing population density paired with traditional housing offers little protection from noise.

Another consideration is the impact that conducting research in traditional villages is having on sleep. The primary field research site was in one of the non-electric villages (Lounikavek), so in order to conduct research, installation of a large solar panel was necessary to power equipment (i.e. laptop for data download, Actiwatch charging docks). Surprisingly, sleep interruption from phones ringing was reported more frequently in the non-electric villages ( $n = 6$ ; 14%) than the electric villages (who have

much easier access to electric outlets;  $n = 1$ ; 2.5%). The few individuals living in Lounikavek with cell phones would use the field research site to charge phones, and half of the individuals reporting phone ringing as a sleep interruption were living in Lounikavek. This suggests that the field research site itself may be promoting use of technologies that are impacting sleep.

## 4.5. Fragmented Sleep

There is historical evidence that ancestral sleep included bimodal sleep patterns (e.g. Ekrich, 2001), of which evidence has been found in current non-industrial settings as well (e.g. Samson et al., 2017a). Although no consistent daytime sleep pattern emerged in the present sample, there was a higher instance of fragmentation of nocturnal sleep bouts than has been seen in other non-industrial populations (e.g. Yetish et al., 2015). It is not surprising to see a “first sleep, second sleep” pattern in mothers, who have to wake at night for their baby, but even males (~40%) and females (~50%) had high prevalence of sleep fragmentation (see section 2.42). The relatively temperate climate in Vanuatu did not necessitate a daytime siesta to escape from heat or direct sun, however, perhaps such a pattern would emerge more during warmer seasons, or in societies at different latitudes. It has been hypothesized that nocturnal bimodal sleep patterns may have been common in preindustrial Europe due to long nights experienced at high latitudes (e.g. Yetish et al., 2015). Wehr (1999) also found evidence for a biphasic sleep pattern when individuals in the laboratory were exposed to experimentally long nights. The scotoperiod on Tanna was ~12.5 hours. Conversely, increased sleep fragmentation in the Toba during shorter nights of the summer, compared to the winter (de la Iglesia et al., 2015). The authors suspect that this may be due to higher temperatures disrupting nocturnal sleep. The longest night experienced by the Toba in the winter was 12.3 hours, which may not be long enough to see bimodal sleep patterns (de la Iglesia et al., 2015), although scotoperiod on Tanna was ~12.5 hours, and fragmentation was seen in ~14% of all nights recorded.

Fragmentation in sleep and increased nocturnal awakenings may be a strategy evolved in environments where nocturnal vigilance is required. Sleep efficiency (including REM sleep) is usually decreased when risk of predation is higher, and the Hadza show nocturnal awakenings across individuals such that there is only 18 minutes during the nocturnal period where all individuals were asleep at the same time (Samson

et al., 2017b). Since predation risk is low on Tanna, this is unlikely to be the cause of fragmentation, but could have been maintained from days where other humans posed a threat.

## 4.6. Social Roles and Social Jetlag

Long sleep durations on Tanna compared to industrial populations was not surprising. Long sleep durations on Tanna compared to other non-industrial groups was less expected. This could reflect the agrarian lifestyle and relatively temperate climate of Tanna Island. Ekrich reports that subsistence demands kept non-industrial Europeans from slumber (Ekrich, 2001), but some subsistence demands are probably more restrictive of sleep than others. A subsistence horticultural lifestyle, such as on Tanna, may provide more opportunity for sleep, especially during seasons not associated with planting or a large harvest, compared to lifestyles of nomadic hunter-gatherers, for example. Hunter-gatherers are likely to have more ecological constraints than farming populations, as food may be less reliable. Yetish et al., (2015) did find 3 traditional hunter-gatherer populations had sleep fairly short sleep (5.7 – 7.1 hours), whereas a population of horticulturalists and fishermen in Papua New Guinea, thus living similar lifestyle and climate compared to Tanna also had fairly long sleep (8.40 hours). Alarm clocks are not used on Tanna Island, and there are no designated work and free days. Individuals do report taking days off from horticultural responsibilities, however working in the garden on these days is replaced with obligations for religious worship (e.g. church attendance).

Social jetlag can be assessed by looking at wakeup time versus nocturnal sleep duration. Sleep duration would be correlated with bedtime but not wake time, if wake time was fixed by an external cue like sunrise, social cues, or crowing of roosters, or by circadian clock control of wakeup. Robust circadian entrainment to sunrise may be the case on Tanna, as average wake up was around sunrise. In non-electric communities, significant correlations emerged between nocturnal sleep duration with bedtime and wake time. In the electric communities the correlation was only significant between nocturnal sleep duration and bedtime, but not wake time; evidence for social jetlag in the electric communities. Although sleep onset appears more variable than wake up time (Figure 3.9), which may suggest social jetlag, bedtime and rise time were positively correlated in both communities; the later the bedtime, the later the rise time. The same

was found for sleep onset and wake onset. This implies compensation (homeostasis of sleep duration) is more important than circadian clock control or external cues for determining wakeup.

A significant interaction with adult type suggests that sleep and light exposure differences between communities were driven primarily by mothers in the electric villages. Mothers with access to electricity had the shortest sleep overall, and the highest amounts of light at night. Reduced nocturnal sleep in this group may have been causally related to increased light exposure during nighttime infant care (e.g., feedings), since mothers in non-electric villages would have had the same nocturnal responsibilities but carried them out without electric light. Some mothers with access to light even reported during interview that they leave the light on all night for ease of dealing with the baby, and to suppress fears of the dark. Males were delayed in their sleep timing, relative to females and mothers. Males are often up late drinking kava, which is an important custom in Vanuatu, as the nakamal is an important place for older men pass along knowledge and advice to young males within the village. The sedative effects of kava may imply an increased sleep efficiency, however sleep efficiency of males in the present sample was no higher than that of the women. There are mixed results in the literature regarding sex differences in traditional populations. Namibian men living as agropastoralists had shorter sleep duration and lower sleep efficiency than women, due to differences in labour demands (Prall et al., 2018), although study of non-industrialized Hatians revealed no sex differences in sleep parameters (Knutson, 2014). Social roles are often quite different based on sex, and on Tanna care for children is primarily the responsibility of women. Anecdotal reports from some women (both females and mothers) during interview did indicate that early wake times are sometimes a necessity to prepare meals for children who attend school. This is suggestive that as these communities move more towards industrialized models, social jetlag is likely to increase. Taken together, the variability in gender differences suggest a strong influence of lifestyle, gender roles, and social obligations on sleep.

## **4.7. Limitations**

There were many advantages to study of this particular population. Living traditional lifestyles similar to the way Western societies lived prior to industrialization is the best proxy we have for ancestral sleep. The residents in all communities of Tanna

Island are living primarily small-scale subsistence horticultural lifestyles, in a non-money economy, with no social welfare assistance. Communities work together and everyone contributes to survival. There is little exposure to caffeine and limited alcohol, which limits substance abuse problems, or other variables that would need to be controlled. With continued globalization, increasing tourism, and increasing technologies, these traditional lifestyles are quickly changing.

The biggest limitation of the present study is that the “non-electric” communities, despite having no access to an electrical grid providing on-demand light, do have access to electric light in the form of solar torches. The high prevalence of torch use in these communities was unexpected. Ultimately the light levels in both communities at night were very low, and effects on sleep emerged nonetheless between communities in the predicted direction. Sleep in this population is however, not without influence of industrialization, and does reflect that of a true non-electric way of life.

As previously discussed, bed type and hut type may play a large role in sleep duration and efficiency. Sufficient data to quantify such relationship were not collected for several reasons. It was deemed appropriate only to take photos of sleeping spaces from individuals closely linked to the research project (i.e. research assistants and their family) as opposed to collection from all participants. Before arriving in the field, the researchers were unaware that different materials were used for domiciles, and due to miscommunication (i.e. misunderstanding of what defined a “grass hut”; see section 2.1.2) this was not realized early enough in the data collection process to adequately measure this variable. Cement homes may provide more protection from outside elements such as temperature fluctuations, wind, and offer more noise protection. Additional information about hut type, type of bed, and type and number of light sources in each household would have been invaluable to this analysis. There is unfortunately a difficult balance to achieve between research interests and respect of privacy while working in the field.

Using actigraphy has inherent limitations. Actigraphy has been validated against polysomnography, but it is important to remember that activity thresholds can only estimate sleep. Individual differences exist in levels of activity during wake and sleep, and it is possible to have periods of immobile waking, or periods of gross movement during sleep that may be mis-classified by actigraphy (Sadeh & Acebo, 2002).

Actigraphy is non-invasive and has been reported not to alter sleep behaviour since there is no observed “first night effect” (Ancoli-Israel et al., 2003), however the Ni-Vanuatu are not accustomed to wearing wristwatches, and several participants felt uncomfortable that they were being monitored. One mother mentioned that she removed the Actiwatch each time she went to the bathroom because she was afraid that she was being watched through the watch’s light sensor. It is more probable that alteration in sleep behaviour occurred due to recordings in the populations measured on Tanna, than in Western societies. Actimetry data has been found to be more reliable when worn on the non-dominant wrist, unfortunately this strategy was problematic in the present study. Languages native to Vanuatu are not written languages, and most individuals in the villages studied do not read or write. It was difficult to assess which hand would be dominant, unlike in the West where this is defined based on hand used for writing. The specific actigraph used, Actiwatch-2, does not distinguish between watch removal and periods of inactivity, so there is a possibility of overestimation of nap data, and therefore also data of 24-hour sleep duration. As mentioned in section 2.41, there was an attempt to control for this by asking individuals about days/times they napped (to corroborate watch data), and at the level of cleaning, where long periods without any counts of activity were excluded from analysis. All data using utilizing measures of daytime sleep should be interpreted with caution.

Subjective reports should also be interpreted with caution (see section 2.12). Ni-Vanuatu have different language, communication, and anecdotally, ways of thinking than that in the industrialized West. This became evident at both the level of data collection and analysis. During interviews, misunderstandings and breakdown in communication occurred, and adjustments had to be made in terms of wording of questions, and interpretation of responses (e.g. I thought I understood a reference to one’s cousin only to later find out that “cousin” has different meaning/definition on Tanna). Interviews were conducted in the indigenous language of each village and even research assistants have varied knowledge of the language unique to each village. Different patterns of sleep complaints seemed to emerge based on the research assistant conducting the interview, so it is possible that research assistants may have been guiding responses or also struggling with miscommunication. I was unable to understand the interviews which made trouble shooting and clarification of responses difficult in the moment. As a person of white race, and an outsider, I garnered a lot of respect, which may have

increased risk of observer bias. It is not possible to know for sure, but I suspect that some discrepancies in data, or lost data may be due to this high level of respect (e.g. non-compliance may have resulted from giving consent to participate when an individual may have preferred not to, but did not want to disrespect me). It is important to understand that the interview questions were both designed and interpreted from a Western perspective, and that this may not get at the depth or complexity of cultural factors contributing to variables of interest. Many questions asked were black-and-white but life in Vanuatu is flexible. For example, “*How many children do you share a sleeping space with?*” could vary daily in the villages, as a single designated sleeping space may not be as common on Tanna. Since quantitative analysis does not easily allow for such flexibility, this may have accounted for discrepancies uncovered when analyzing data. For example, a married couple who reported living and sleeping together, reported sharing their space with a different number of children.

Several of these limitations emerged because rapid change in Ni-Vanuatu lifestyle and culture could not be anticipated and therefore adequately planned for. Future research with these populations will benefit from the knowledge gained in this study, and the limitations described here will aid in guiding any further data collection on Tanna Island.

## **4.8. General Conclusions**

### **4.8.1. Postindustrial vs Developing Economy Sleep Degradation Hypotheses**

The postindustrial sleep degradation hypothesis posits that sleep is impaired in industrialized societies due to light and electronics (Samson et al., 2017a). Alternatively, the developing economy sleep degradation hypothesis posits that sleep is impaired in developing societies due to things like excessively noisy environments paired with traditional housing that offers little protection from temperature extremes and noise (Samson et al., 2017).

Ultimately the data from Tanna Island supports the postindustrial sleep degradation hypothesis. 1. Individuals with on-demand access to electric lighting were exposed to greater amounts of light at night, had delayed sleep onset and shorter sleep

duration. 2. Overall sleep durations on non-industrialized Tanna were long (7.4 – 7.8 hours) compared to industrialized averages (6.57 hours). When examined in context with data from existing non-industrial literature however, both (or neither) hypothesis is supported. Table 1.1 shows that both industrial and non-industrial populations have wide ranges in sleep duration, with overall averages between them being very similar.

It seems that examinations of sleep within more or less homogenous groups (i.e. a culture, class, area, community etc.) are where effects of light on sleep will be most evident. Differences in sleep seen across cultures however, likely also reflect many other aspects of lifestyle in addition to lighting. It may be the case that the effects of light are as hypothesized by the postindustrial sleep degradation hypothesis, while simultaneously sleep may be improved by other changes in the environment associated with Western levels of economic development. In other words, both hypotheses are simultaneously true, and while industrial standards of living, (and therefore access to comfortable sleeping arrangements, protection from elements, buffer from noise, etc.), tend to improve sleep, access to lighting around the clock (and perhaps other things like alarm clocks, daylight savings time) counteracts some of these improvements.

#### **4.8.2. Cross Cultural Comparison**

Through studying sleep of over 60 species Samson and Nunn (2015) conclude that ecological constraints are more important for determining sleep duration than functional benefits. Tanna lifestyles may simply allow for more sleep (e.g. flexible work schedules, no alarm clocks) compared to other industrial and non-industrial societies. Hunter-gatherers for example, may have more ecological constraints. Food may be less reliable, and they are required to adjust the timing of their sleep and activity relative to the availability of food. Nocturnal vigilance may be required in non-industrial populations who use outdoor sleeping spaces, or live in environments with natural predators. There are no predators on Tanna Island, and food is readily available which could allow for longer sleep durations. In addition to the sleep shortening effects of electric light, average sleep in industrialized groups may be less than Tanna due to greater social jetlag (although this is becoming more prominent on Tanna as Western influences increase, like school attendance, and working for money). Westerners are very often using alarm clocks to interrupt their biological night for morning social obligations like school and work. There is also much more stimulation in the form of electronics (the

light from which also has biological alerting effects), and chemical compounds (caffeine and other drugs) that reduce sleep. Modern industrial conveniences create environments where less physical activity is required, so although speculative, it may be possible that need for sleep is decreased since the need to conserve energy is reduced.

### **4.8.3. Are we getting enough sleep?**

Humans have shorter sleep and greater sleep efficiency than other primates (Samson & Nunn, 2015). Moving to the ground increases risk of predation, so humans had to evolve ways of sleeping that allowed for shorter duration, and therefore humans have more REM sleep compared to other primates (Samson & Nunn, 2015). There are many benefits of being awake, such as reduced likelihood of predation, increased time for social bonding, and acquisition of new skills.

It is possible that even in communities reporting short sleep, individuals may be getting enough for what they need to function at daily tasks, and otherwise homeostatic pressure should prevail. Some of the Hadza have been reported to sleep short durations (6.25 hours), but spend extended time in bed (> 9 hours; Samson et al., 2017c). Being awake but in bed may foster mating and benefit reproduction, so there may be some evolutionary benefit for short sleepers. If sleep duration was insufficient in this population then homeostatic pressure should have acted to increase sleep duration during the extended time in bed. Alternatively, differences in sleep architecture (i.e. increased slow wave sleep) may compensate in such short sleepers. In the West, short sleepers have increased pressure for SWS, and also a shorter duration of melatonin secretion (Aeschbach et al., 2003), although melatonin could be impacted by historical exposure to light. Non-electric societies may provide good models to study natural variation in sleep duration without the impacts of electric light on melatonin. Horne (2011) claims that humans are biologically capable of adapting to durations between 6 to 9 hours.

Ultimately, human sleep may be flexible in order to accommodate differing social needs. It seems unlikely that sleep has decreased drastically in modern times. Nunn et al., (2016) proposes that we are short sleepers because we have better things to do, which is not a modern phenomenon.

#### **4.8.4. Future Directions**

Continued cross sectional research in Vanuatu (annual) as Western influence increases would be very revealing of how the progress towards full industrialization changes sleep behaviors. It seems clear that there are many other variables affecting sleep and continued cross-cultural study and investigation within changing levels of industrialization will provide more insight into the effects of the adoption of electricity on natural sleep patterns, and further highlight the effects of lifestyle and societal norms.

#### **4.8.5. Final Thoughts**

People of all cultures have long relied on illuminants such oil lamps, fire light, or starry nights to perform tasks in the dark hours. Even non-electric villages on Tanna have adopted use of small solar powered torch lamps at night. During conversation with a woman from a non-electric village in Tanna, I asked why she felt the need to use the solar torch, and what her community did before them, since they must have been acquired only recently. She replied to me that even before the solar lamps, individuals would often carry a fire stick with them when walking through the villages, for visibility and for a sense of safety. It seems that there is some innate sense of comfort brought by illumination. These sources of illumination have drastically changed our world, especially industrialized nations. To what extent does this non-natural light impact our biology, and influence our health and well-being remains under investigation. Based on the evidence reviewed herein, my opinion is that electric light, designed to make life easier, is likely also doing us a disservice. Nonetheless, it has become clear through this research, that light and light-emitting technology are only pieces of a complicated puzzle of things affecting our sleep. Climate, lifestyle, heritability, genetics, culture, social status, job stress, gender role, and individual differences in circadian parameters are all surely exerting their effects on the timing and duration of our sleep. We live in a world where technology is advancing more rapidly than we can understand its impacts, and societies are either forced to, or excited to adjust.

Sleep suffers because we have “better” things to do. But this is not a modern phenomenon. Sleep in industrialized nations is impaired because of light, work, and social demands, and more. Sleep in non-industrialized societies is impaired because of lack of protection, comfort, exposure to environmental extremes, work, social demands

and more. So, sleep may be impaired no matter what, but the factors impairing it have changed. The existing literature as a whole does not currently provide enough evidence to claim that sleep duration has decreased in modern society, and it is hard to know if we are chronically sleep deprived, but since sleep is flexible we have evolved mechanisms to recover from sleep loss (i.e. homeostatic pressures that increase SWS, and increase propensity to sleep therefore napping etc.). In cases where the environment allows for it, sleep duration increases, but it may not be too far-fetched to believe that we are getting as much sleep as we need to reap the functional benefits necessary to perform in our daily lives. There may be little selective pressure to sleep greater amounts, but since research has shown sleep is connected to vast amounts of health outcomes, it is also not unreasonable to prioritize it, and attempt to create flexible environments that would reduce social jetlag and allow for increased sleep. At least for me, I'd certainly be happier with a little more shut-eye.

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# Appendix A.

## Participant Interviews

Date: Dei Participant #: Numba blong man Community: Komuniti  
Nam: \_\_\_\_\_ Genda \_\_\_\_\_ Apprx age: Stret Yia

### Sleep Interview Slip Toksave

General Introduction (after consent): Thank-you for allowing me to learn about your daily life and your sleep routine. I will now ask you some questions. If it is okay with you, we will begin.

Open stating: Tankyu blong allowem mi blong lanem abaot everi life blong yum o slip blong yu. Nowia bae mi askem yu sam question. sapos hemi stret long yu, ten yumitu statem.

1. Do you have a partner? YES / NO yu gat patner? YES/ NO  
2. If yes, does your partner share your sleeping area or does he/she stay in another house to sleep? SLEEP TOGETHER / SLEEP SEPARATE  
sapos yes, yu wetem patner blong yu I sharem ples blong slip p mania o woman I slip long nara haus SLIP TUGETA/ SLIP LONG NARA HAUS
3. How many children do you have? 0 1 2 3 4 5 6 7 or more  
yu gat hamas pikinini? 0 1 2 3 4 5 7 o mo  
List children ages here: \_\_\_\_\_
4. How many people do you live with? 0 1 2 3 4 5 6 7 or more  
hamas pipol yu stap live wetem olgeta? 0 1 2 3 4 5 7 o mo
5. Who did you share your sleeping area with this past week...  
number of adults \_\_\_\_\_ number of children \_\_\_\_\_  
hu nao yu sharem haus blong slip wetem long las week...  
namba blong ol man \_\_\_\_\_ namba blong pikinini \_\_\_\_\_
6. Do you use light/lantern/torch (solar or battery) in the evening? YES / NO  
yu stap usem light/hurricane light/ torch (solar o battery) long tiem wei I stat blong tudak? YES/NO
7. Do you use light/lantern/torch (solar or battery) in the late evening? YES/NO  
yu stap usem light/ hurricane light/torch (solar o battery) bifo long middle nite? YES/NO
8. Do you use light/lantern/torch (solar or battery) in the middle of the night? YES/NO  
yu stap usem light/ hurricane light/torch (solar o battery) afta long middle nite? YES/NO

9. Do you use light/lantern/torch (solar or battery) at sunrise? YES / NO  
yu stap usem light/hurricane light/ torch (solar o battry) long tiem wei I stat blong deilite?  
YES/NO

10. Do you have a **working** electric light in your house (it's working now)? YES / NO  
yu gat power light blong wok long em long haus blong yu (istap wok nowia)? YES/ NO

11. Do you use an electric light in your house in the evening? YES / NO  
yu stap usem power light long haus blong yu afta long tiem wei I stat blong tudak? YES/NO

12. Do you use a **working** electric light in your house in the late evening? YES/NO  
Yu stap usem power light long haus blong yu bifo long middle nite? YES/ NO

13. Do you use a **working** electric light in your house in the middle of the night? YES/NO  
Yu stap usem power light long haus blong yu afta long middle nite? YES/ NO

14. Do you use a **working** electric light in your house at sunrise? YES /NO  
Yu stap usem power light long haus blong yu long tiem wei I stat blong delite long?  
YES/NO

15. Each day, what do you do for the day?

- A) Work for money    B) Work in the garden    C) Work in the village  
D) Caring for children    E) Social visiting

Wanwan dei, wanem nao yu stap mekem?

- (A) wok from money (B) Wok long Karen (C) wok long villej (D) Lukaotem ol pikinini  
(E) Visitem ol friends

16. Each evening, what do you do?

- A) Work for money    B) Work in the garden    C) Work in the village  
D) Caring for children    E) Social visiting    F) Spend time at Nakamal

Everi aftanun, wanem nao yu stap mekem?

- (A) Wok from Money (B) Wok long Karen (C) Wok long villej (D) Lukaotem ol pikinini  
(E) Visitem ol friends (F) Spenem tiem long Nakamal

17. Is there a day of the week you do not work? YES/NO  
Igat wan dei long week we yu no wok? YES/ NO
18. If yes, is it always the SAME day or DIFFERENT? SAME//DIFFERENT  
Sapos yes, hemi wan samemak dei o wan nara dei? SAMEMAK DEI/ WAN NARA DEI
19. IF SAME, which day do you not work? \_\_\_\_\_  
Sapos samemak dei, wanem dei nao yu no wok long hem?.....
20. Do you drink kava most days? YES /NO  
Yu stap drink kaka everi dei? YES/ NO
21. Is there a fire where you sleep? YES/NO  
Igat fire long ples we yu slip long em? YES/ NO
22. Do you tend to the fire in the night? YES/NO  
Yu stap tanem yu iko long fire long nite? YES/ NO
23. How many times in the week do you tend to the fire? 0 1 2 3 4 5 6 7 omo  
Hamas taem long week nao yu stap wakeup long nite tanem yu iko long fire?  
0 1 2 3 4 5 6 7 o mo
24. Do you have to be awake in the night to do work? YES/ NO  
yu stap wakeup long nite blong mekem wok? YES/ NO
25. How many times in the week are you awake in the night to do work? 0 1 2 3 4 5 6 7  
omo  
Hamas taem long week nao yu stap wakeup long nite blong mekem wok?  
0 1 2 3 4 5 6 7 o mo
26. Are you awake in the night sometimes for socializing, celebrations or ceremonies? Yes/No  
yu stap wakeup long nite somteam blong mitting, lafads, ol kakai mo kastom? YES/NO
27. How often in the week are you awake in the night for socializing, celebrations or  
ceremonies?? 0 1 2 3 4 5 6 7 omo  
Hamas taem long week nao yu stap wakeup long nite blong mitting, lafads, ol kakai mo  
kastom? 0 1 2 3 4 5 6 7 o mo

28. Do you wake up in the night when you don't want to? YES/NO  
 Yu stap wake up long nite taem yu no wantaem blong wake up? YES/NO
29. Why? From wanem? \_\_\_\_\_
30. If you wake up in the night, do you sleep again after? YES/NO  
 sapos yu wake up long nite, yu slip back again? YES/NO
31. Do you nap/sleep during the day? YES/NO  
 Yu stap slip long dei tu? YES/NO
32. How often in the week do you nap/sleep during the day? 0 1 2 3 4 5 6 7 o mo  
 Hamas taem long week nao yu stap slip long dei? 0 1 2 3 4 5 6 7 o mo
33. When do you go to sleep at night? [SEE PICTURE]  
 Wenem tiem now yu stap ko sleep long hem long night? \_\_\_\_\_
34. When do you wake up in the morning? [SEE PICTURE]  
 Wenem tiem now yu stap wake up long hem long morning? \_\_\_\_\_
35. When do you eat the biggest meal of the day? [SEE PICTURE]  
 Wanem taem stret nao yu stap kakai bigwan long dei? \_\_\_\_\_
36. When do you first eat in the day? [SEE PICTURE]  
 Wanem taem stret nao yu kakai fes wan long dei? \_\_\_\_\_
37. When do you last eat in the day? [SEE PICTURE]  
 Wanem taem nao yu kakai las wan long dei? \_\_\_\_\_
38. Do you ever eat in the middle of the night? 0 1 2 3 4 5 6 7 o mo  
 yu no stap kakai long middle blong nite? 0 1 2 3 4 5 6 7 o mo

**Follow up Questions (post study)**

**follem ap ol question (studi)**

**Ask these questions when pick up watch**

**Askem ol question ia taem vu tekem ol hand watch**

\*CIRCLE all that apply (can be one or more than one circle)

circlem olgeta we oli stret (yu save circlem wan o mo circle)

1. Were you sick when you wore the watch?

BISLAMA

- A) No      B) Monday   C) Tuesday   D) Wednesday   E) Thursday  
F) Friday   G) Saturday   H) Sunday

2. Did you sleep during the day when you wore the watch?

BISLAMA

- A) No      B) Monday   C) Tuesday   D) Wednesday   E) Thursday  
F) Friday   G) Saturday   H) Sunday

3. Did you go to sleep earlier than usual?

BISLAMA

- A) No      B) Monday   C) Tuesday   D) Wednesday   E) Thursday  
F) Friday   G) Saturday   H) Sunday

Why? \_\_\_\_\_

4. Did you go to sleep later than usual?

BISLAMA

- A) No      B) Monday   C) Tuesday   D) Wednesday   E) Thursday  
F) Friday   G) Saturday   H) Sunday

Why? \_\_\_\_\_

5. Did you wake up earlier than usual?

BISLAMA

- A) No      B) Monday   C) Tuesday   D) Wednesday   E) Thursday  
F) Friday   G) Saturday   H) Sunday

Why? \_\_\_\_\_

6. Did you wake up later than usual?

BISLAMA

- A) No      B) Monday   C) Tuesday   D) Wednesday   E) Thursday  
F) Friday   G) Saturday   H) Sunday

Why? \_\_\_\_\_

7. Did you take off the watch or watch fall off?

BISLAMA

- A) No      B) Monday   C) Tuesday   D) Wednesday   E) Thursday  
F) Friday   G) Saturday   H) Sunday

MEN ONLY:

8. Did you drink Kava or alcohol when you wore the watch?

Long ol pas week, ol wanem deis nao yu drink kava o alcohol?

- A) No      B) Monday   C) Tuesday   D) Wednesday   E) Thursday  
F) Friday   G) Saturday   H) Sunday

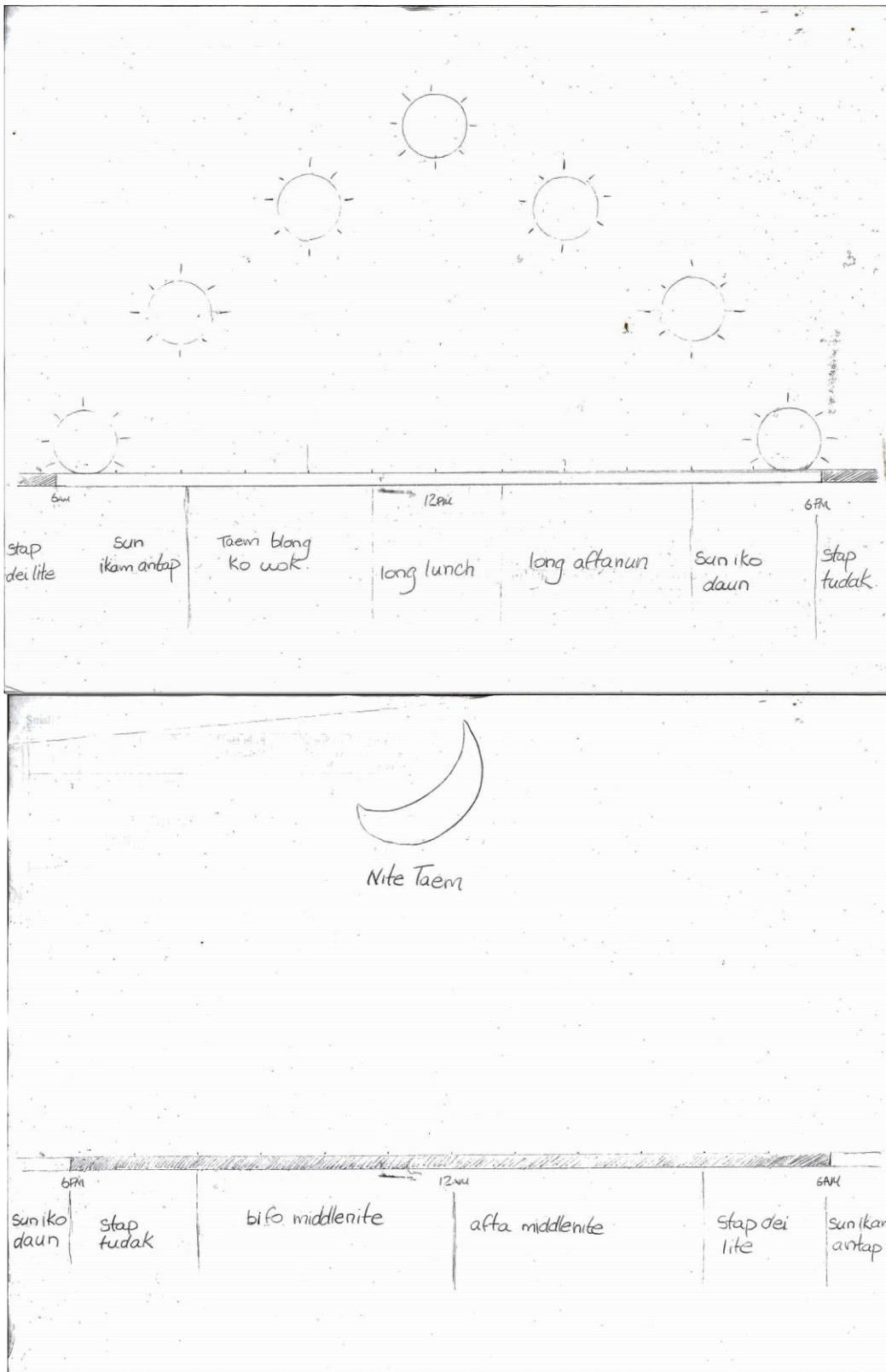
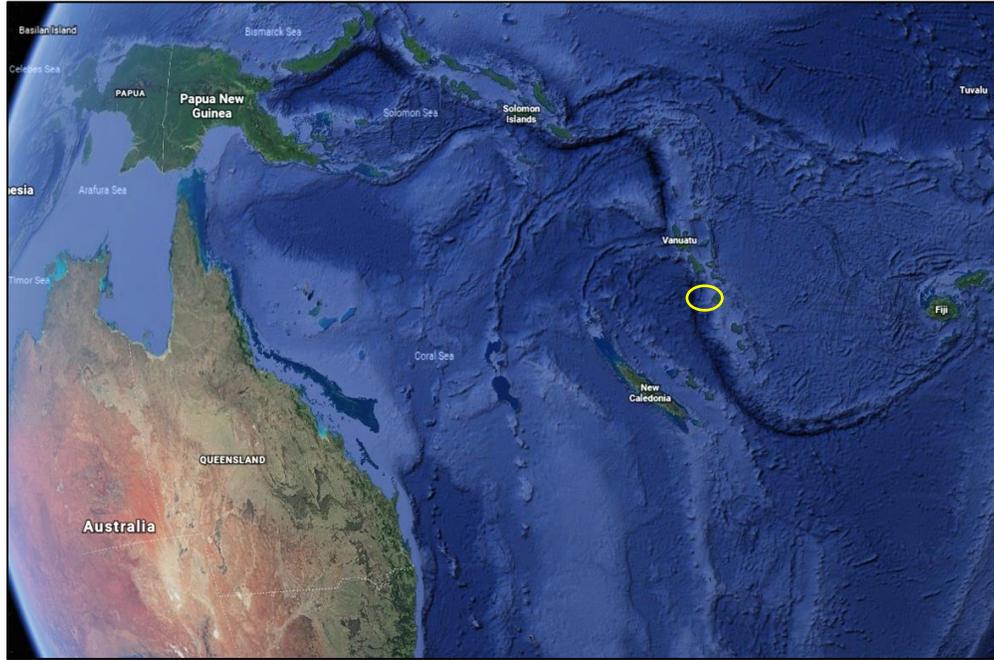


Figure A1. Pictoral Images representing time of day for use during interviews

# Appendix B.

## Location



Note: Images obtained from Google Earth

## Appendix C.

### Field Preparation & Notes

**Table C.1. Data Collection Schedule**

April – May 2017						
Sun	Mon	Tue	Wed	Thu	Fri	Sat
						April 1
2	3	4	5	6	7	8 Depart YVR 18:30
9	10 Arrive Port Vila 16:05	11 Shop for supplies	12 Arrive Tanna 11:10	13 Setup	14 <b>WEEK 1: Deliver watches</b>	15
16 Interviews	17 Interviews	18 Interviews	19	20	21 <b>WEEK 1: Pickup &amp; download</b>	22 <b>WEEK 2: Deliver Watches</b>
23	24 Interviews	25 Interviews	26 Interviews	27	28	29 <b>WEEK 2: Pickup &amp; download</b>
30 <b>WEEK 3: Deliver watches</b>	May 1	2 Interviews	3 Interviews	4 Interviews	5	6
7 <b>WEEK 3: Pickup &amp; download</b>	8 Clean up day	9 Scheduled depart Tanna 15:50	10 Delayed departure due to Cyclone	11 Depart Port Vila 16:50	12	13

Scale: 1 square = \_\_\_\_\_

Week 1

	Color	Handwatch #	Nem	Genda											
				F/M	usia	Komuniti	Famili tingting	Dei	Ethics Y/N	Height Weight Y/N	Toktok Y/N	Rekam UP Y/N	Pern Y/N	Leta bong yu	Bim Cert
1	Red	6219		F	21	Letaus	1	14/04/17	Y	Y	✓	✓	JT	02 JT	Y
2	Yellow	8171		M	5mos	Letaus	1	14/04/17	Y	Y	✓	✓	JT	02 JT	Y
3	Green	8182		F	26	Lenamir	2	14/04/17	Y	Y	✓	✓	JT	JT	X
4	Green	6232		F	30	Lenamir	3	14/04/17	Y	Y	✓	✓	JT	02 JT	Y
5	Green	6230		F	31	Lenamir	4	14/04/17	Y	Y	✓	✓	JT	02 JT	Y
6	Green	6491		F	34	Lenamir	5	14/04/17	Y	Y	✓	✓	JT	02 JT	X
7	Red	6235		F	31	Loukatani	6	14/04/17	Y	Y	✓	✓	JT	02 JT	X
8	Yellow	6498		M	6mos	Loukatani	6	14/04/17	Y	N	✓	✓	JT	02 JT	Y
9	Red	7484		F	24	Loukatani	7	14/04/17	Y	Y	✓	✓	JT	02 JT	Y
10	Yellow	6170		M	2mos	Loukatani	7	14/04/17	Y	N	✓	✓	JT	02 JT	Y
11	Red	6979		F	32	Loukatani	8	14/04/17	Y	Y	✓	✓	JT	02 JT	Y
12	Yellow	8246		M	3-4mos / 5days	Loukatani	8	14/04/17	Y	N	✓	✓	JT	02 JT	NA
13	Red	6969		F	24	Loukatani	9	14/04/17	Y	Y	✓	✓	JT	02 JT	X
14	Yellow	8186		M	5mos	Loukatani	9	14/04/17	Y	N	✓	✓	JT	02 JT	Y
15	Green	2895		F	36	Loukatani	10	14/04/17	Y	Y	✓	✓	JT	02 JT	X

Figure C.1. Field Notes: Data Record Table for Actiwatch & Demographics

#	Dei	Nem	Weight	Height	%	Fes leta biang name biang. su
1	14/04/17		155.0	5.7inc	33%	02 JT
	14/04/17		121.6	5.5inc	24%	02 JT
2	14/04/17		160.0	5.6inc	34%	02 JT
	14/04/17		187.0	5.5inc	37%	02 JT
3	14/04/17		152.8	5.4inc	35%	02 JT
	14/04/17		158.8	5.6inc	35%	02 JT
4	14/04/17		146.4	5.1inc	31%	02 JT
	14/04/17		159	5.0inc	34%	02 JT
5	14/04/17		168.4	5.4inc	33%	02 JT
	14/04/17		154	5.3inc	33%	02 JT
16	14/04/17		160.4	5.65inc	26%	02 JT
17	14/04/17		106.6	5.25inc	18%	02 JT
18	18/04/17		120.	5.3inc	24%	02 JT
19	16/04/17		163.8	5.8inc	19%	02 JT
21	20/04/17		173.8	5.5	35%	02 JT
24	22/04/17		175	5.6	19%	02 JT
23	22/04/17		184.0	5.4	39%	02 JT
25	22/04/17		181.6	5.1	41%	02 JT
27	"		167	5.2	39%	02 JT
31	22/04/17		146.6	5.35	29%	02 JT
29	22/04/17		176.6	5.35	38%	02 JT
32	"		184.2	5.10	22%	02 JT
33	"		136.2	5.4	29%	02 JT
32	"		131	5.4	30%	02 JT
35	"		115	5.2	19%	02 JT
36	"		182.6	5.35	43%	02 JT
37	"		182.4	5.7	28%	02 JT
38	"		152.8	5.7	15%	02 JT
39	"		165	5.25	35%	02 JT
40	23/04/17		172.8	5.8	37%	02 JT
41			160.2	5.35	33%	02
42			120.4	5.15	24%	02
43			170	5.0	23%	02
45			204.8	5.4	42%	02
46			164.7	5.7	16%	
47	Mary		136.4	5.4	23%	
			171.6	5.8	22%	
			172.4	5.6	25%	
			236.0	5.7	40%	
			134.4	5.35	19%	
			141.4	5.55	16%	

Scale: 1 square = \_\_\_\_\_

Figure C.2. Field Notes: Data Record Table for Height & Weight

Intro - sample

Halo!

We are researching how getting more or less light + food might make people sleep better.

We want to compare families with a mom, dad and baby with other adults that don't have babies. Each of these people should be healthy and be available for 7 days. Babies should be younger than 1 year old and not walking.

Mom, dad, baby and other adults will wear one of these watches for 7 days without taking it off.



Week 1 (April 14-21) → 5 families (5 moms, 5 dads, 5 babies) + 5 <sup>mom</sup> no baby

Week 2 (April 22-28) → 5 families (5 moms, 5 dads, 5 babies) + 5 mom no baby

Week 3 (April 29-May 7) → 5 families (5 moms, 5 dads, 5 babies) + 5 mom no baby

We will visit each person during the week to measure their height and weight. We will ask them questions about their sleep, food and light. We need to carefully write all answers in this book.

After 7 days we will take back the watch, ask a few questions. We will give them a gift for participating.

- = mom (who has baby)
- = dad (who has baby)
- = baby (0-6 months)
- = other adult (mom no baby)

Scale: 1 square = \_\_\_\_\_

Summary steps

**INSTRUCTIONS FOR RESEARCHERS**

Mifala stap mekem research ia blong luk luk lo ol samting olsem light, kakai, mo hao ol pipol oli stap tugeta blong slip longtaem o short taem, long Tanna.

Mifala wantaem findem ol families wetem ol mama, daddy mo ol pikinini. Ol pikinini ia oli mas stap lo age blong 1 yia, mo oli no save wokabaot yet. Mifala nidem wanwan long ol pipol olsem (mama, daddy mo ol pikinini) blong oli healthy mo oli save stap blong 7 deis.

Ol families we oli wantaem tekem pa

Yumi wantaem 5 famili long wan area long wan week, mo yumi wantaem mekem wok ia blong 3 diferent weeks.

Week 1 (April 14 – 21) → 5 families, (5 moms, 5 dads, 5 babies) + 5 moms w/ baby's more than 7 yrs

Week 2 (April 22 – 28) → 5 families (5 moms, 5 dads, 5 babies) + 5 moms w/ baby's more than 7 yrs

Week 3 (April 29 – May 7) → 5 families (5 moms, 5 dads, 5 babies) + 5 moms w/ baby's more than 7 yrs

Wanwan long ol handwatch ia oli differen so hemi gud tumas blong yumi mas save wich wan now wanwan man I stap wearem. Bae yumi writem daun ol numba mo name lo sid blo wanwan long ol mania. Yumi mas letem olgeta oli save blong keepem mo wearem handwatch mo no sharem/givem long nara man.

Wanwan long ol family memba ia bae oli gat coloured sticka. Mama= Red; Papa= Blue; Baby=Yellow; ol nara man= Green

Bae yumi visitem wanwan long ol mania long weeken mo measurem ol height mo weight. Bae yumi askem olgeta ol question long ol slip blong olgeta. Yumi mas tekem gud note long ol answa blong olgeta.

7 deis afta yumi givem watch lo olgeta, yumi visitem wanwan long ol mania blong oli save givem bak watch, mo givem olgeta sam questions. Bae yumi givem olgeta sam gifts from oli participate wetem yumi.

Scale: 1 square = \_\_\_\_\_

Figure C.3.1 Data Collection Instructions for Researchers

INSTRUCTIONS FOR RESEARCHERS

Day 1:

- Find 6 healthy families (mom, dad and baby) and 6 other adults
- Read each the consent form and write their response
- Give each person a watch (including the baby)
- Write down the watch # next to their name (in this book)
- Label the watch with colour sticker
- Tell mom and dad the instructions (or the other adult)

Day 2-6:

- Visit each person. Make sure they are wearing the watch
- Ask each adult (mom, dad or other adult) the "General Questionnaire" questions and write answers in this book
- Measure adult height and weight and write it in this book

Day 7:

- Visit each person and take the watch
- Ask each adult the "End of Study" questions.
- Give them gift (colourful watch for adults and t-shirt for babies)

Wok blong wan week:

Dei 1

- Findem wan gudfala mama, papa, pikinini mo ol mama we oli nogat pikinini.
- readem lo peper mo wriem daun ol tingting blong olgeta.
- sapos family ia I wantaem tekem part then bae mifala givem watch long mama, papa, mo pikinini.
- wriem daun ol numba blong wanwan watch mo ol names blong olgeta. Wriem daunt tu ol nara information blong olgeta.
- talem long mama mo papa ol instructions ia.

Dei 2 - 6

- visitem wanwan long ol mania (mama, papa mo pikinini). Mekem sua se oli warem hand watch mo followem ol instruction ia.
- Askem wanwan long ol mania long interview mo wriem daun ol answa. (no mekem blong ol pikinini)
- Measurem wanwan long ol mania height mo weight mo wriem daun. (no mekem blong pikinini)

Dei 7

- Vistem wanwan long ol mania mo tekem ol handwatch.
- Askem wanwan long olgeta long "end blong study ia" ol questions.
- Givem olgeta ol gift olsem (handwatch, mo ol t-shirt blong ol baby ia)

Instructions #4001mapa

WATCH NUMBERS

Each watch is different so it is very important for us to know which person is wearing which watch.

We must write down the watch number beside the name of each person. We will ask each person to wear the watch we gave them, and NOT to share or trade them.



← Watch number = last 4 numbers on the back of each watch

Scale: 1 square = \_\_\_\_\_

Figure C.3.2 Data Collection Instructions for Researchers

*Consent*

Date: \_\_\_\_\_ Community: \_\_\_\_\_ Subject ID: \_\_\_\_\_  
 Title: Co-Sleeping in a small-scale society  
 Ethics application number: 2017s0085

Principal Investigator: Andrea Smit, FASS/Department of Psychology, Sleep and Circadian Rhythms Laboratory,  
 Research Supervisor: Dr. Ralph Mistlberger, FASS/Department of Psychology, Sleep and Circadian Rhythms Laboratory,  
 Research Collaborator: Dr. Tanya Broesch, FASS/Department of Psychology, Culture and Development Laboratory,

Tankyu blong toktok wetem mifala. Mifala I lanem about life blong yufala finish from mifala ting se emia emi diferen long culture blong mifala. Purpose blong mifala hemi blong lukluk long ol slip blong ol mama, papa mo ol pikinini. So mifala askem sapos yufala save wearem hand watch ia blong 7 deis. Gud somting se yu no mas tekem aot watch ia long hand blong yu. Bae mi measure height mo weight blong yu. Yu mas save tu se afta long 7 dei bae mi kam blong tekem bak ol watch ia. Mo afta lem bae mi pem yu 500vt Sapos yu ting se ino stret long yu lo middle blong ol deis ia bae yu tekem 200vt nomo. Sapos yu ting se yu no wantaem participate yu save talem long mi tingting blong yu.

Yu ting se emia emi wan gudfala samting we yu wantaem triam? Yu wetem family blong yu I likem blo join lem nowia? Sapos yu no wantaem tekem part then bae mifala pem yu 200vt blong tekem part blong yufala. Mi tappy wetem ani tingting we yu kam up wetem.

**Istret blong yu save wearem hand watch ia blong 7 deis mo no tekem aot, mo tu letem mifala ikam blong askem yu sam questions?**

\_\_\_\_\_ YES \_\_\_\_\_ NO

Tankyu blong tekem up taem blong yufala long dei ia.

Questions/comments or to learn about the research results: Feel free to contact Ambong Thompson, Vanuatu Cultural Center at Tel: \_\_\_\_\_ You may also contact the researcher, Andrea Smit her supervisor, Dr. Ralph Mistlberger Sleep and Circadian Rhythms Laboratory, Simon Fraser University, Burnaby, BC, Canada,

Concerns or Complaints: If you have any concerns or complaints, please contact Ambong Thompson, Vanuatu Cultural Center at Tel: \_\_\_\_\_ You may also contact Dr. Jeff Toward, Director, Office of Research Ethics, Simon Fraser University, Burnaby, BC, Canada,

Scale: 1 square = \_\_\_\_\_

*Instructions Participants*

**INSTRUCTIONS FOR PARTICIPANTS:**

Toksavae blong ol man we bai oli tekem part long activity ia:

Ol Mama, papa mo ol narafala man

- wearem/putum handwatch ia long hand blong yu blong 7 deis.
- NO MAS tekem aot. Bae ino save wok sapos yu tekem aot.
- NO MAS sharem o exchangem. Bae ino save wok sapos yu no wearem same watch we mi stap givem long yu.
- NO MAS coveremap wetem klos
- Prestem button taem yu stap ready blong ko slip long nite, o slip long dei.

Ol Pikinini

- Putum watch ia long leg blong baby blong yu blong 7 deis.
- NO MAS tekem aot.
- NO MAS sharem o exchangem
- NO MAS coveremap wetem klos. Hemi okay blong putum antap long klos.

*Rita Smit*

Scale: 1 square = \_\_\_\_\_

Figure C.3.3. Data Collection Instructions for Researchers; Ethics Script and Instructions to Participants

## Appendix D.

### Actiwatch-2 Actograms

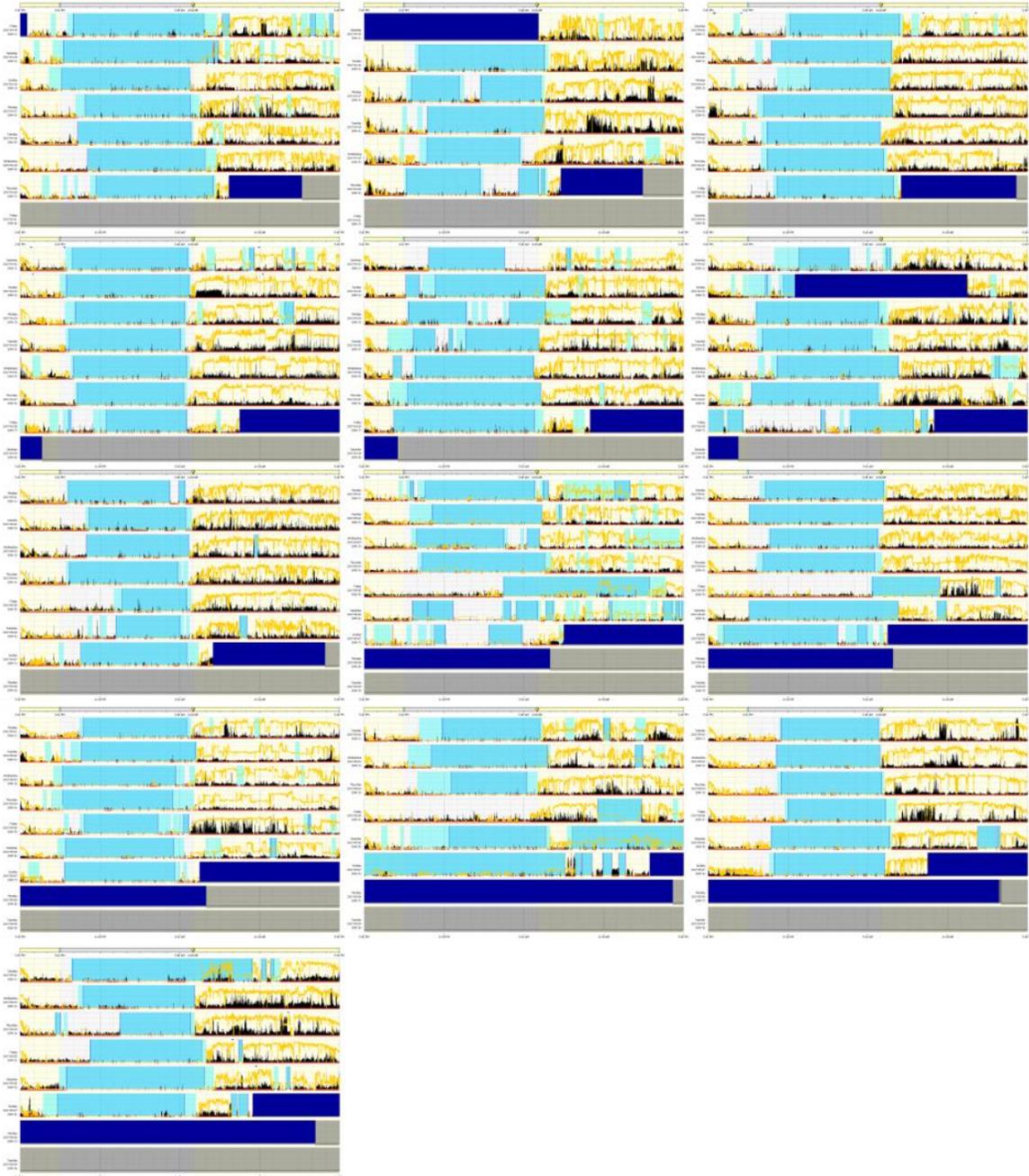
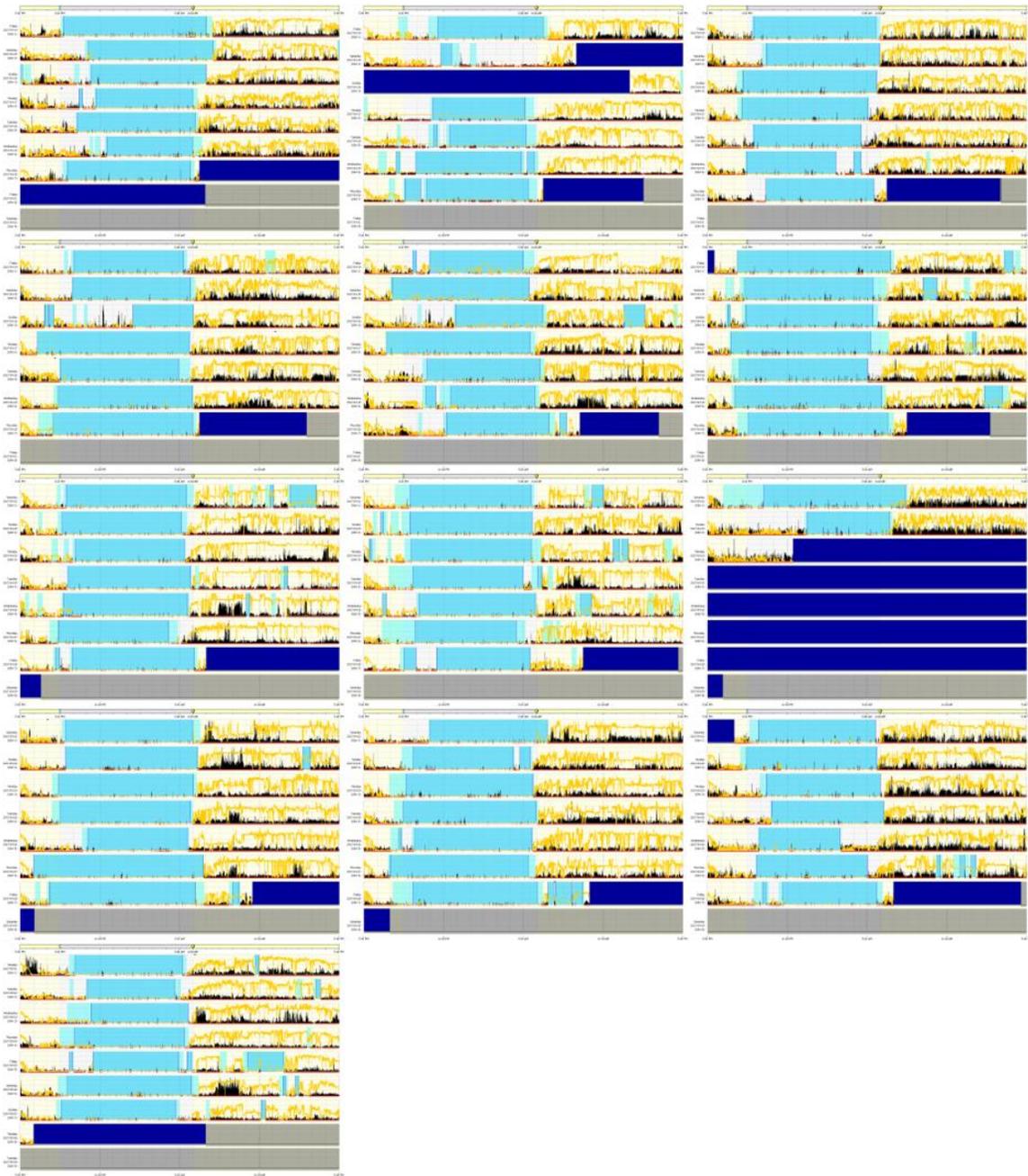
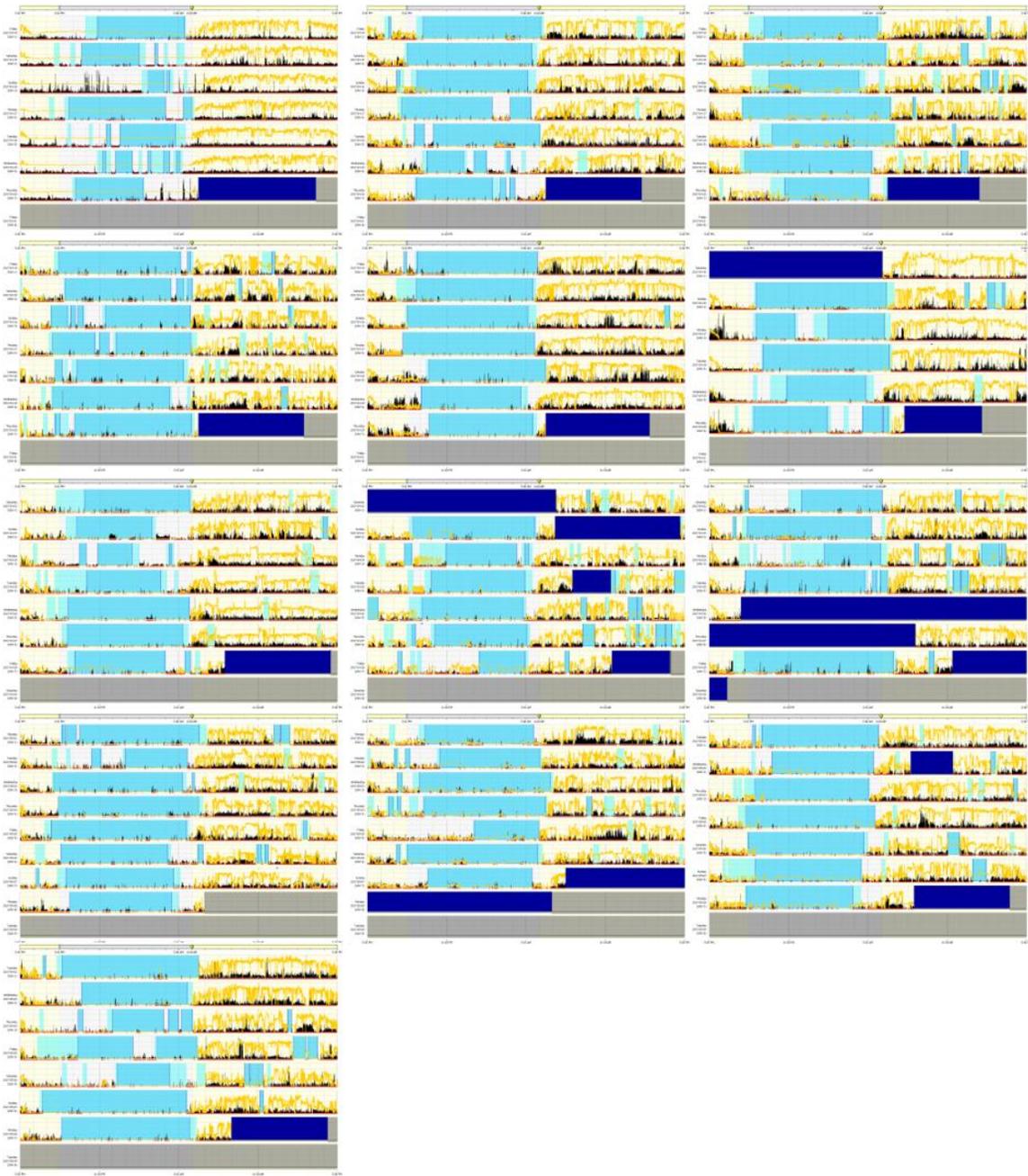


Figure D.1. Males from Electric Communities

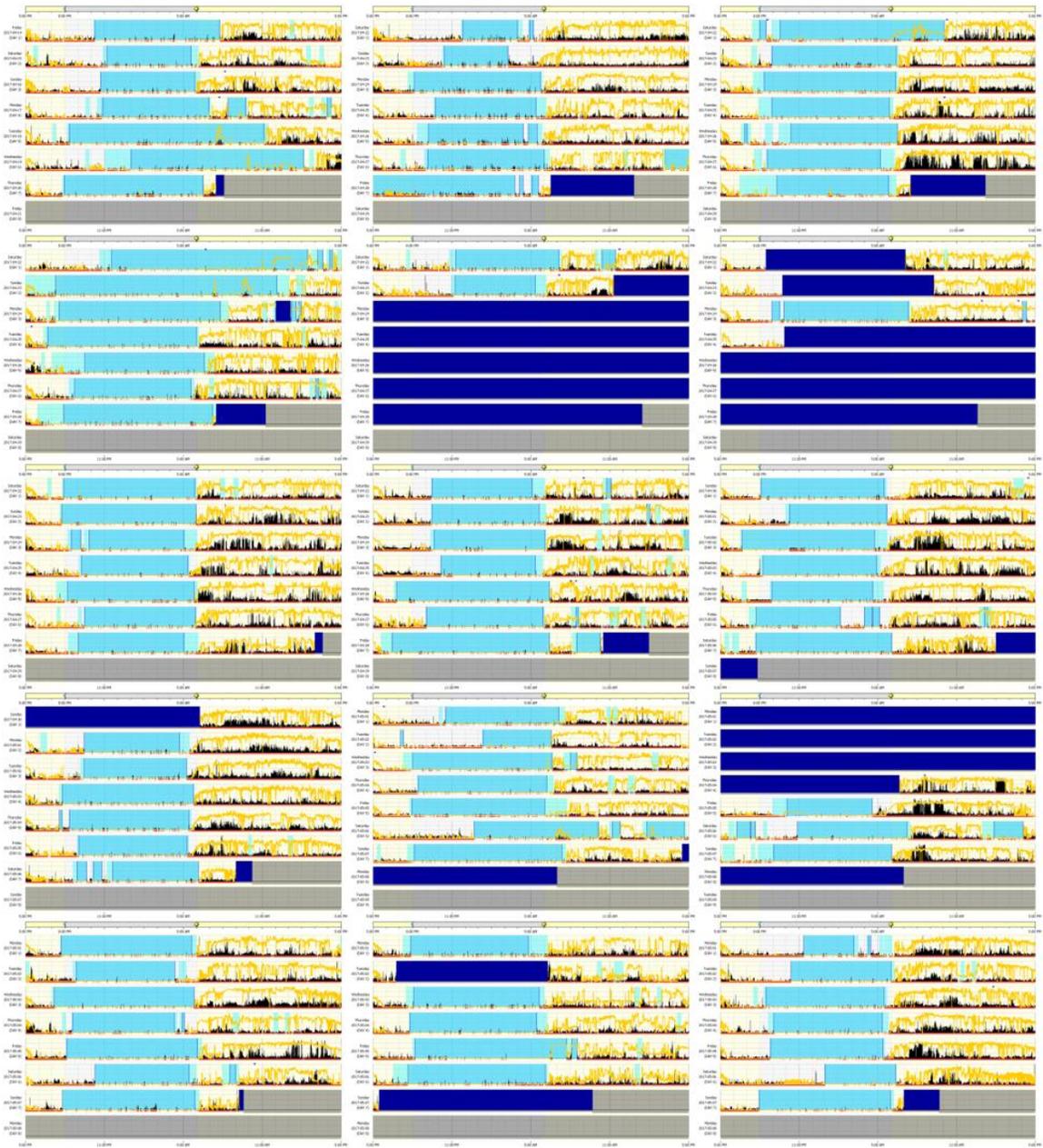


**Figure D.2. Females from Electric Communities**

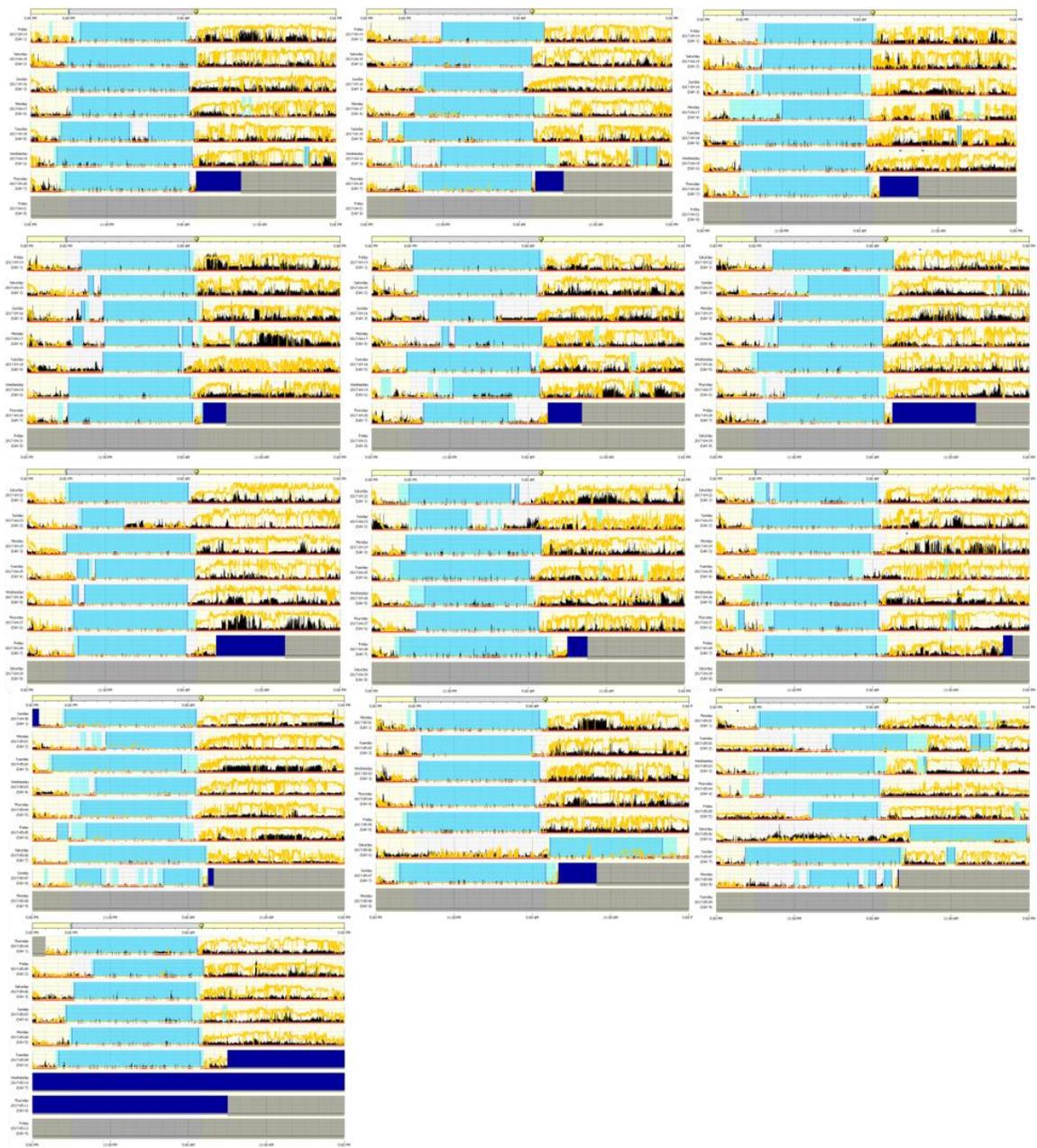


**Figure D.3. Mothers from Electric Communities**

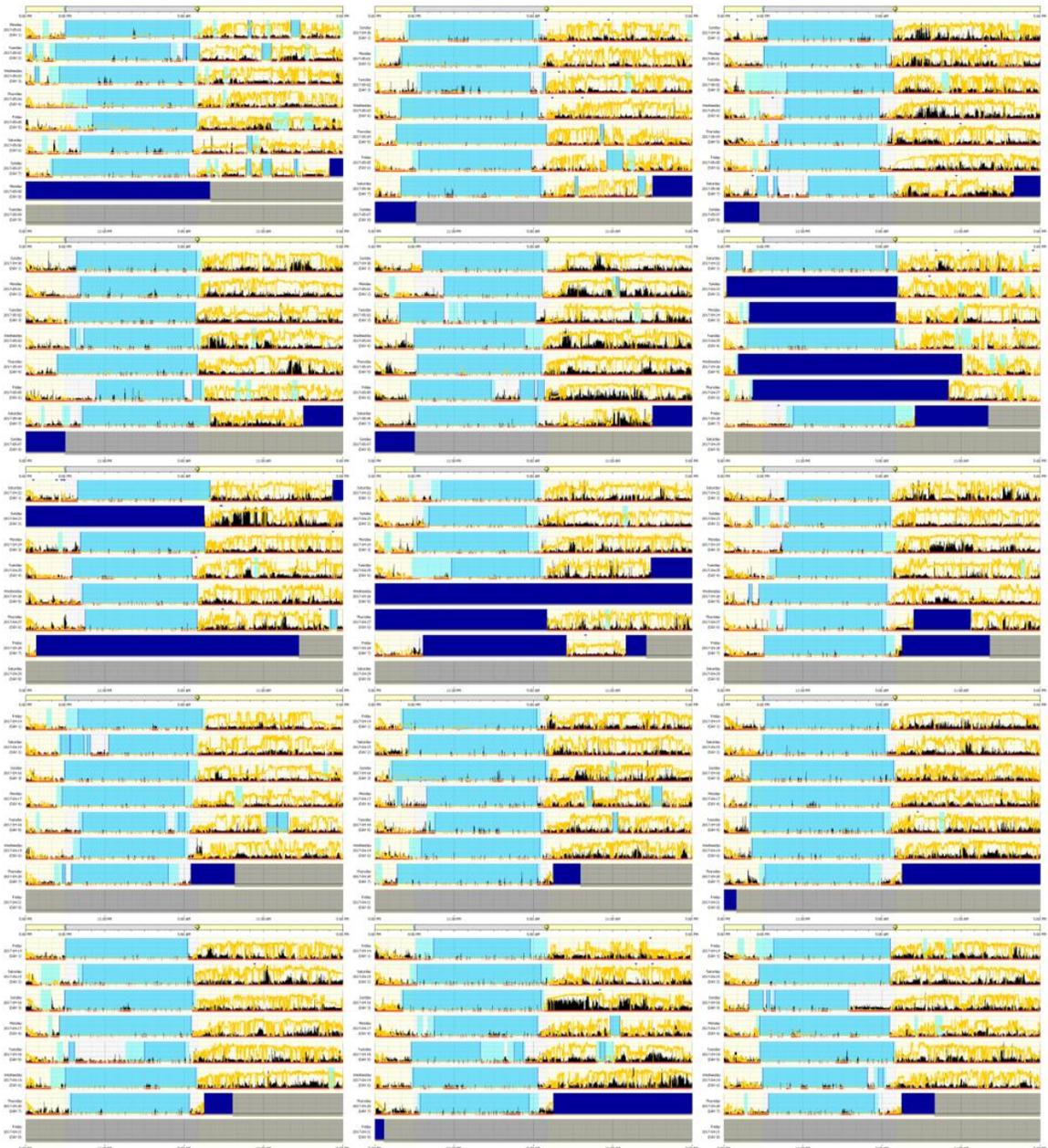
Note: Light data from the first Actogram was excluded as an error occurred with the Actiwatch light sensor. Activity data from this record was maintained in analyses.



**Figure D.4. Males from Electric Communities**



**Figure D.5. Females from Electric Communities**



**Figure D.6. Mothers from Electric Communities**